Computed tomographic evaluation of the canine intercondylar notch in normal and cruciate deficient stifles

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Summary
In the human and veterinary orthopaedic literature it has been implied that intercondylar notch stenosis is a mechanical factor in cranial cruciate ligament rupture and intraarticular graft failure. The patients in this study were classified as normal (32), unilateral cruciate rupture (23), or bilateral cruciate rupture (17). The dogs were placed under general anaesthesia and both stifles were scanned via computed tomography (CT) as previously described. Three CT slices at predetermined levels were evaluated within the notch. Measurements included opening notch angle, notch width and height, condyle width, and notch width index (notch width/condyle width) at two different heights within the notch. Intercondylar notch measurements at the most cranial extent were significantly more narrow in unilateral and bilaterally affected stifles when compared to the normal population. Significant differences were noted in the opening notch angle (ONA), notch width index (NWI), NWI at two thirds notch height (NWI/3), and tibial slope index (TSI). No significant differences were noted between unilateral and bilaterally affected stifles. Increased mechanical contact of the cranial cruciate ligament with a stenotic intercondylar notch may predispose the ligament to mechanical wear and structural weakening. Intercondylar notch measurements have been used as a tool to predict the risk of anterior cruciate ligament injury in young human athletes, and to assess the risk factors for intra-articular graft replacements. Our findings may be useful in developing similar predictive models using stifle CT scans.

Keywords
Intercondylar notch, computed tomography, cruciate ligament, canine

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Introduction
Cranial cruciate ligament (CCL) injury is one of the most commonly diagnosed canine orthopaedic diseases (1). Clinical presentations, breed predisposition, physical abnormalities, and surgical techniques have been studied extensively (2–4). The development of secondary degenerative joint changes, and the need for surgical stabilization is widely accepted. The causes that lead to CCL rupture are considered to be multifactorial (5, 6). Damage to the CCL in the dog has been associated with trauma, immune-mediated mechanisms (7, 8), age-related degeneration of the CCL (9), obesity (10), and conformational abnormalities. Recent literature has extensively evaluated the tibial plateau angle and a possible association with CCL degeneration (11–13). However, conflicting information has been reported as to whether tibial slope angle actually predisposes to CCL injury or whether it contributes to instability within the stifle after the CCL injury. Intercondylar notch stenosis is a conformational abnormality that has been implicated in the veterinary (14) and human literature (15–17) as a predisposing factor to CCL injury.

The canine CCL originates within the intercondylar notch of the femur along the caudo-medial aspect of the lateral condyle (18). This ligament extends disto-cranially to attach to the cranial intercondylar area of the tibia immediately cranial to the intercondylar eminence (18). The intact CCL prevents cranial translation of the tibia in relation to the femur, hyperextension of the stifle and internal rotation of the tibia (18). Intercondylar notch stenosis is widely believed to contribute to human ACL rupture and failure of intraarticular graft reconstruction due to increased tensile forces on these structures (19).

Contact between the human anterior cruciate ligament and intercondylar fossa occurs in the normal knee during full extension when the anterior cruciate ligament abuts the intercondylar shelf and lateral wall of the intercondylar fossa (20). Congenital intercondylar fossa stenosis may predispose young human individuals to bilateral anterior cruciate ligament ruptures with only minimal trauma (16, 17). Bilateral ACL ruptures occur in 2–4% of all cruciate ligament ruptures in human beings; however up to 37% of dogs that are admitted with unilateral rupture later develop a rupture of the contralateral CCL (16, 17, 21) The intercondylar notch (ICN) has been extensively researched in young human athletes with radiographic analysis and computed tomography (CT) (15–17). To the authors' knowledge, similar CT studies have not yet been conducted in order to compare ICN differences between normal and naturally occurring CCL injured canine stifles. The purpose of this study was to perform concurrent radiographic analysis of the tibial slope and CT analysis of the intercondylar notch in normal, unilateral and bilateral cruciate deficient stifles.

Materials and methods
Our study included 72 client or hospital personnel owned dogs that weighed >10 kg.
Signalment and the affected limb were recorded. The dogs that were included in this study were classified as normal (32), unilateral cruciate rupture (23), or bilateral cruciate rupture (17). The patients with either unilateral or bilateral cranial cruciate ligament rupture were diagnosed by physical examination and radiographs, or direct visualization of the cranial cruciate ligament disruption at the time of surgical stabilization. Five dogs were disqualified from this study due to small body size, stifle pathology in addition to cranial cruciate rupture or missing data. Three dogs that were initially included in the unilateral category were moved to the bilateral group upon rupture of the contralateral cruciate ligament within the first 12 months following participation within the study.

**History and signalment**

The historical information included: age, weight, breed, sex, neuter status, duration of lameness, precipitating cause of injury, additional orthopaedic abnormalities of the rear limbs (hip dysplasia, fracture, panosteitis, etc.) and interval between initial and contralateral CCL injury if bilateral. Animals that had congenital malformations (e.g. medial patellar luxation) or additional pathology of the stifle (e.g. osteochondritis dessicans, premature growth plate closure or intra-articular fractures) were excluded from the study population.

**Orthopaedic examination**

The orthopaedic examination included: lameness evaluation, presence or absence of drawer motion, cranial tibial thrust (CTT), and pain on hyperextension of the stifle. Palpable joint effusion, presence of a medial buttress, and a positive ‘sit test’ were evaluated for each stifle. Lameness was graded at a walk on a 0–4 scale with ‘0’ being normal, ‘1’ having any subtle lameness, ‘2’ obvious but weight bearing lameness, ‘3’ intermittent non-weight bearing, and ‘4’ a constant non-weight bearing lameness. Additional orthopaedic conditions (e.g. hip dysplasia, previous fracture, muscle strain) that included the rear limbs were further characterized, but did not exclude the participating animal. The owners of all of the dogs that were included in the normal or unilateral categories were contacted one year after the initial examination in order to ensure correct group placement at the time of data analysis.

**Radiography**

Mediolateral and craniocaudal radiographs of both stifles were obtained with the dog under general anaesthesia. The dog was positioned in lateral recumbency, for the mediolateral view, with the affected hind limb down and in direct contact with the surface of the cassette. The stifle and hock joint were kept at approximately 90°. The opposite leg was pulled cranially or abducted in a flexed position. The radiographs were evaluated for superimposition of the tibial and femoral condyles, and, if necessary, the central beam was repositioned and the radiographs were repeated until adequate superimposition was achieved. Tibial plateau angle was calculated from this radiograph as previously described by Slocum (22).

**Computed tomography**

All CT studies were performed using a helical CT scanner⁴. All of the owners of the patients signed a consent form indicating the need for general anaesthesia and an elective procedure involving ionizing radiation. The normal population was recruited from normal animals owned by hospital personnel, client owned animals seeking orthopaedic evaluation, and anaesthetically stable client owned animals undergoing anaesthesia for a non-orthopaedic condition. The cruciate deficient population was scanned immediately prior to surgical stabilization to eliminate the need for a separate anaesthetic episode. All of the CT images were acquired while the dog was positioned in dorsal recumbency with the pelvic limbs extended parallel to each other. Both stifles were imaged simultaneously. The anatomy of the canine intercondylar fossa is oriented 12° from the dorsal plane of the femoral diaphysis and is obliqued 7°, proximolateral to distomedial, in the sagittal plane (23). The gantry angle was customized for the positioning of each dog based on the lateral scout view by applying a template to the computer screen that aligned to the dorsal plane of the femur and allowed alignment of slices perpendicular to the intercondylar fossa as previously determined (19). All of the images were made at 120 kVP and 200 mAS. CT images were viewed with a window level and window width of 350 and 2000 CT units, respectively. Contiguous transverse 1.5 mm slices perpendicular to the intercondylar fossa were acquired from the level of the tibial plateau to immediately proximal to the femoral condyles. Three sections of each intercondylar notch with repeatable anatomic landmarks were evaluated. The cranial slice was defined by the first CT slice caudal to the origin of the long digital extensor that fully included the medial and lateral condyles. The ‘caudal slice’ was determined by the most caudal one that fully included both medial and lateral condyles. The mathematical centre was calculated between the proximal and distal slices and this slice was also evaluated. Measurements included the opening notch angle (ONA), notch width (NW), notch height (NH), and the condyle width (CW) as previously described (Fig. 1) (19). The measurements were reported in centimetres. A ratio is used to describe the width of the intercondylar fossa to overcome variation in femur size between patients and radiographic magnification. Notch width index (NWI) was calculated by dividing NW at the distal extent of the femoral notch by CW. A second notch width index (NW2/3) was obtained by dividing NW at 2/3 of the level of the NH by CW. Two tibial slope indexes (TSI) were calculated by dividing the radiographically measured tibial slope by the NWI and NW2/3, respectively.

**Statistics**

One-way ANOVA and measures of association (Eta) were calculated in order to ensure that the study population did not reflect any

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⁴ GE Prospeed S Helical Scanner, Milwaukee, WI, USA.
unexpected or unusual associations which might invalidate other findings of interest in the data set. No significant findings or associations among these variables and the stifle disease categories (normal, unilateral, and bilateral) were noted. One-way analysis of variance was performed to evaluate differences in means for the various internal measurements of the canine stifle according to stifle condition (0=normal; 1=unilateral cruciate rupture; 2=bilateral cruciate rupture). A total of 27 quantitative variables were evaluated. A forward stepwise regression analysis and Pearson correlation analysis were used for independent variables of age, weight, and gender in relation to any effect on the intercondylar notch. A one-way ANOVA and Tukey’s Honestly Significant Difference post–hoc test were used in order to determine significant differences for measured variables between groups. The results were tabulated and reported as mean ± standard deviation. A P-value of ≤ 0.05 was used to determine significance.

Results

The mean age of the dogs in the normal study population was 3.9 ± 2.6 years and 5.2 ± 3.0 years in the cruciate deficient population. The weight of the dogs in the normal and cruciate deficient study populations were 30.6 ± 11.1 kg and 36.7 ± 13.1 kg, respectively. Significant differences were not noted between age, weight, breed, gender, or limb affected between normal and cruciate deficient populations. Labrador Retrievers and Labrador Retriever mixes comprised the majority of the study population. The tibial slope measured in the normal group was not significantly different from the tibial slope that was measured in cruciate deficient stifles (Table 1). Significant differences were noted between populations with additional orthopaedic abnormalities when compared to those with isolated cruciate deficiency. Significant differences were also not noted in notch measurements in cruciate deficient stifles, with increasing chronicity of cruciate rupture as noted by duration of lameness in months. Notch measurements did not show any significant variation dependant upon the degree of lameness at presentation.

Six of 27 measurements performed within the intercondylar notch were found to be significant (Table 1). The opening notch angle was significantly narrow in the affected dogs at the cranial slice when compared to the normal study population. This angle was not significantly different between study populations at the middle or caudal intercondylar slices that were evaluated. The notch width was significantly narrow in bilaterally affected dogs (0.76 ± 0.21) at the cranial extent of the intercondylar notch when compared to the normal population (0.90 ± 0.21). The NWI was significantly smaller in unilateral and bilaterally affected dogs at the most cranial slice when compared to the normal study population. This finding was not significant at the middle and caudal slices. The tibial slope index that was calculated using NWI was significantly larger in unilateral and bilaterally affected dogs when compared to the normal study population. A significant difference was not detected in TSI calculated using NWI2/3. The authors did not find any instances where unilateral affected dogs were significantly different from bilateral dogs. None of the measurements taken from the middle slice achieved significance. Five of the six measurements that reached significance were obtained from the cranial extent of the intercondylar notch.

Discussion

In the human literature, many authors have proposed a pathological relationship between the ACL and the intercondylar notch/
or failed repair of the cranial cruciate ligament (25). Reports on the intercondylar fossa of the dog are rare (6, 14, 22, 26, 27). To the authors’ knowledge, the intercondylar fossa of a normal canine population has not been directly compared to a similar population of naturally occurring cruciate deficient canine stifles via computed tomography. Early veterinary literature documented the validity of assessment of the canine intercondylar notch via radiographic analysis (23, 14). The same authors concluded that appropriate positioning was imperative and that it required heavy sedation or general anaesthesia in order to obtain reliable results. A protocol for the evaluation of the intercondylar notch via computed tomography was developed and allowed more thorough evaluation of the intercondylar notch without superimposition of adjacent structures (Fig. 2) (19). This technique required general anaesthesia but was technically easier due to the ability to tilt the gantry angle to scan parallel to the notch as measured from the dorsal surface of the femur on the scout film. The use of CT eliminated variability problems in radiographic technique, projection and magnification, which are encountered with plain films (17). Sellmeyer et al. determined that if the gantry angle is either under- or overrotated by up to 4° from the ideal 12° off the cranial/dorsal aspect of the femur, then the measurements taken within the intercondylar notch will not be significantly affected (28).

**Table 1** Measurements/calculations performed at three predetermined levels within the intercondylar notch (ICN). Slice 1 = cranial extent of the ICN; Slice 2 = mathematical centre of the ICN; Slice 3 = caudal extent of the ICN. Measurements were performed in centimeters. Unilateral and bilateral categories are displayed separately for completeness. No statistical difference was detected between unilateral and bilateral study populations in any category.

<table>
<thead>
<tr>
<th></th>
<th>Normal (32)</th>
<th>Unilateral (23)</th>
<th>Bilateral (17)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TS</strong></td>
<td>25.7 ± 3.5</td>
<td>27.8 ± 3.9</td>
<td>27.9 ± 4.4</td>
</tr>
<tr>
<td><strong>ONA</strong></td>
<td>63.4 ± 7.3</td>
<td>55.4 ± 10.9*</td>
<td>56.5 ± 9.2*</td>
</tr>
<tr>
<td><strong>NW</strong></td>
<td>0.90 ± 0.22</td>
<td>0.83 ± 0.23</td>
<td>0.76 ± 0.19**</td>
</tr>
<tr>
<td><strong>CW</strong></td>
<td>3.27 ± 0.39</td>
<td>3.5 ± 0.51</td>
<td>3.3 ± 0.48</td>
</tr>
<tr>
<td><strong>NWI</strong></td>
<td>0.27 ± 0.04</td>
<td>0.23 ± 0.04*</td>
<td>0.22 ± 0.04*</td>
</tr>
<tr>
<td><strong>NWI 2/3</strong></td>
<td>0.16 ± 0.02</td>
<td>0.14 ± 0.02*</td>
<td>0.14 ± 0.02*</td>
</tr>
<tr>
<td><strong>TSI</strong></td>
<td>161.6 ± 26.4</td>
<td>202.6 ± 43.3*</td>
<td>196.4 ± 39.4*</td>
</tr>
<tr>
<td><strong>ONO</strong></td>
<td>61.9 ± 7.5*</td>
<td>61.3 ± 9.9</td>
<td>61.4 ± 9.4</td>
</tr>
<tr>
<td><strong>NW</strong></td>
<td>0.93 ± 0.15</td>
<td>0.95 ± 0.24</td>
<td>0.89 ± 0.18</td>
</tr>
<tr>
<td><strong>CW</strong></td>
<td>3.48 ± 0.44</td>
<td>3.76 ± 0.53</td>
<td>3.49 ± 0.49</td>
</tr>
<tr>
<td><strong>NWI</strong></td>
<td>0.27 ± 0.03</td>
<td>0.25 ± 0.04</td>
<td>0.26 ± 0.04</td>
</tr>
<tr>
<td><strong>NWI 2/3</strong></td>
<td>0.20 ± 0.02</td>
<td>0.20 ± 0.03</td>
<td>0.20 ± 0.02</td>
</tr>
<tr>
<td><strong>TSI</strong></td>
<td>130.7 ± 25.9</td>
<td>140.6 ± 26.9</td>
<td>140.7 ± 25.2</td>
</tr>
<tr>
<td><strong>ONO</strong></td>
<td>75.2 ± 9.5</td>
<td>72.2 ± 11.6</td>
<td>71.9 ± 12.3</td>
</tr>
<tr>
<td><strong>NW</strong></td>
<td>0.93 ± 0.16</td>
<td>0.93 ± 0.19</td>
<td>0.86 ± 0.16</td>
</tr>
<tr>
<td><strong>CW</strong></td>
<td>3.48 ± 0.42</td>
<td>3.76 ± 0.51</td>
<td>3.57 ± 0.50</td>
</tr>
<tr>
<td><strong>NWI</strong></td>
<td>0.27 ± 0.03</td>
<td>0.25 ± 0.03</td>
<td>0.24 ± 0.03**</td>
</tr>
<tr>
<td><strong>NWI 2/3</strong></td>
<td>0.25 ± 0.04</td>
<td>0.26 ± 0.04</td>
<td>0.23 ± 0.06</td>
</tr>
<tr>
<td><strong>TSI</strong></td>
<td>105.4 ± 20.9</td>
<td>112.5 ± 31.2</td>
<td>136.0 ± 55.1</td>
</tr>
</tbody>
</table>

*Significant difference in the unilateral and bilateral study populations as compared to the control population. P-value of ≤0.05.
**Significance detected in the bilateral cruciate deficient study population compared to the normal study population. P-value of ≤0.05.

Fig. 2 Computed tomographic images taken through the intercondylar notch demonstrating notch variability. A) Intercondylar notch evaluated from a stifle with an intact cranial cruciate ligament and a wide intercondylar notch; B) Narrow notch in a cruciate deficient stifle with minimal acquired osteoarthritic changes; C) Narrow intercondylar notch evaluated from a dog with chronic cranial cruciate ligament disease and severe secondary osteoarthritic changes.
In the human literature, a wealth of computed tomographic intercondylar notch studies have been documented (15–17). Human studies established a normal range for the notch width index at 0.231 ± 0.044 (15). It was noted that the intercondylar notch width index for men is larger than that for women. Athletes who sustained non-contact anterior cruciate ligament tears had statistically significant intercondylar notch stenosis (NWI, 0.189) (15). La Prade performed a prospective study using college level athletes and came to the conclusion that the odds of an ACL tear in stenotic knees was 66 times higher than in non-stenotic knees (29). Benefits of this study included an initial CT evaluation for all of the study participants prior to cruciate rupture and an evaluation over an extended period of time. This study allowed congenital notch stenosis to be evaluated separately from acquired notch stenosis. Souryal hypothesized that the limit of ‘critical’ stenosis is a NWI of less than 0.20 for men and 0.18 for women (1 SD below the mean) (15).

Our study found that the cranial extent of the intercondylar notch (Slice 1) yielded statistically significant differences between normal stifles and cruciate deficient stifles. Four of eight measurements, taken from the cranial slice, indicated a significantly narrower notch occurs in cruciate deficient stifles than in the normal population. Measurements that reached significance included the ONA, NWI and NWI23. The measurements that reached significance in both unilateral and bilateral cruciate deficient stifles were measured angles and calculated ratios that were indexed to condylar width. Although NW was significant at the cranial extent of the notch in bilateral affected dogs, this could have been influenced by size variance of the femur within the population. Our findings are consistent with a previous radiographic study that determined that affected dogs had a significantly smaller proximal (i.e. caudal) NWI and distal (i.e. cranial) NWI than normal dogs (14). This study also determined that a significant difference was not noted in notch dimensions between unilateral and bilaterally affected canine population. Contact between the intercondylar notch and the cranial cruciate ligament begins at about 115° of extension (23). The contact area moved cranially in the intercondylar notch as the stifle was extended (23). A narrow opening notch angle would place additional mechanical impingement on the ligament not only in full extension but also during internal rotation of the proximal tibia in relation to the femur as compared to the normal population.

Tendons and ligaments that pass through or around bony structures in the mammalian skeleton are subject to compressive as well as normal tensile forces that can alter their biochemical composition (30). Direct compressive mechanical impingement of a ligament in this environment can cause remodeling of the ligament and weakening of the mechanical properties (30). Tendons and ligaments that are located in areas of compression increased the proteoglycan content and became increasingly fibrocartilaginous compared to tensile regions (31). These adaptive changes may increase the incidence of ligament failure due to the avascularity of the fibrocartilage regions. A previous study compared the notch dimensions between three orthopaedically normal canine breeds with variable relevant risks to ligament rupture. This study concluded that Labrador Retrievers and Golden Retrievers have a significantly more narrow intercondylar notch when compared to a similar population of Greyhounds. Interestingly, none of the dogs in this study demonstrated laxity or any evidence of gross cruciate pathology; however they did demonstrate significantly higher GAG content in the impinged region of the high risk CCLs consistent with collagen remodeling (32).

The cruciate deficient population in our study was scanned after having ruptured their cruciate ligament. It was impossible to determine the contribution of congenital notch stenosis versus acquired notch stenosis from adaptive remodeling and osteophyte production in this population (Fig. 2). Further limitations of this study include the inclusion of dogs in the control population that are at a high risk of cruciate rupture (i.e. Labrador Retrievers and Labrador mixes). Although there was a one year follow-up period for each of the control dogs, a longer period of time would be desirable after the initial scanning in order to ensure that these dogs did not rupture their cruciate ligament.

Intercondylar notch measurements have been used as a tool to predict the risk of anterior cruciate ligament injury in young human athletes, and to assess risk factors for intraarticular graft replacements (17). Our findings may be useful in order to permit the development of similar predictive models for the canine stifle. Considerations for notchplasty in patients who are at a high risk for CCL injury or intra-articular graft repair may be appropriate for individuals whose intercondylar notch measurements are judged to be stenotic.

Intercondylar notch stenosis could be the result of a congenital malformation or may be acquired due to progressive osteoarthritic changes (23). The NWI has been shown to be significantly larger for dogs (Greyhounds) that are at a low risk of CCL injury when compared to breeds with a much higher risk (Labrador and Golden Retrievers) (32). Our study reflects similar findings in CCL deficient stifles. Further controlled studies are warranted in order to define the potential aetiologies and causal relationships associated with intercondylar stenosis and CCL injury.

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References


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