The effect of computed tomographical gantry angle on the measurement of the canine intercondylar notch

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Summary
This study was conducted to evaluate the clinical application of computed tomography of the canine femoral intercondylar notch. The canine femoral intercondylar notch is angled 12 degrees from the dorsal plane and oblique 7 degrees proximolateral to distomedial in the sagittal plane. Measurements of the notch were performed with eight, 12, and 16 degrees of gantry tilt. With the exception of proximal opening notch angle, significant differences were not detected in measurements referenced to 12 degrees of gantry tilt. Evidence from this study indicated a ± 4 degree variation in gantry tilt angle from a desired angle of 12 degrees did not significantly affect clinical interpretations of intercondylar notch measurements or notch width index ratios.

Keywords
Intercondylar notch, computed tomography, canine

Introduction
The canine femoral intercondylar notch (ICN) serves as the origin of both the cranial and caudal cruciate ligaments (1). The femoral notch also serves as an interdigitating area for the intercondylar eminence (1). This anatomic area has received much attention in human orthopaedic medical literature (2–8). Computed tomography (CT) is the imaging modality of choice for assessing femoral notch measurements in humans (3, 4). Multiple investigators have identified the human femoral notch as a key in ascertaining the likelihood of anterior cruciate ligament (ACL) rupture (2–7).

Femoral ICN stenosis has been identified as a risk factor for ACL injury in human patients (2–6). Many studies have discovered that a narrowed femoral notch is associated with non-contact ACL injuries as well as a significant predictor of bilateral injuries (2–7). Canine femoral ICN stenosis may be a factor in non-contact cranial cruciate ligament (CrCL) injuries, and have an association with the bilateral nature of the disease. Mechanisms of physical injury to the ACL by a stenotic notch have been described (9, 10). It is reasonable to expect that the same mechanisms may also play a role in physical trauma to the canine CrCL. Notch width is significantly narrowed in canine breeds at high risk for CrCL rupture with a significant increase in MMP-2 and sulphated GAGs at the anatomical location in which the CrCL is impinged by the stenotic notch (11). The normal anatomic measurements of the human intercondylar notch are well known (2, 4, 7, 12).

A notch width index (NWI) has been developed and proven to be a repeatable objective measurement in humans (2–5). This index is the ratio of the notch width to the total width of the femoral condyles and allows adjustment for size variability among individuals. Investigation of the canine femoral ICN is limited (11, 13–15). A radiographic and anatomical study of 21 mixed breed dogs was performed and normal notch anatomy was reported (14). Two additional studies concluded that patient positioning for radiographic assessment of the ICN was extremely critical (13, 15). Measurements of the notch grossly, radiographically, and by CT, did not show any significant difference (13–15). Measurements made by CT were easier and potentially more accurate due to the lack of superimposition of soft tissue or osseous structures (15).

Difficulty in positioning has been addressed and substantiated in the human literature (8, 16, 17). Appropriate positioning for femoral notch radiographs is difficult and requires at least heavy sedation in canine patients (13, 14). CT capabilities are becoming widely available and affordable in veterinary medicine, however, the canine patient is typically under general anaesthesia or heavy sedation in order to obtain an appropriate scan. CT scans are now exceedingly rapid, and the risk factors associated with short-term general anaesthesia or sedation may significantly be outweighed by the advantages of this imaging modality.

Documented advantages of knee CT in human literature include: identification of meniscal injuries, intercondylar notch stenosis, and assessment of the cruciate liga-
ments with three dimensional reconstruction software or contrast arthrography (3, 4, 18). Computed tomography imaging of the canine stifle offers increased sensitivity to early osteoarthritic changes and may prove to be useful in diagnosing additional stifle pathology (15, 18).

The canine femoral intercondylar notch is angled 12 degrees from the dorsal plane and seven degrees proximolateral to dis-tomedial in the sagittal plane (14). Computed tomographical images should ideally be obtained 12 degrees from the dorsal plane (15). There is only one study that defined the canine ICN by CT, where the gantry tilt angle is 15 degrees (15). The gantry tilt is approximated in both the human and canine literature due to the difficulty of positioning the femoral long axis parallel to the CT couch. This positioning difficulty is due to limited extension capabilities of the hip and stifle as well as the varying degree of soft tissue coverage. Currently it is not known whether an approximation of the gantry tilt based on the CT scout scan will alter the measurement of the canine femoral intercondylar notch. The purpose of this study was to identify an acceptable gantry tilt range of error, when measuring the canine intercondylar notch by computed tomography. Our hypothesis was that canine femoral notch measurements would not differ significantly between eight and 12 degrees and between 12 and 16 degrees of gantry tilt relative to the dorsal femoral plane.

Materials and methods

Sixteen femora from individual dogs, obtained from the University of Missouri Veterinary Anatomy Laboratory, were used for this study. All of the soft tissues had been removed by boiling, and the femora were completely dried. Further fixation was not performed. One femur was lost, and the remaining fifteen femora were weighed and measured. Weight was recorded in grams and length was recorded in centimeters. Two cranial cortical anatomical landmarks, one just proximal to the trochlear groove and the other at the level of the lesser trochanter, were placed equidistant from the CT couch to ensure parallel orientation. The femur was then secured to the couch with a clamp (Fig. 1).

All of the femora were scanned using a GE Prospeed SX Scanner\(^4\) with the gantry tilted at eight, 12, and 16 degrees (Fig. 2). Contiguous transverse 1.5 mm CT slices were obtained moving proximal to distal until the intercondylar notch was no longer imaged.

Three transverse slices of the ICN were used for measurements (Fig. 3). The most

\(^4\) General Electric Medical Systems, Milwaukee, WI, USA.
proximal and distal images in which the notch was completely visible were obtained. A central notch image was obtained from a CT slice taken halfway between the most proximal and distal images. The electronic cursor of the CT was used to measure total femoral condyle width (CW), maximum notch width (MNW), maximum notch height (MNH), and width at two-thirds of the maximum notch height (NW2/3) and recorded in centimeters (Fig. 4). An opening notch angle (ONA) was obtained with the electronic cursor of the CT by measuring the angle produced by two straight lines drawn from the narrowest points of the notch on the medial and lateral sides and connected to a point at the most cranial limit of the notch (Fig. 5). Three planes were measured on each femur at eight, 12, and 16 degrees of gantry tilt relative to the couch. Two notch width indices (NWI) were calculated by dividing the MNW by the CW and the NW2/3 by the CW.

Statistical analysis

Eighteen sets of NWI ratios were calculated based upon three different planes (proximal, middle, and distal), two notch width measurements (MNH and NW2/3), and three different gantry tilts (eight, 12, and 16 degrees). The femoral condyle width measurement having the corresponding plane and gantry tilt factors was used as the divisor for the matching index calculation. Paired t-tests were used to evaluate means for significant differences between all three pairwise combinations of gantry tilt angles for all of the measured variables and index calculations. The NWI ratios that were determined at 12 degrees of gantry tilt were used as the reference values for comparison to NWI ratios derived from eight and 16 degrees of gantry tilt. Cross-tabulation for both eight and 16 degree ratios compared to 12 degree ratios as the reference values provided information on concordant and discordant results for these pairwise comparisons. McNemar’s test was applied to these 2x2 data tables to determine if significant differences existed in clinical interpretations based on eight or 16 degree gantry tilts compared to a reference standard based upon a 12 degree tilt.

In situations involving multiple comparisons comprised of three different pairings of gantry tilt angles, the Bonferroni correction...
was applied to a P-value of 0.05, resulting in a level of significance being established at $P \leq 0.0167$. For other statistical evaluations not involving multiple comparisons, the level of significance was set at $P \leq 0.05$. All results are reported as mean ± standard error (SE).

## Results

The femora had a mean weight of 19.93 g (± 1.99, range 9 g-36 g) and mean length of 8.9 cm (± 0.57, range 6.7–13.3 cm). Two femora weighed 9 g and had lengths of 6.7 cm and 6.8 cm, respectively. Ten femora weighed between 14 and 24 g and ranged in length from 7.0 cm to 11.0 cm. Three femora weighed between 29–36 g and ranged in length from 10.0 cm to 13.3 cm.

Our study did not demonstrate any significant differences for any of the proximal, middle, or distal NWI ratios derived from eight- or 16-degrees when compared to those derived from 12-degrees as the reference standard. The mean NWI calculated from the MNW at 12 degrees of gantry tilt was 0.29 cm proximally, 0.30 cm centrally, and 0.30 cm distally. The mean NWI calculated from NW2/3 at 12 degrees of gantry tilt was 0.24 cm proximally, 0.24 cm centrally, and 0.19 cm distally (Table 1).

The central ICN images did not demonstrate any significant differences between ONA, MNW, NW2/3 or MNH when the eight- and 16-degree images were compared to the 12-degree images. There were not any significant differences from the eight-degree measurements in relation to the 16-degree measurements. With 12 degrees of gantry tilt, the ONA, MNW, NW2/3 and MNH in the central slice were 65.18 degrees, 0.75 cm, 0.60 cm, and 0.59 cm, respectively (Table 2).

Distal ICN plane images did not demonstrate any significant differences in ONA, MNW, NW2/3 or MNH when the eight or 16-degree measurements were compared to the 12-degree measurements. The ONA and MNH in the distal plane were only significantly different when the eight-degree and 16-degree measurements were compared. None of the other measurements showed any significant difference, when these two extremes were contrasted. With 12 degrees of gantry tilt, the ONA, MNW, NW2/3 and MNH in the distal slice were 79.54 degrees, 0.67 cm, 0.42 cm, and 0.40 cm, respectively (Table 3).

The proximal ICN images did not demonstrate any significant differences in ONA, MNH, or NWI between the 12-degree measurement and the eight-degree or 16-degree measurement. A significant difference (critical value: $P \leq 0.0167$) was found in the ONA when the eight-degree measurement was compared to both the 12-degree and the 16-degree measurements. Measurements from proximal CT slices for ONA, MNW, MNH, and NWI based upon MNW were significantly different when the eight-degree measurement was compared to the 16-degree measurement (Table 4).

## Discussion

Despite the fact that many authors recommend CT imaging of the ICN, as opposed to plain radiography, in both humans and dogs,
the variability of the CT slice angle relative to the femoral condyle has not been addressed. Our results indicated that a +4 degree variation in gantry tilt angle from a desired angle of 12 degrees was not significant for central or distal ICN measurements nor interpretations of NWI ratios. The femora in this study were placed comparable to an anesthetized dog in dorsal recumbency. Our study suggests that clinically accurate measurements of the intercondylar notch can be obtained in an anesthetized dog placed in dorsal recumbency with the pelvic limbs extended.

Computed tomographical imaging has become widely available in veterinary medicine. Spiral CT scanners offer a cost-effective, rapid, accurate assessment of the canine femoral intercondylar notch. Documented advantages of CT imaging of the femoral intercondylar notch are numerous and include: the lack of superimposition of soft tissue structures, ease of positioning and accurate interpretation, despite the presence of osteophytes (13, 14). Additional advantages of canine stifle CT imaging may include interpretation of meniscal pathology and cruciate ligamentous injury, increased accuracy of tibial slope measurement and identification of predisposing factors for CrCL rupture.

The CrCL in dogs is similar in function to the ACL in man. Patients with injuries to these ligaments represent a large population in both species. Injuries are categorized in the human literature as ‘contact’ or ‘non-contact’. This categorization can be extrapolated to canine patients. Contact CrCL injuries do occur in dogs as seen with road traffic accidents and playing activities; however, non-contact injuries are more frequent (1). In addition, humans are more likely to develop a non-contact injury (approximately 70%) (7). Non-contact CrCL injuries are bilateral in 31%-37% of cases (1). Non-contact ACL injuries are bilateral in 2%-9.6% of cases (4, 5, 8). Non-contact ACL injuries have been studied, and CT has been used to identify risk factors and potential aetiologies of the injury itself (2–8, 17).

The femoral ICN has been well described with CT in humans (3, 4). In contrast, limited research has been performed on dogs (15). The human and veterinary literature describes variable locations for ICN measurements (2–8, 15, 17). This variability makes comparison of data difficult. Selection of the CT slice in which measurements should be obtained also varies between human and canine studies (3, 4, 15). Human literature focuses on obtaining an image that is halfway between the most proximal and distal slices in which the full notch can be viewed (3, 4). Fitch et al. selected a slice 4 mm proximal to the most distal slice in which the full notch could be viewed (15). Variability in canine femoral length results in the movement of this slice selection proximally or distally. We chose to measure proximal, central and distal slices at all gantry tilts to address this variability. Our central image was calculated as previously described for humans.

Specific measurements of the ICN on the selected CT slice vary within human and veterinary literature (3, 4, 15). The MNW, MNH, and CW in the human ICN have been evaluated in the past to develop a standardized index ratio that accounts for variability in patient size (3, 4). Similar ratios have been proposed in one canine CT ICN study (15). Ratios were developed with respect to ICN measurements taken at the cranial, central, and caudal 1/3 of the selected CT slice and compared to the CW on that same slice (15). Our study focused on five distinct measurements (ONA, CW, MNW, MNH, NW2/3). These measurements were selected to remain consistent with previous measurements and ratios reported in humans that have had a significant association with ACL rupture and a bilateral predisposition (3, 4). These measurements and the ratios obtained from them showed no significant difference in the eight and 16 degree gantry tilt with respect to the desired 12 degree tilt with the exception of the eight-degree ONA measured at the proximal slice.

Computed tomographical studies performed on the human ICN have utilized the ONA measurement (3, 4). A significant association of ACL rupture with a narrowed ONA has been identified (3, 4). In the human literature, a central slice has been historically used to measure the ONA (3, 4). Our study suggests that the selected gantry angles did not have any significant effect on measurements of the ONA in this region. A significant difference in the ONA measurement was found between the eight-degree measurement and both the 12- and 16-degree measurements in the proximal CT slice. The ONA is calculated by connecting a straight line from the narrowest point medially and laterally of the ICN with a point at the most cranial limit of the notch. These differences are expected at a proximal area, in which a small change in gantry tilt can distort the ICN. This location of the ICN may not have much clinical significance in the pathology of CrCL ruptures as the ligament originates distal to the proximal slice. The ONA measurement has not been previously reported in the veterinary literature. It may warrant further investigation as a tool to identify predisposing factors in the rupture of the CrCL.

Standardization of the CT slice selection and canine ICN measurements are necessary for future investigation of ICN stenosis as a factor in CrCL rupture. A repeatable central notch image can be easily obtained from a CT slice, calculated halfway between the most proximal and distal images in which the ICN is visible. In this study, significant differences were not identified in the measurements calculated from the eight or 16-degree gantry tilt, when compared to the 12-degree gantry tilt in the central image. In the human literature, significant associations with ACL rupture were identified with ONA, CW, MNW, MNH, and NW2/3 ICN measurements and ratios calculated from those measurements (3, 4). It is therefore recommended that ONA, CW, MNW, MNH, and NW2/3 measurements be obtained from the central slice. This technique would standardize future studies evaluating the canine ICN.

The role of intercondylar notch stenosis in the pathogenesis of CrCL rupture is not currently known. However, it has been documented that the CrCL contacts the ICN at 115 degrees of stifle extension (14). A recent publication studying the canine ICN suggested that impingement of the CrCL may have a direct relationship on its rupture (11). Our study suggests that CT imaging is a reliable imaging modality for studying the canine ICN. Furthermore, there appears to be some degree of allowable error in femoral positioning relative to the gantry. Further
studies are necessary to characterize canine ICN stenosis as well as to prospectively identify its possible role in the rupture of the CrCL.

References

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