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Comparison of tibial anatomical-mechanical axis angle between predisposed dogs and dogs at low risk for cranial cruciate ligament rupture

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ABSTRACT

The purpose of this prospective, radiographic, descriptive study was to compare measurements of tibial anatomical-mechanical axis angle (AMA-angle), tibial plateau angle (TPA), relative tibial tuberosity width (rTTW) and Z-angle from mediolateral radiographs of the tibia between two canine breeds (72 dogs) not predisposed to cranial cruciate ligament rupture (CCLR) and those from a consecutive series of 185 large dogs and 17 West Highland white terriers (WHWT) diagnosed with unilateral, surgically confirmed CCLR. Correlations among these measurements were determined, and levels of inter- and intra-observer variability among and within three observers for each measurement were established using Kendall's coefficient of concordance.

Breed had a significant effect on AMA-angle. The median AMA-angle of the subject population of large dogs affected by CCLR was 2.80° (range 1.09°–5.21°); for the WHWT, it was 6.34° (range 5.68°–8.88°); and for the clinically normal dogs, it was 0.74° (range 0.00°–5.40°). In the CCLR group, AMA-angle and TPA were strongly correlated ($r = 0.745$; $p < 0.0001$). A receiver operating characteristic (ROC) curve analysis showed that an AMA-angle higher than 1.87° had a sensitivity of 0.941 (95% confidence interval [CI]: 0.898–0.966) and a specificity of 0.965 (95% CI: 0.919–0.987) for predicting CCLR and was more accurate than TPA, rTTW and Z-angle at predicting CCLR ($p < 0.0001$). Good inter- and intra-observer agreement was found for all measurements. The highly significant difference in AMA-angle found between clinically normal dogs and dogs with CCL injury suggests that AMA-angle magnitude may be a clinically relevant predisposing factor for the development of canine CCLR.

Introduction

Cranial cruciate ligament rupture (CCLR) is a common cause of degenerative joint disease in the stifle joints of adult dogs and is reported to be associated with trauma, immune-mediated mechanisms, age-related degeneration, obesity, and conformational abnormalities, such as patellar luxation and narrowed intercondylar notch (Moore and Read, 1996; Vasseur, 2003; Comerford et al., 2006). Stifle instability following CCLR is an important pathophysiological mechanism leading to the development of progressive osteoarthritis and stifle joint 'organ' failure (Kim et al., 2008; Cook, 2010; Griffon, 2010; Comerford et al., 2011). Slocum and Devine (1983) identified cranial tibial thrust (CrTT) as a major component of the instability that follows CCLR. CrTT is a cranially directed tibiofemoral shear force generated as axial compression acts on the caudally inclined tibial plateau during weight bearing (Dejardin, 2003).

The magnitude of CrTT depends on ground reaction forces and extensor muscle forces and is passively constrained by the CCL. It was theorised by Slocum and Devine that CrTT is proportional to the slope of the tibial plateau and can therefore be quantitated by measuring the tibial plateau angle (TPA; Slocum and Devine, 1983, 1993; Dejardin, 2003). During the past 30 years, TPA has been extensively studied to determine whether it predisposes dogs to CCLR (Slocum and Devine, 1983; Wilke et al., 2002; Zeltzman et al., 2005; Cabrera et al., 2008; Buote et al., 2009).

Some studies have documented a close relationship between TPA magnitude and the amount of CrTT generated during axial tibial loading (Slocum and Slocum, 1993; Morris and Lipowitz,

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2001; Warzee et al., 2001; Reif et al., 2002; Mostafa et al., 2009). However, this correlation between the steepness of the tibial plateau and the development of CCL deficiency has not been confirmed in other studies, regardless of whether dogs are predisposed to CCLR (Duval et al., 1999; Wilke et al., 2002; Reif et al., 2004; Venzin et al., 2004). Thus, as conjectured by several authors (Wilke et al., 2002; Reif and Probst, 2003; Venzin et al., 2004), TPA may not be the sole predisposing factor for the development of canine CCLR, even for breeds predisposed to such rupture (Whitehair et al., 1993; Stauffer et al., 2006; Witsberger et al., 2008; Fitzpatrick and Solano, 2010; Taylor-Brown et al., 2015).

In addition to TPA, other tibial measurements have recently been described, such as the angle between the tibial mechanical axis and a line joining the most cranial aspect of the tibial tuberosity to the midpoint between the two tibial intercondylar tubercles (the Z-angle) and the relative tibial tuberosity width (rTTW; Inauen et al., 2009; Renwick et al., 2009; Vedrine et al., 2013). However, these measurements do not seem to have a strong association with CCL disease (Inauen et al., 2009; Renwick et al., 2009; Vedrine et al., 2013; Witte, 2015; Aertsens et al., 2015). It has been suggested that other biomechanical parameters might be more clinically relevant than TPA with respect to the pathogenesis of CCLR (Venzin et al., 2004). Morphometric characteristics of the pelvic limbs have been studied to define any association between CCL deficiency and deformity of the proximal tibia (Osmond et al., 2006; Mostafa et al., 2009; Glassman et al., 2011; Ragetlty et al., 2012). These studies reported that a greater caudal inclination of the proximal tibial shaft in relation to its distal axis might be considered a risk factor for steep TPA and CCLR (Osmond et al., 2006; Mostafa et al., 2009; Griffon, 2010; Glassman et al., 2011; Ragetlty et al., 2012).

The consequence of the caudal angulation of the proximal tibia is a proximal anatomic axis that is not fully aligned with the longitudinal anatomic axis, inducing malalignment between the anatomical and mechanical axes (Paley, 2012; Raske et al., 2013). AMA-angle is defined as the angle between these two axes and is used to quantify this caudal angulation of the proximal tibia (Osmond et al., 2006; Mostafa et al., 2009; Glassman et al., 2011).

In addition, this malalignment can increase the caudal displacement of the weight-bearing axis and can cause a focal increase in joint forces with a loss of compliance of supporting structures such as the joint capsule, leading to cartilage erosion (Hulse et al., 2010; Raske et al., 2013). In accordance with recent studies investigating the anatomical and mechanical axes of the tibia (Han et al., 2008; Hulse et al., 2010; Paley, 2012; Shao et al., 2013), we hypothesised that if higher AMA-angle magnitude could contribute to the incidence of CCLR, then the AMA-angle would be of greater magnitude in breeds predisposed to CCLR than in breeds at low risk, such as German Shepherd dogs and Basset Hounds (Whitehair et al., 1993; Witsberger et al., 2008; Taylor-Brown et al., 2015). Moreover, the aim of this study was to document any influence of breed on AMA-angle, TPA, rTTW and Z-angle.

Materials and methods

Data collection

All client-owned dogs included in this prospective study were presented at our clinic between January 2012 and June 2015 (Clinique Vétérinaire du Vernet, Le Vernet, France). The inclusion criteria were based on species (dogs), breed (predisposed or not predisposed to CCLR; Whitehair et al., 1993; Witsberger et al., 2008; Taylor-Brown et al., 2015), mediolateral radiographic tibial views obtained under general anaesthesia and clinical examination results. Informed consent was obtained from all dog owners and study protocol did not impact clinical management decisions. The control group consisted of a consecutive series of healthy (as evaluated by normal physical examination), normal (as confirmed by orthopaedic and radiographic examinations) German Shepherd dogs and Basset hounds (older than 7 years). In the control group, the left and right tibiae were systematically measured. The German Shepherd group was divided in two subgroups based on age (a young control group that were presented for hip dysplasia screening and an old control group from 7 to 14 years that were anaesthetised for reasons unrelated to the stifles; Table 1). Dogs included in the CCLR group had naturally occurring, unilateral, surgically confirmed, partial or complete rupture of the CCL and no evidence of any other concurrent stifle pathology upon physical and radiographic examinations. All medical data from the dogs were recorded.

Radiographic procedure

All mediolateral radiographic tibial images were obtained under general anaesthesia (acepromazine, 0.05 mg/kg SC [Calmivet, Vetoquinol] and morphine, 0.2 mg/kg SC [Morphine Lavoisier, CDM Lavoisier] 20–30 min before tiletamine-zolazepam took effect, 3–5 mg/kg IV [Zoletil 100, Virbac]). The radiographs were obtained with a digital system and were assessed using a DICOM viewer (Sedecal, Entrad) with the stifle at a 90° flexion angle for all dogs using a previously reported method (Slocum and Slocum, 1993; Reif and Probst, 2003).

Radiographic measurements of the tibia

AMA-angle was determined as the angle formed by the tibial anatomical axis and the tibial mechanical axis (Fig. 1; Han et al., 2008; Paley, 2012; Shao et al., 2013). As previously defined (Baroni et al., 2003; Bailey et al., 2007; Paley, 2012), the mechanical axis is the straight line extending from the midpoint between the intercondylar tubercles of the tibial plateau to a point equidistant to the cranial and caudal aspects of the trochlea of the talus. The tibial anatomic axis was defined as a line connecting the midpoint between the cranial and caudal cortex of the tibia at 50% and 75% of the tibial shaft length (Osmond et al., 2006; Dismukes et al., 2008; Glassman et al., 2011).

Table 1
Studied population characteristics.

	Median (min–max)	
	Control group	CCLR group
Number of dogs	72	202
Age (years)	9.3 (1.0–14.2)	4.6 (0.9–13.1) [a]
Weight (kg)	34.8 (22.0–47.5)	35.8 (7.0–84.0)
Sex (M/F)	41/31	79/123
Breeds included		
Old German Shepherd dog (7.0–14.2 years)	43	1
Young German Shepherd dog (1.0–6.5 years)	20	0
Basset hound	9	0
Labrador retriever	0	43
Golden retriever	0	20
Rottweiler	0	32
Boxer	0	27
American Staffordshire terrier	0	13
Cane Corso	0	15
Bernese Mountain dog	0	9
West Highland white terrier	0	17
Mixed, other breeds	0	25
Number of tibiae measured	144	202

M, male; F, female; CCLR, cranial cruciate ligament rupture.
[a] $p < 0.05$ using a Mann-Whitney non-parametric comparison.