Radiographic quantitative assessment of cranial tibial subluxation before and after tibial plateau leveling osteotomy in dogs

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Objective—To determine the influence of stifle joint flexion angle, cranial cruciate ligament (CrCL) integrity, tibial plateau leveling osteotomy (TPLO), and cranial tibial subluxation on the distance between the location of the origin and insertion of the CrCL ($CrCL_d$) in dogs.

Samples—4 pairs of pelvic limbs from adult dog cadavers weighing 23 to 34 kg.

Procedures—Mediolateral projection radiographs of each stifle joint were obtained with the joint flexed at 90°, 105°, 120°, 135°, and 150°. Radiopaque markers were then placed at the sites of origin and insertion of the CrCL. Afterward, radiography was repeated in the same manner, before and after CrCL transection, with and without TPLO. Following CrCL transection, radiographs were obtained before and after inducing overt cranial tibial subluxation. Interobserver variation in measuring the $CrCL_d$ without fiduciary markers was assessed. The effect of CrCL integrity, cranial tibial subluxation, flexion angle, and TPLO on $CrCL_d$ was also determined.

Results—Interobserver agreement was strong, with an intraclass correlation coefficient of 0.859. The $CrCL_d$ was significantly shorter (< 1 mm) at 90° of flexion; otherwise, flexion angle had no effect on $CrCL_d$. Cranial tibial subluxation caused a 25% to 40% increase in $CrCL_d$. No effect of TPLO on $CrCL_d$ was found, regardless of CrCL integrity, forced stifle joint subluxation, or flexion angle.

Conclusions and Clinical Relevance—Overt cranial tibial subluxation in CrCL -deficient stifle joints can be detected on mediolateral projection radiographs by comparing $CrCL_d$ on neutral and stressed joint radiographs at joint angles between 105° and 150°, regardless of whether a TPLO has been performed. (*Am J Vet Res* 2011;72:410–416)

The CrCL is an integral stabilizing structure of the stifle joint in dogs.[1,2] Complete CrCL rupture, a common orthopedic condition affecting dogs, results in marked craniocaudal instability of the stifle joint. Cranial subluxation of the tibia relative to the femur occurs consistently during weight bearing.[1,2] This femorotibial shearing motion results in progressive osteoarthritis, impingement and damage of the menisci, and subsequent lameness associated with CrCL insufficiency.[2,3]

Obtaining accurate measurements of the degree of subluxation aids with detection of CrCL rupture.[4] Definitive diagnosis of CrCL insufficiency, however, typically relies on the ability to elicit craniocaudal instability on direct palpation.[5] Several specialized stress radiographic techniques that produce cranial translation of the tibia have been described for objective documentation of joint laxity.[4,6,7] These techniques involve the use of external compressive translational devices or performing the tibial compression test during radiography.[4,6,7] Quantification of the magnitude of cranial tibial translation is performed by calculating the relative displacement of osseous landmarks on lateral radiographic views of the stifle joint before and after inducing subluxation. For example, translation has been described according to the displacement of the caudal femoral condyles, or long digital extensor fossa, along a plane parallel to the tibial plateau.[6,7] Quantification of cranial tibial translation can be performed by use of radiopaque markers placed in each bone, but this requires invasive, surgical implantation when used in vivo.

The femorotibial joint is not a simple hinge joint; rather, the femoral condyles have an elliptic contour and sagittal plane femorotibial motion adopts a complex roll-and-glide pattern.[8] As such, the stifle joint does not have a single instant center of rotation and it is not known whether all of the reported means of

Abbreviations

CrCL	Cranial cruciate ligament
$CrCL_d$	Distance between the origin and insertion of the cranial cruciate ligament
TPLO	Tibial plateau leveling osteotomy

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obtaining static radiographic measurements of subluxation would be valid at various stifle joint flexion angles. Unless the stifle joint flexion angle remains consistent, these previously reported methods may not accurately measure normal or abnormal cranial tibial translation. Further, tibial osteotomies for the treatment of CrCL insufficiency impart functional stability by altering the geometry of the proximal aspect of the tibia.[9] Procedures such as TPLO cause a relative shift of certain osseous landmarks, which may preclude accurate comparisons of femorotibial alignment before and after surgery.

The location of the origin and insertion of the CrCL are considered isometric; that is, the distance between these points does not change substantially throughout a range of motion.[10–12] Increases in the $CrCL_d$, regardless of stifle joint flexion angle, may therefore indicate either femorotibial joint distraction or, more likely, cranial tibial translation. We were interested in developing a clinically applicable method to evaluate the efficacy of surgical procedures in resolving cranial tibial subluxation in dogs with CrCL insufficiency by assessing $CrCL_d$. The objectives of this study were to determine whether the origin and insertion of the CrCL could be repeatedly and accurately identified on mediolateral projection stifle joint radiographs and to determine the influence of stifle joint flexion angle, CrCL integrity, cranial tibial subluxation, and TPLO on $CrCL_d$. We hypothesized that the femoral and tibial attachment sites of the CrCL could be easily and precisely identified on mediolateral projection radiographs throughout a wide range of stifle joint motion. We also hypothesized that stifle joint flexion angle, transection of the CrCL (with the stifle joint maintained in reduction), and treatment with TPLO would not alter the $CrCL_d$, whereas induced cranial tibial subluxation would significantly increase the $CrCL_d$.

Materials and Methods

Specimens—Eight pelvic limbs were collected by disarticulation of the coxofemoral joint from 4 adult mixed-breed dogs (mean ± SD body weight, 26 ± 4 kg) that were euthanatized for reasons unrelated to the study. The specimens were wrapped in saline (0.9% NaCl) solution–soaked towels and stored at –20°C until testing. In preparation for testing, the limbs were thawed to room temperature (approx 25°C), and all musculature was dissected from the limbs while carefully preserving the gastrocnemius muscle and soft tissue structures surrounding the stifle joint. Tissues were kept moist throughout the preparation and data collection periods by spraying the specimens with saline solution.

Joint preparation—A 3.5-mm cortical screw[a] was placed cranially in the proximal metaphysis of each femur, approximately 3 cm distal to the femoral head. A double loop of size-0 polydioxanone[b] was placed in the rectus femoris muscle remnant proximal to the patella. A tension spring[c] was used to connect the screw to the patellar suture, mimicking the quadriceps mechanism and maintaining tension on the patellar tendon. Three 1-mm holes were drilled in the center of the medial cortex along the length of the tibial and femoral diaphyses, where the proximal and distal holes were positioned at one- and two-thirds of the length of the tibia and femur.[13] These holes were used to define the longitudinal axes of the bones during testing and radiography for measuring the stifle joint flexion angle.[13]

Prior to radiography, a radial osteotomy of the proximal tibia was performed with a 24-mm biradial saw blade as previously described.[14] A 3.5-mm cortical screw was placed across the osteotomy site in lag fashion from the tibial tuberosity, with the tibial plateau in a sham position (no tibial plateau rotation). A 3.2-mm negative profile end-threaded pin[d] was placed in the craniomedial aspect of the tibial plateau segment to facilitate plateau rotation during radiography. With the osteotomy in the original position (no tibial plateau rotation), each specimen was placed in a custom radiolucent frame by use of two 4.0-mm threaded bolts placed from medial to lateral in the tibial diaphysis and one 4.0-mm threaded bolt placed in a similar fashion in the proximal femoral diaphysis. The frame was designed to maintain the limb in the same position while obtaining radiographs over a range of motion from 150° to 90°, in 15° increments. The frame was also used to assist maintaining the stifle joint in reduction or cranial tibial subluxation following CrCL transection.

Radiography—With each specimen mounted to the radiolucent frame, a plastic goniometer was used to measure stifle joint flexion angles, by aligning each arm with the marks on the tibial and femoral diaphyses. The radiographic beam was centered over the stifle joint and collimated to include the entire tibia and femur. With the aid of a computed radiography system,[e] a series of mediolateral projection radiographs was obtained at flexion angles of 150°, 135°, 120°, 105°, and 90°. Images were stored in standard imaging format.[e,f] Stifle joint flexion angle was measured radiographically after each radiograph to ensure the acquired image was within 5° of the targeted angle. No fiduciary markers were used for the first series of radiographs of the normal (CrCL intact, with sham TPLO) stifle joint. Tibial plateau angle was measured by use of methods described elsewhere.[15]

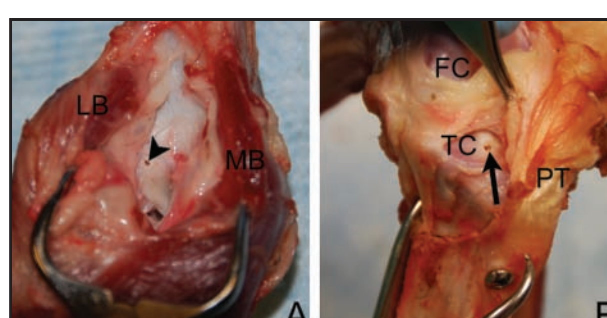

Figure 1—Photographs of preparation of a cadaveric canine stifle joint for assessment of the $CrCL_d$. A—Exposure of the origin of the CrCL (arrowhead) was obtained through caudal arthrotomy, between the lateral (LB) and medial (MB) bellies of the gastrocnemius muscle. B—Exposure of the insertion of the CrCL (arrow) was obtained by incising the craniomedial aspect of the joint capsule and reflecting the intermeniscal ligament and medial meniscus caudally. FC = Medial femoral condyle. PT = Patellar tendon. TC = Medial tibial condyle.

The origin of the CrCL was then exposed by accessing the joint through a caudal arthrotomy, between the medial and lateral bellies of the gastrocnemius muscle (**Figure 1**). A craniomedial arthrotomy was performed, and intra-articular structures (menisci and cruciate ligaments) were carefully evaluated to ensure there was no gross evidence of pathological change in the stifle joint. For adequate exposure of the insertion of the CrCL, the craniomedial joint capsule was incised along the tibial plateau to allow caudal retraction of the intermeniscal ligament and medial meniscus. Holes 2 mm deep and 2 mm in diameter were made at the most caudoproximal extent of the CrCL origin and the most cranial extent of the CrCL origin for subsequent placement of stainless steel radiopaque fiduciary beads (2 mm in diameter).[g]

The fiduciary markers were carefully impacted into the holes at the origin and insertion of the CrCL, and the radiographic series was repeated in the normal stifle joint. Radiographs were then obtained with the tibial plateau segment rotated caudally to produce a tibial plateau angle of 6° (CrCL intact, with treatment TPLO); the rotated plateau segment was stabilized with a 1.6-mm Kirschner wire. The CrCL was transected via the craniomedial arthrotomy site, and radiography was repeated with the stifle joint maintained in reduction (CrCL deficient and reduced, with treatment TPLO) and after inducing cranial tibial subluxation (CrCL deficient and subluxated, with treatment TPLO). To induce stifle joint subluxation, the tibia was cranially displaced relative to the femur with the aid of the radiolucent frame and maintenance of the hock in flexion (tibial compression test). This manipulation induced the maximal amount of cranial tibial subluxation possible. Finally, radiographs were obtained with the tibial plateau segment returned to a sham position and the stifle joint maintained in reduction (CrCL deficient and reduced, with sham TPLO) and after induction of cranial tibial subluxation (CrCL deficient and subluxated, with sham TPLO). Hence, each stifle joint was radiographed through a full range of motion before and after CrCL transection, with and without TPLO, in reduction and in cranial tibial subluxation (**Figure 2**). Following radiography, the stifle joint was carefully disarticulated and the position of the fiduciary beads was visually assessed to determine whether there was any variation in bead placement or anatomic variation in the origin and insertion of the CrCL.

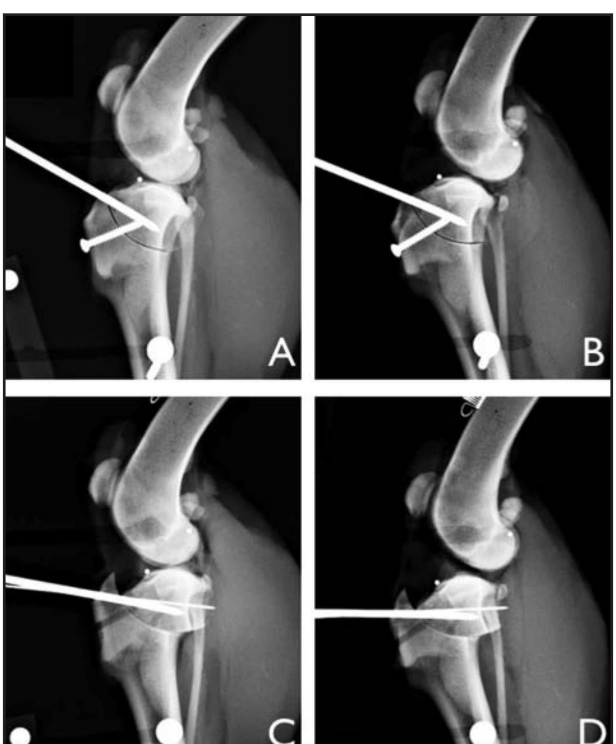

Figure 2—Representative set of mediolateral projection radiographs of a cadaveric canine stifle joint at 135° before (A) and after (B) cranial tibial subluxation, with the tibial plateau segment in the sham position, and before (C) and after (D) cranial tibial subluxation after tibial plateau rotation. Radiographs of joint specimens were also acquired over a full range of joint motion in 15° increments.

Radiographic analysis—The sets of radiographic series performed without use of fiduciary beads were evaluated by 3 blinded observers (MDW, AP, and SEK) to assess whether the most caudoproximal extent of the origin and most cranial extent of the insertion of the CrCL could be consistently and accurately identified over the range of motion evaluated. Images were reviewed, and measurements were made by use of image-viewing software and associated caliper tools.[f] The origin of the CrCL was defined as the point on the cranioproximal margin of the femoral condyles immediately caudal to the roof of the intercondylar notch (**Figure 3**). The insertion of the CrCL was defined as the point at the cranial margin of the medial tibial condyle. The $CrCL_d$ was measured by a single observer (SEK) on subsequent radiographic series as the distance between the center of the fiduciary beads positioned at the origin and insertion of the CrCL.

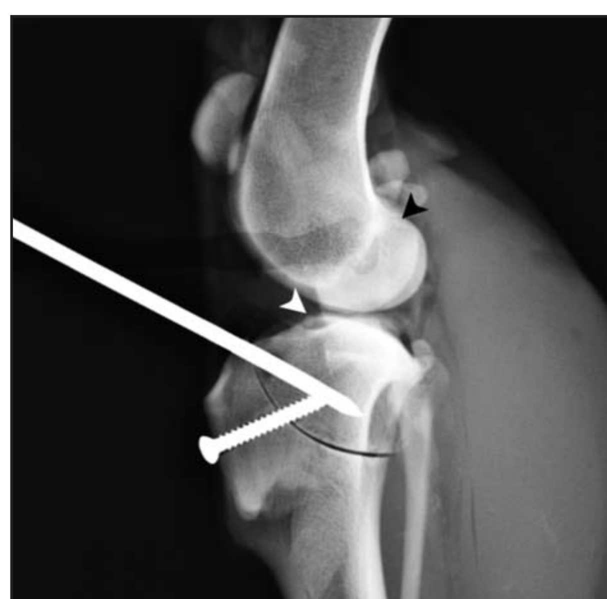
Figure 3—Mediolateral projection radiograph showing the method by which the CrCL sites of origin and insertion were defined in a cadaveric canine stifle joint. The origin was defined as the point on the cranioproximal margin of the femoral condyles immediately caudal to the roof of the intercondylar notch (black arrowhead). The insertion was defined as the point at the cranial margin of the medial tibial condyle (white arrowhead).

Statistical analysis—A statistical software package[h] was used to perform all analyses. Interobserver agreement of $CrCL_d$ measurements in which pooled data were used was assessed by calculation of intraclass correlation coefficients for the 3 observers, calculation of Pearson correlations between 2 observers, and construction of Bland-Altman plots with 95% limits of agreement. The $CrCL_d$ measurements in the normal (CrCL intact, with sham TPLO) sequence from each blinded observer were compared with the measurements obtained with fiduciary beads by means of a 1-way repeated-measures ANOVA. The Pearson correlation was also used to assess the relationship between the measurements by blinded observers and those obtained with the fiduciary beads. Isometry (or the effect of stifle joint flexion angle) and the effect of stifle joint status (CrCL transection, cranial tibial subluxation, or TPLO) were assessed by use of $CrCL_d$ measurements normalized to the length of the medial tibial condyle with a 2-way repeated-measures ANOVA. Isometry was further assessed by calculating the mean of the maximum difference in $CrCL_d$ over the range of motion evaluated, within each radiographic sequence with the stifle joint in normal alignment (ie, no subluxation). When significant differences were identified via ANOVA, pairwise comparisons were made with a Tukey test. A value of $P < 0.01$ was considered significant for all analyses. Results are reported as mean ± SD.

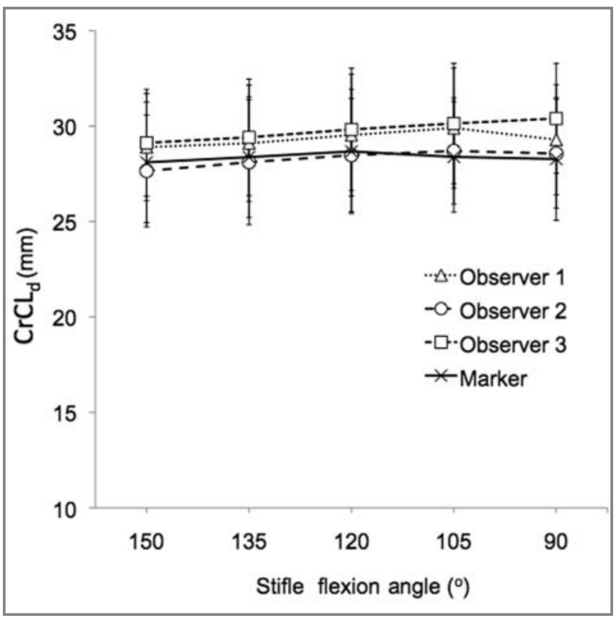

Figure 4—Mean ± SD $CrCL_d$ in 8 cadaveric canine stifle joints as measured in a normal (CrCL intact, with sham TPLO) radiographic sequence by 3 independent observers without fiduciary markers and by 1 observer with fiduciary markers, over a full range of motion in 15° increments.

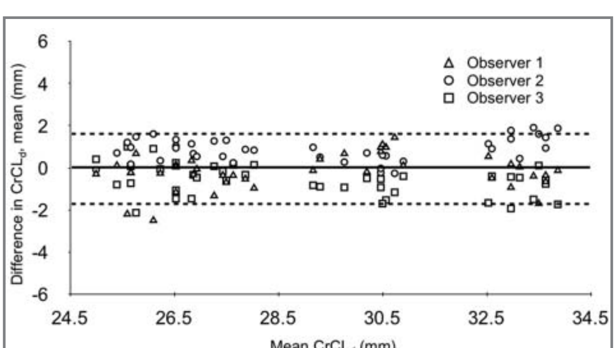

Figure 5—Bland-Altman plot of differences between overall mean $CrCL_d$ in a normal (CrCL intact, with sham TPLO) radiographic sequence, as measured by 3 independent observers. Eight stifle joints were measured by each observer. Dashed lines represent 95% limits of agreement.

Results

Specimens—Mean ± SD tibial plateau angle of the 8 cadaveric canine stifle joints in the sham condition was 28 ± 2.8°. Mean tibial plateau length was 28 ± 2.7 mm.

Interobserver variation—The $CrCL_d$ values from each blinded observer were graphically displayed (**Figure 4**). There was no significant intraobserver change in $CrCL_d$ over a range of motion, nor were there significant differences in $CrCL_d$ between observers at each stifle joint flexion angle. No significant differences were observed between each observer's measurements in the normal sequence and those made by 1 observer with radiographic markers. The 95% limits of agreement for interobserver variation of $CrCL_d$ were within 1.86 mm of the mean values (**Figure 5**). The overall intraclass correlation coefficient for the observer variation data was 0.859, indicating strong correlation between pairs of observers. The Pearson correlation coefficients for each combination of comparisons between 2 observers were all significant ($P < 0.001$; **Figure 6**). Correlations between measurements made with fiduciary beads versus those made by an individual observer were also strong (**Figure 7**) but nonlinear and lower than correlations between the pairs of blinded observers.

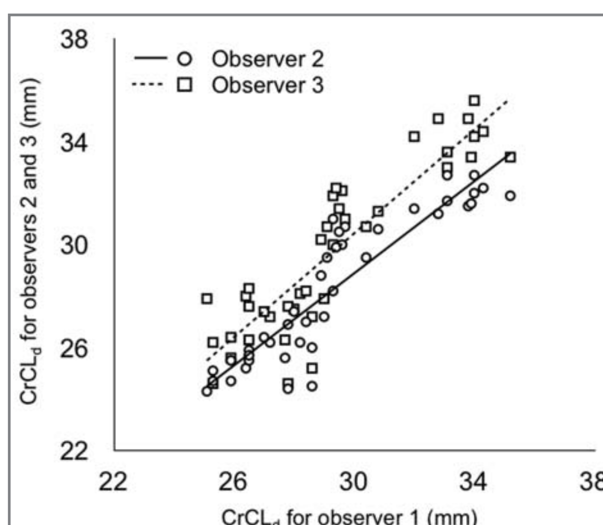

Figure 6—Correlation of $CrCL_d$ measurements by observer 1 with those of observers 2 and 3 in a normal (CrCL intact, with sham TPLO) radiographic sequence of canine stifle joints. Eight stifle joints were measured by each observer, and correlation coefficients (all $P < 0.001$) were as follows: observer 1 versus observer 2, 0.910; observer 1 versus observer 3, 0.892; and observer 2 versus observer 3, 0.952.

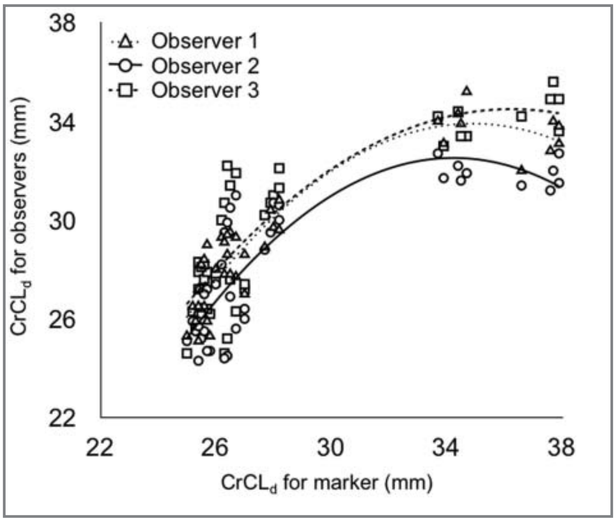

Figure 7—Correlation of CrCL$_d$ measurements by 3 observers in a normal (CrCL intact, with sham TPLO) radiographic sequence of 8 canine stifle joints without fiduciary markers with CrCL$_d$ measurements made by 1 observer with fiduciary markers. Correlation coefficients (all $P < 0.001$) for observer versus marker-aided measurements were as follows: observer 1 versus marker, 0.889; observer 2 versus marker, 0.790; and observer 3 versus marker, 0.840.

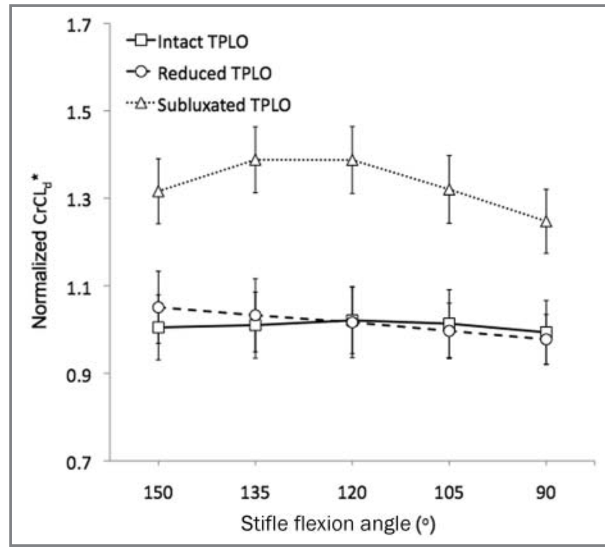

Figure 9—Mean ± SD normalized CrCL$_d$ in normal (CrCL intact), reduced (CrCL deficient, with joint maintained in reduction), and subluxated (CrCL deficient, with stifle joint in forced subluxation) treatment TPLO radiographic sequences of 8 canine stifle joints as measured by 1 observer with fiduciary markers over a full range of motion. *See* Figure 8 for remainder of key.

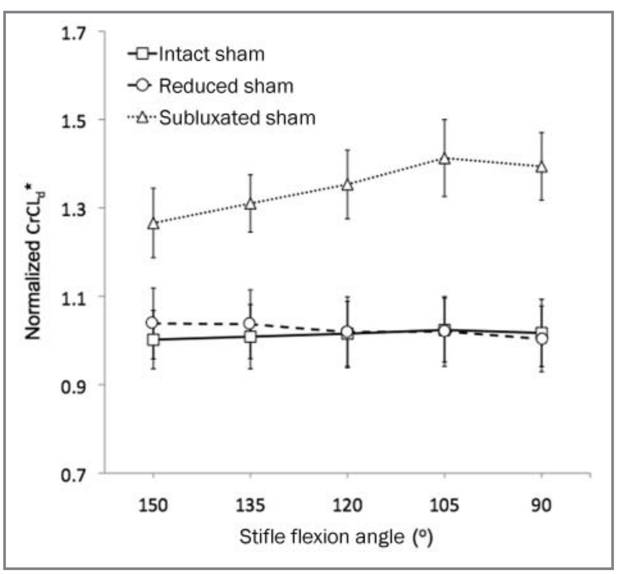

Figure 8—Mean ± SD normalized CrCL$_d$ in normal (CrCL intact), reduced (CrCL deficient, with joint maintained in reduction), and subluxated (CrCL deficient, with joint in forced subluxation) sham TPLO radiographic sequences as measured by 1 observer with fiduciary markers in 8 canine stifle joints over a full range of motion. *The CrCL$_d$ was normalized to the length of the medial tibial condyle.

Effect of stifle joint flexion angle, CrCL deficiency, cranial tibial subluxation, and TPLO on CrCL$_d$—The CrCL$_d$ values normalized to tibial plateau length for measurements made in the sham-treated (**Figure 8**) and TPLO-treated (**Figure 9**) radiographic series with fiduciary beads were graphically displayed. There was a significant ($P = 0.001$) effect of stifle joint flexion angle on CrCL$_d$ but only between 2 flexion angles. Overall, CrCL$_d$ at 90° was smaller than CrCL$_d$ at 120° ($P = 0.004$), although the magnitude of difference was small (equivalent of < 1 mm). No differences in CrCL$_d$ were evident at any other flexion angle. The mean maximal difference in CrCL$_d$ over the full range of motion, within the radiographic sequences of the stifle joint in normal alignment, was 1.2 ± 0.9 mm. Cranial tibial subluxation had a significant ($P < 0.001$) effect on CrCL$_d$; cranial tibial subluxation, with and without TPLO, caused a 25% to 40% increase in CrCL$_d$ over a full range of motion, when compared with reduced ($P < 0.001$) and CrCL-intact ($P < 0.001$) conditions. No difference was detected between CrCL-intact and reduced CrCL-deficient stifle joints (sham TPLO, $P = 0.968$; treatment TPLO, $P = 0.996$). No differences were detected between sham TPLO and treatment TPLO in the normal ($P = 0.999$) and CrCL-deficient stifle joints before ($P = 0.984$) and after ($P = 0.847$) cranial tibial subluxation.

Discussion

The present study revealed that increases in CrCL$_d$, as measured with the techniques used, were primarily due to cranial tibial subluxation. The CrCL$_d$ was only mildly affected by flexion but was not altered by performing a TPLO. Thus, overt cranial tibial subluxation in stifle joints affected by CrCL insufficiency may be detected on radiographs by comparing the CrCL$_d$ on neutral and stress radiographic views, regardless of whether TPLO has been performed, at stifle joint flexion angles between 105° and 150°.

The CrCL$_d$ measurements were used as a means of determining whether the sites of origin and insertion of the CrCL could be consistently identified between observers. Interobserver variation was low, as the Bland-Altman plot showed that the difference in 95% of the compared measurements was < 1.86 mm (ie, there was only a 1 in 20 chance that CrCL$_d$ varied by > 1.86 mm between 2 observers). High intraclass correlations and low variation of CrCL$_d$ measurements were indicative of consistent measurements between observers, which suggests that the CrCL origin and insertion can be located precisely through use of the described radiographic landmarks. Although the measurements were regarded as consistent between observers, it is important to mention that the 1.86 mm difference corresponded to approximately 8% of the mean $CrCL_d$, and ligamentous strain of this magnitude may be of clinical importance.[16]

As illustrated by the scatterplots, correlation was stronger between pairs of measurements made by the 3 blinded observers than between measurements made by each observer and those obtained by 1 observer measuring the distance between the radiographic markers. The discrepancy was attributed to slight variations, on the order of 1.0 to 1.5 mm, in implanting the marker along the margin of the origin of the CrCL. This discrepancy in placing the markers was apparent on gross evaluation of the specimens after testing. Nevertheless, the nominal variation between pairs of observers indicated that $CrCL_d$ can be used when the chosen points are located in reasonable proximity to the attachment sites of the CrCL, as long as consistent landmarks are used within a single subject. This is particularly important in the clinical setting, when the radiographic landmarks denoting the origin and insertion of the CrCL may be obscured by osteoarthritic change.[17,18]

Our finding that the $CrCL_d$ was consistent at most of the stifle joint flexion angles evaluated in joints with normal alignment was not surprising. The CrCL is a primary restraint against cranial tibial translation over a full range of motion, and a component of the ligament must remain taut throughout a full range of motion.[11] Our results corroborate findings of other investigators who also concluded the CrCL origin and insertion are isometric.[10–12] The $CrCL_d$ measurement may be particularly useful for assessing craniocaudal instability when stifle joint flexion angles vary between sets of radiographs (eg, before and after applying a load for stress radiography or when joint angles cannot be controlled, such as would be the situation when obtaining weight-bearing radiographs). Because of the slight shortening of $CrCL_d$ detected at a stifle joint flexion angle of 90°, we do not recommend positioning the stifle joint in pronounced flexion when obtaining radiographs of the limb to quantitate cranial tibial subluxation with our method.

Because the insertion of the CrCL is craniodistal to the origin of the CrCL, the distance between these sites in the sagittal plane will increase when there is cranial or distal translation of the tibia relative to the femur. Because of the caudodistally oriented slope of the tibial plateau and the periarticular soft tissue constraints about the stifle joint, cranial translation is coupled with proximal translation of the tibia when the CrCL is ruptured.[5] So-called joint distraction cannot occur; thus, increases in $CrCL_d$ are solely due to the effects of cranial tibial translation. Although more sophisticated means of described femorotibial joint kinematics can be used to directly measure craniocaudal translation,[1,2,19] $CrCL_d$ is a simple measurement that can be used for detection of craniocaudal instability in dogs with overt subluxation associated with CrCL insufficiency. The results from the analysis of interobserver variation and the maximal difference in $CrCL_d$ over a full range of motion suggested that our method of measuring changes in $CrCL_d$ could not discriminate differences of < 2 mm. Hence, measuring $CrCL_d$ may not be sensitive enough to identify more subtle stifle joint instability, such as that often present in dogs with partial CrCL insufficiency.[4]

Although TPLO can shift the point of contact between the femoral condyles and tibial plateau,[20] altering the proximal tibial geometry by performing TPLO did not significantly change the $CrCL_d$ in the normal stifle joint without subluxation. The surgical procedure may change the relative orientation of the origin and insertion of the CrCL, but we were unable to characterize such changes with our methodology because only magnitude, and not direction, was quantified. Tibial plateau leveling osteotomy does not, however, appear to preclude detection of cranial tibial subluxation, as a similar magnitude of increase in $CrCL_d$ was detected in subluxated stifle joints before and after TPLO. Although TPLO purportedly improves lameness by eliminating cranial tibial subluxation during weight bearing, the effect of TPLO on femorotibial joint alignment in vivo has not been investigated to our knowledge. Because $CrCL_d$ is not influenced by performing a TPLO, this measurement would be a useful parameter for evaluating craniocaudal joint alignment before and after surgery if a standardized methodology for obtaining both neutral and stress radiographic views can be validated in vivo.

Several limitations in the methodology used in the present study should be considered when using the $CrCL_d$ for detection of cranial tibial subluxation. Errors associated with 2-D imaging of this nature may preclude the acquisition of precise measurements. Axial rotation of the femur or tibia may shift the relative positions of the origin and insertion of the CrCL, and choosing the appropriate points for the location of the origin and insertion of the CrCL may be difficult when there are any variations in obliquity between radiographs. We were not able to assess the effects of rotational alignment because our experimental methodology was designed to maintain consistent axial rotation of both the femur and the tibia. Axial rotational malalignment in CrCL-deficient stifle joints in vivo is, however, negligible[1]; hence, accurate identification of the landmarks can be achieved by consistently obtaining true mediolateral-projection stifle joint radiographs. Orthopedically normal stifle joints were used in this study, and the amount of subluxation elicited when the CrCL was transected was substantial. Osteoarthritic stifle joints in dogs with chronic CrCL insufficiency are unlikely to have a similar degree of joint laxity, and significant differences in $CrCL_d$ may not have been identified with a smaller magnitude of subluxation. Identification of the insertion of the CrCL on radiographs may become obstructed by TPLO implants, hindering accurate comparisons of $CrCL_d$ before and after surgery. If our method of quantifying cranial tibial subluxation were to be used, then TPLO implants would need to be positioned distal enough such that the plate would not obscure the joint line. Finally, 1 $CrCL_d$ measurement alone will not indicate whether a joint is subluxated;

assessment of craniocaudal joint alignment by measuring $CrCL_d$ can only be performed when measurements are obtained with the stifle joint radiographed in both a reduced and stressed (or subluxated) position.

Results of the present study supported the hypothesis that $CrCL_d$ can be measured with reasonable accuracy on mediolateral radiographic views when the defined anatomic landmarks are used; however, radiography of the stifle joint at 90° of flexion should be avoided. The $CrCL_d$ was significantly higher in stifle joints with overt cranial tibial subluxation, irrespective of whether or not a TPLO had been performed. In vivo validation of a standardized methodology for use of $CrCL_d$ as an indicator of cranial tibial subluxation should be pursued so that radiographic measurements of $CrCL_d$ may be included as a valid outcome measure in studies of CrCL insufficiency in dogs.

a. 3.5 mm cortical bone screw, Synthes USA, Paoli, Pa.
b. PDS, Ethicon Inc, Somerville, NJ.
c. Tension spring, Hillman, Cincinnati, Ohio.
d. Medium SCAT pin, Imex Veterinary Inc, Longview, Tex.
e. DICOM, NEMA, Rosslyn, Va.
f. Kodak Directview 5.2, Carestream Health, Rochester, NY.
g. 2-mm stainless steel ball bearings, McMaster-Carr Supply Co, Cleveland, Ohio.
h. Sigmastat, SPSS Inc, Chicago, Ill.

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Correction: Evaluation of a three-dimensional kinematic model for canine gait analysis

In the report "Evaluation of a three-dimensional kinematic model for canine gait analysis" (*Am J Vet Res* 2010;71:1118–1122), the image displayed as Figure 2B is incorrect. The correct figure is printed here.

Corrected figure appears on the next page