Relatively Broad Femoral Condylar Notches (Large Notch Width Indices) May Protect Portuguese Water Dogs From ACL Rupture

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INTRODUCTION: The morphologies of the femoral condyles and intercondylar notch (ICN) have been examined extensively in hopes to uncover anatomical parameters that could assist in predicting the risk of anterior cruciate ligament (ACL) ruptures. In both humans and canines, stenosis of the ICN has been proposed as an indicator for increased risk of ACL ruptures [1]. The ICN is filled mainly by the ACL and posterior cruciate ligament (PCL), which is why many researchers have hypothesized that a direct anatomical impact exists between the ICN breadth and ACL rupture in some activities and traumatic events. Narrowing of the ICN is believed to induce impingement and limit ACL movement, which could impede normal function of the ACL over time and when notable trauma occurs [1]. Stenosis of the ICN can be estimated by the notch width index (NWI = ICN diameter / outer diameter of condyles). Bouras et al. [2] noted that young female humans with a stenotic femoral notch shape (small NWI) have a high risk of ACL injury, compared to those with an increased NWI. Study of the age-related condylar morphologies of the canine can serve as a model to increase our understanding of age-related morphologies that impact ACL rupture in humans. Additionally, our extensive ongoing studies of possible underlying genetics factors that could influence the emergence of the condylar morphologies that contribute to the increased risk of ACL ruptures in canines can potentially advance understanding of the etiologies of this problem in humans [3,4,5].

METHODS: Portuguese Water Dog (PWD) carcasses were obtained from animals that had been autopsied for various organ pathologies in prior studies that were part of a large research effort known as "The Georgie Project" [6,7]. Our sample of PWDs (n=342; M=143 and F=199) ranged in age from 2-16 years old. The bones had been manually dissected of soft tissues. Various linear measurements were made using a digital caliper (Mitutoyo) of the femoral condylar region (**Fig. 1**). The notch height (NH; labeled E in **Fig. 1**) and three ICN widths: anterior (Ant.NW; A), central (Cent.NW; B), and posterior (Post.NW; C), and their indices were calculated (i.e., each divided by overall (total) condylar width, T.CW = D in **Fig. 1**). Using the measurements shown in **Fig. 1**, the NWIs are: anterior NWI (Ant.NWI = A/D), central NWI (Cent.NWI = B/D), and posterior NWI (Post.NWI = C/D). Stenosis of the intercondylar ICN was estimated using the ICN width angle (N.Ang), ICN shape index (NSI = B/E), and anterior/posterior ICN width (A/P.NW). The N.Ang was calculated as the arctangent of ½ the Post.NW divided by the NH and multiplying by 2. Statistical analyses included a multivariate regression analysis, and one-way ANOVA testing of a subset of our sample that was stratified according to specimen size (i.e., Ltot and body mass). All statistics were conducted using NCSS 2020.

RESULTS: Measurement results for all parameters are reported for males and females as averages, medians, standard deviations, and ranges in **Table 1**. Multivariate regression analyses were conducted to control for specimen size as a confounding factor. The explanatory variables included in the model were total length of the femur (Ltot), specimen mass, and two dichotomous group variables sex and condylar osteoarthritis (OA) (**Table 2**). No interaction terms were significant, and there were no significant factors for any of the parameters reported. Ltot and OA explained most of the variations of the reported parameters, and females on average were smaller than males in regards to the condylar morphology. However, little sexual differentiation was observed between male and female ICN morphology. For parameters whose models explained less than 20% of the variation in the response variable (see **Table 2: Adj. R^2**) we conducted a one-way ANOVA between males and females using the stratified subset, which showed no significant difference (Parameters: Ant.NW, N.Angle, Ant.NWI, Post.NWI, NSI).

DISCUSSION: In a study of canine ACL morphology and physiology, Comerford et al. [8] expressed the need for and studied condylar morphologies in breeds with divergent predispositions for ACL ruptures, namely Greyhounds (GHs), Labrador Retrievers (LRs), and Golden Retrievers (GRs) (low-risk, high-risk, and high-risk respectively). Both the ICN width (NW) and (NWI) tend to be comparatively smaller in canine breeds with high rates of ACL ruptures such as Labrador Retrievers (LRs) and Golden Retrievers (GRs) [8]. A similar relationship has been reported in humans, especially females [1]. Our sample of PWDs, a breed with a low-risk for ACL ruptures, showed larger Ant.NWI than high-risk breeds as reported by Comerford et al. [8] (PWD= 0.16, GR= 0.10, LR= 0.11). The same was true for both central and posterior NWIs, where both PWDs and GHs had larger NWIs. Our study furthers the results discussed by Comerford et al. [8] by reporting the effect of osteoarthritis. Our study showed that those specimens with condylar OA had significantly greater stenosis of the ICN than femora without OA.

SIGNIFICANCE/CLINICAL RELEVANCE: PWDs, a breed at low-risk for ACL ruptures, have a wider ICN than canines with higher prevalence of ACL ruptures, supporting the suggestion that the ICN morphology may be a contributing factor for ACL ruptures in canines.

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Figure 1

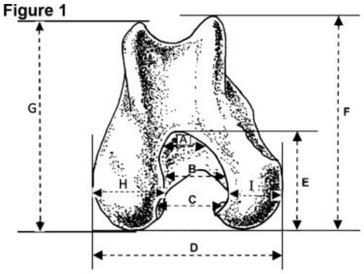

Table 1

	Mean	Median	SD	Range		Mean	Median	SD	Range
N.Angle	(deg)				**T.CW**	(mm)			
Male	38	38	6	12-66	Male	33.5	33.4	2	29.3-40.0
Female	37	37	5	24-48	Female	31.4	31.2	1.7	26.8-40.5
N.Ht	(mm)				**Med.CW**	(mm)			
Male	13.8	13.8	1.2	5.0-17.3	Male	10.9	10.8	0.9	9.0-15.5
Female	13	12.9	1	10.3-18.0	Female	10.3	10.3	0.7	8.3-12.7
NSI					**Lat.CW**	(mm)			
Male	0.6	0.6	0.1	0.3-1.0	Male	13.5	13.2	1.2	11.3-18.1
Female	0.6	0.6	0.1	0.4-0.8	Female	12.5	12.5	0.9	10.2-17.5
Ant.NW	(mm)				**Med.CH**	(mm)			
Male	5.4	5.5	0.9	2.9-7.9	Male	37.8	37.6	2.2	32.8-42.4
Female	5.2	5.2	0.8	3.1-7.3	Female	35.3	35.1	1.9	30.2-43.7
Cent.NW	(mm)				**Lat.CH**	(mm)			
Male	7.9	7.9	1.2	4.2-10.8	Male	37	36.6	2.1	31.9-41.9
Female	7.4	7.4	0.8	5.0-10.1	Female	34.7	34.5	1.8	30.0-40.8
Post.NW					**Cent.NWI**				
Male	9.3	9.5	1.4	3.5-11.9	Male	0.2	0.2	0	0.1-0.3
Female	8.6	8.7	1	5.8-11.0	Female	0.2	0.2	0	0.1-0.3
Ant.NWI					**Post.NWI**				
Male	0.2	0.2	0	0.1-0.2	Male	0.3	0.3	0	0.1-0.4
Female	0.2	0.2	0	0.1-0.2	Female	0.3	0.3	0	0.2-0.4

Table 2

	Multiple Regression Analysis				
	Adj R^2	Ltot	Weight	Sex	OA
Ant.NW	0.14	**0.03*** **	0.003	0.07	**-0.4** **
Cent.NW	0.26	**0.04*** **	-0.002	-0.2	**-1.09*** **
Post.NW	0.27	**0.06*** **	-0.003	-0.2	**-0.9*** **
T.CW	0.55	**0.1*** **	**0.02* **	**-0.7*** **	**1.7*** **
NH	0.20	**0.04*** **	0.002	**-0.4* **	**-0.5** **
N.Angle	0.02	**0.1** **	-0.02	-0.09	**-1.9* **
Med.CH	0.52	**0.1*** **	**0.03*** **	**-0.9*** **	**0.9** **
Lat.CH	0.46	**0.1*** **	**0.03** **	**-0.8*** **	**0.9** **
Med.CW	0.34	**0.03*** **	**0.01** **	**-0.2* **	**0.83*** **
Lat.CW	0.41	**0.05*** **	0.008	**-0.3* **	**1.26*** **
Ant.NWI	0.07	**0.001** **	-1.08E-05	0.01	**-0.02*** **
Cent.NWI	0.20	**0.004* **	-0.0002	-0.0004	**-0.04*** **
Post.NWI	0.16	**0.001*** **	-0.0002	-0.001	**-0.04*** **
NSI	0.04	0.001	-0.0003	-0.002	**-0.05*** **