

Comparative digital study using four methods of measurements of the tibial distal anatomical axes for determining the anatomical-mechanical angle in dogs with cranial cruciate ligament rupture

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OBJECTIVE

This study evaluates the amplitude of the anatomical-mechanical angle (AMA-angle) using 4 measuring methods of the tibial distal anatomical axes (DAA) previously described, comparing the literature results to determine if there are significant differences in patients with cranial cruciate ligament (CrCL) rupture.

ANIMALS

This study was comprised of 30 tibiae (29 dogs), including 1 bilateral case.

METHODS

A retrospective study was selected for this research. DAA measurements were performed on all surgically confirmed cases of canine CrCL rupture at Hospital Veterinário de Especialidades Bruselas from 2019 to 2022. Four different published methods (identified by surname of the corresponding author of the original publication) were compared. Tibial measurements were made using Veterinary Preoperative Orthopedic Planning Pro software (<https://vpop-pro.com/>) on mediolateral radiographic projections obtained from a digital database.

RESULTS

The mean (range) in the DAA method conducted by Hulse obtained a AMA-angle of 5.4° (3.3 to 8.1°), 3.0° (0 to 5.8°) for Osmond et al, 3.2° (0.9 to 6°) for Miles, and 5.9° (2.4 to 8.8°) for Tudury. Differences among the means of the AMA-angle of the authors methods were found with a statistical difference ($P < .05$), except between Osmond and Miles. The mean AMA-angle with the Osmond method concurred with previous study results that determined the magnitude using the same measurement method of DAA in patients with CrCL rupture.

CLINICAL RELEVANCE

The AMA-angle magnitude has been associated with higher sensitivity and specificity for predicting the development of CrCL rupture compared to other anatomical factors evaluated; therefore, future comparisons with different methods of measurement of the DAA between healthy and affected patients are recommended to determine whether any of them can increase the percentage value as a predictive factor for the occurrence of this condition.

Keywords: anatomical axis, cranial cruciate ligament, mechanical axis, stifle, tibial measurements

Cranial cruciate ligament (CrCL) rupture causes stifle instability, one of the main causes of lameness in dogs, and its pathogenesis has been reviewed and summarized in the literature.^{1,2} The anatomy of the stifle joint has been extensively evaluated in order to better understand the risk factors that may be

associated with the development of CrCL rupture, and a relationship between the proximal tibia conformation and rupture of the CrCL has been described in many studies.³⁻⁶ Although some variations in stifle morphology can result in significant microtears in the CrCL rupture, these variables have not been recognized as significant predictors of the condition.⁶⁻⁹

The anatomical-mechanical angle (AMA-angle) was indicated as the angle formed by the tibial anatomical axes (AA) and the tibial mechanical axes (MA) and quantifies the magnitude of the caudal

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displacement of the functional weight-bearing axis of the tibia in relation to its anatomical axis.^{3,5,6,10} In one study,⁶ an AMA-angle $> 1.9^\circ$ demonstrated a sensitivity of 0.941 (95%) and a specificity of 0.965 (97%) for predicting CrCL rupture. Other research¹¹ showed that an AMA-angle $> 2.42^\circ$ had a sensitivity of 95% and specificity of 95% for predictivity. This relationship was confirmed as a significantly higher AMA-angle was observed in the group with CrCL rupture,¹² which was consistent with what was previously suggested, concurring that this angle was a more accurate predictive factor than other factors described.⁶

The AA is represented by a single contoured line centered between the cranial and caudal cortices along the entire length of the tibia, connecting to the center of the proximal and distal articular surfaces.^{13,14} Several designs of the tibial distal anatomical axis (DAA) have been described in the literature¹⁵⁻¹⁹ as formed by a line passing through 2 midpoints between the cranial and caudal cortices.^{3,5,10,20}

The aim of the present study was to evaluate the AMA-angle using 4 different distal AA to compare the results of their amplitude as depicted in the literature and determine if there were significant differences in patients with a CrCL rupture.

Methods

Inclusion criteria

Medical records of all dogs examined at the Hospital Veterinário de Especialidades Bruselas from 2019 to 2022 in which a diagnosis of CrCL rupture had been made were reviewed. The diagnoses were determined through orthopedic evaluation and complementary tests and were confirmed in surgery. The inclusion criteria were based on adult dogs having a mediolateral radiographic view with the stifle joint and tarsus flexed at a 90° angle and with condylar superimposition < 2 mm.²¹⁻²³ There was no evidence of any other concurrent stifle pathology, including fractures, osteoarthritis, or neoplasia.

Radiographic measurements of the tibia

All data were collected from dogs of random breeds, sex, weight, and age. Radiographic marks were made on a predetermined software (Markup Editor in Photo Macintosh Operating System). To determine the tibia shaft length, a measurement was taken from the proximal end of the tibia in the area of the extensor groove of the long digital extensor muscle to the end of the tibia immediately proximal to the talus. A mark at the intercondylar eminence^{22,24,25} was used to standardize the individual measurements of each of the DAA methods. Thirty digital radiographic studies, with real-life templates, were exported in JPEG format at native resolution to a commercial software, Veterinary Preoperative Orthopedic Planning Pro (<https://vpop-pro.com/>), where all digital measurements were made.

Determination of the AMA

The DAA is defined as the line connecting midpoint A and midpoint B between the cranial

and caudal cortex placed along the length of the tibia.^{3,5,10,13} Four different DAAs were determined using the Anatomic Axis tool in the Veterinary Preoperative Orthopedic Planning Pro software. This tool allows modification of the location of the 2 midpoints placed along the tibia. The first DAA to be evaluated, illustrated by Hulse,¹⁶ was set with the first midpoint at the level of the distal border of the tibial crest; the second midpoint was at the diaphyseal/metaphyseal junction distally where the tibia widens. The midpoints at 50% and 95% of the tibial length were described by Miles et al.²⁰ Subsequently, the midpoints at the 50% and 75% level were depicted by Osmond et al,³ and finally, Tudury¹⁸ determined the midpoints at 33% and 66% of the tibia length.

The MA of the tibia was determined by a line drawn between the center of a circle created on the body of the talus and the midpoint of the 2 tibial intercondylar eminences using the mark made previously as a reference for each DAA.^{14,25,26} The amplitude obtained between MA and DAA were determined as AMA-angle, and these were each compared (Figure 1) as previously reported in the literature.^{6,11,12}

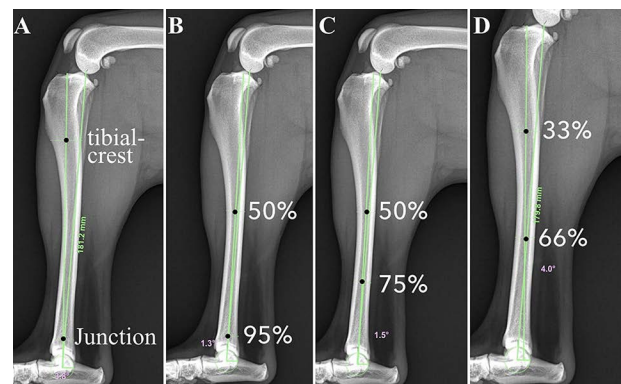


Figure 1—Anatomical-mechanical angle measured on a mediolateral radiographic view of the tibia with distal anatomical axis of (A) Hulse,¹⁶ (B) Miles et al,²⁰ (C) Osmond et al,³ and (D) Tudury.¹⁸ A—Midpoints at the level of the distal border of the tibial crest and at the diaphyseal/metaphyseal junction distally where the tibia widens. B—Midpoints at 50% and 95% of the tibial length. C—Midpoints at 50% and 75% of the tibial length. D—Midpoints at 33% and 66% of the tibial length.

Statistical analysis

A descriptive analysis, using mean, maximum, minimum, and coefficient of variation, was used to understand the variability of the data. The 4 methods of measurements of the tibial distal AA were compared using a paired *t* test (assuming that the samples are dependent), considering significant differences at $P < .05$. Furthermore, we used a Bland-Altman plot as a visual representation of the differences between the compared methods across the range of observed values. The `t.test()` and `BlandAltmanLeh()` R functions were used for the respective data analyses. Statistical procedures were carried out in R Software, version 4.2.1 (R Foundation for Statistical Computing).²⁷

Results

A total of 30 tibiae (29 dogs) were included in this study. Characteristics of the canine population that were used in the 30 radiographs are depicted (Table 1). Mean AMAs using each DAA are shown (Table 2). Significant differences at 5% ($P < .05$) were

Table 1—Characteristics of the canine population with cranial cruciate ligament (CrCL) rupture.

Population	Category
	Dogs with CrCL rupture
Number of dogs	29
Age (y)	4.6 (1.0–9.0)*
Weight (kg)	30.7 (16.8–45.5)*
Stifle L/R	20/10
Bilateral cases	1
Sex (M/F)	16/14
Breeds	
Mixed	9
Boxer	4
Pitbull	2
American Staffordshire Terrier	2
Labrador Retriever	2
German Shepherd	2
Akita	2
Other breeds	9
Number of tibiae measured	30

*Data expressed in Mean (range).
F = Female. L = Left. M = Male. R = Right.

found between Hulse and Osmond, between Hulse and Miles, between Hulse and Tudury, between Osmond and Tudury, and between Miles and Tudury using t test. No significant differences were found between Osmond and Miles (Table 3).

Figure 2 shows the visual representation of discrepancies between the compared approaches

Table 2—Maximum, minimum, mean and coefficient of variation (CV) for 4 measurement methods for outcome measure in 30 canine tibiae of the anatomical-mechanical angle for each distal anatomical axis.

Method	Maximum	Minimum	Mean	CV
Hulse	3.3	8.1	5.4	19.6
Osmond	0	5.8	3.0	44.0
Miles	0.9	6	3.2	45.9
Tudury	2.4	8.8	5.9	24.3

Table 3—Paired t test comparisons among measurement methods for outcome measure in 30 canine tibiae of the anatomical-mechanical angle for each distal anatomical axis.

Method	Hulse	Miles	Osmond	Tudury
Hulse	—	*	*	*
Miles	—	—	ns	*
Osmond	—	—	—	*

* = 5% significant. ns = Nonsignificant.

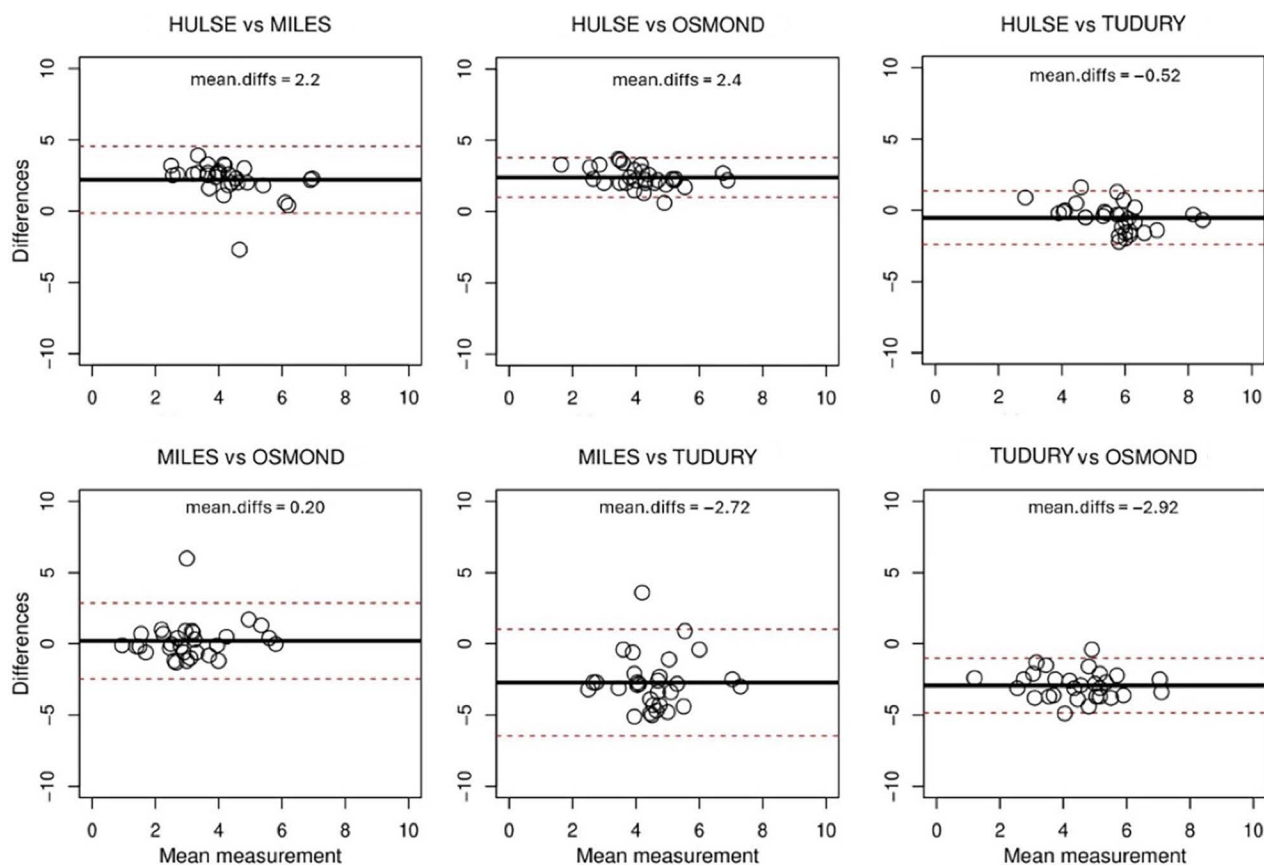


Figure 2—Bland-Altman plot comparisons among measurement methods for outcome measure in 30 canine tibiae of the anatomical-mechanical angle for each distal anatomical axis. mean.diffs = Mean differences.

across the range of observed values (Bland-Altman plot). Note that the largest mean differences were found for Hulse and Miles, Hulse and Osmond, Miles and Tudury, and Miles and Osmond, whereas Hulse and Tudury and Miles and Osmond showed differences close to zero. However, the *t* test (Table 3) indicated that these differences close to zero were not significant only for Miles and Osmond. However, due to the dispersion of the measurements, the Bland-Altman plot indicated that the difference between the measurements by Miles and Tudury (-2.72) could not be statistically different since the confidence interval covers the zero value up to its lower and upper limits. The same occurs for Hulse and Tudury (-0.52) and for Miles and Osmond (0.20). According to the Bland-Altman plot, the difference between these methods could not be significant. However, the *t* test and Bland-Altman plot corroborate in indicating no differences between the methods only for Miles and Osmond.

Discussion

Different DAAs designated for other purposes were not used to measure the magnitude of the AMA-angle. The results obtained in this study found significant differences between almost all authors' methods, but it is impossible to determine the superiority of one DAA compared with the results previously reported in the literature to determine an AMA-angle magnitude as a predictive risk factor for CrCL rupture.^{6,11,12}

Previous reports indicated that large dog breeds are considered at high risk for presenting this condition at an early age, such as the boxer²⁹ and the Labrador.²⁹ Guénégo et al⁶ reported that the magnitude of AMA-angle was breed dependent and that this angle was strongly correlated with the tibial plateau angle. Labrador retrievers are the most highly represented breed, followed by rottweilers and boxers. Although Labrador retrievers and boxers were represented in the current study, the largest number of breeds were mixed. This may be due to the fact that the popularity of adopting dogs with this trait has increased and is reflected in a greater number of mixed-breed patients in general. However, due to the retrospective nature of this study, the sample size was small because the choice was limited to the number of available dogs that met the inclusion criteria; therefore, the study does not present general values for the total population affected by this condition.

Guénégo et al^{6,11} used the DAA initially described by Osmond et al³ to determine the AMA-angle that resulted in the most accurate risk factor associated with CrCL rupture. The mean AMA-angle in this study using Osmond's DAA (3.0 ± 1.3) concurred with the description of patients with complete CrCL rupture, with a mean of 3.02 ± 1.20 in such cases.¹² Furthermore, this factor is clinically relevant in patients with CrCL rupture in this study since it was confirmed that AMAs greater than 1.9° ⁶ and greater than 2.42° ¹¹ are associated with this condition.

The AMA-angle is a reflection of the caudal angulation of the entire tibia and is considered a clinically

relevant predisposing factor, along with the degree of tibial plateau incline in the destabilizing forces involved in the development of a CrCL rupture.^{6,11,12} The altered biomechanics involved in the pathogenesis of a defective stifle joint may be secondary to conformational abnormalities in the proximal tibia or distal femur.^{3,5,10} Although it is still not entirely known how the AMA-angle magnitude and consequent craniocaudal position of the patella may affect the initiation or progression of CrCL rupture,¹¹ these specific tibial measurements should be considered when choosing the tibial plateau slope alteration procedure.^{6,11,12,30,31} Despite this, there is insufficient information indicating that the reduction of the AMA-angle by itself is an aid to joint stability.^{19,32} However, good to excellent results have been reported using surgical techniques that manage to reduce the AMA-angle.^{30,32-34}

The center of rotation of angulation-based leveling osteotomy (CBLO) technique aligns the proximal and distal segment anatomical/mechanical axis, maintaining approximately 30% of the normal cranial tibial thrust.^{16,35} However, an evaluation of the degree of reduction in the magnitude of the initial AMA-angle with the DAA design described for planning the technique has not been reported. Conversely, previous studies^{19,30,32} used the same DAA to assess the magnitude of the initial and final AMA-angle and to plan the submitted surgical technique. Mazdarini et al. (2021)¹⁹ used the DAA illustrated by Miles²⁰ for CBLO planning and reported a mean initial AMA-angle of 1.9 (range, 0.2 to 5.1°), in contrast with the results of this study (3.2 ; range, 0.9 to 6°). The modified cranial closing wedge osteotomy based on the AMA-angle technique uses the same DAA for measuring initial AMA-angle and planning the technique itself, with the midpoints at 50% and 75% of the tibial shaft length.³⁶

The choice of anatomical axis design should always be appropriate for the intended objective,²⁰ so it is considered possible to use a different DAA to evaluate the AMA-angle and its reduction and another to plan the digital technique. Miles²⁰ compared multiple approximations and concluded that the DAA better reflects the true anatomical axis of the distal tibia if the first landmark is restricted to the distal half of the tibia (50%). The second, the distal landmark, is either proximal to the distal metaphyseal flare of the tibia (95%) or at the midpoint of the distal articular surface (100%). Using this DAA recommendation in one study,¹⁹ it was concluded that the main source of error in CBLO planning and execution was identification of the tibial plateau landmarks and the subsequent misidentification of the center of rotation of angulation. Hulse¹⁶ recommended the first midpoint level of the distal border of the tibial crest and at the diaphyseal/metaphyseal junction distally for planning the CBLO. Tudury¹⁸ used 33% and 66% for cranial closing wedge osteotomy. In the present study, it was observed that the AMA-angle using the DAA of Hulse and Tudury represented greater values in relation to the results of Miles and Osmond. Miles²⁰ suggested that extending the choice of landmark for the distal tibial anatomical axis into the proximal half

of the tibia rapidly risks clinically significant deviation from the “true” alignment as determined by linear regression. This may imply that neither Tudury’s nor Hulse’s DAA method should be recommended for digital planning, but more studies are required to confirm this information.

The limitations in this study, in addition to the small sample size, was that there was no comparison of results between different observers in order to decrease the overall average coefficient of variation,^{22,24,37} although a good high intra- and interobserver variability was described.³⁸ Another limitation in this study was that it did not include healthy patients to compare results for each DAA method. No significant differences were found between Osmond’s and Miles’ methods; therefore, this could suggest that similar results would be obtained. However, a larger number of samples is necessary to confirm this relationship.

It is advisable to conduct further research following the methodology of Guénégo et al,⁶ which used the DAA between a control group of healthy patients and those affected with CrCL rupture to determine if there would be significant differences that can increase the accuracy of this angle as a predictive risk factor for developing the condition. Thus, it is not possible to know whether a delineation of the midpoints (landmarks) on the tibia length differs from that previously described to evaluate the AMA-angle that determines a superiority of a DAA to measure its amplitude. The literature thus far suggests a comparison of the AMA-angle at least using the one deemed as “true” by Miles.²⁰

Significant differences were found between the amplitude of the AMA-angle of all authors, except between Osmond and Miles. The AMA-angle magnitude has been associated with an increased risk of CrCL rupture. Therefore, it is recommended to consider choosing a tibial plateau slope alteration surgical technique. The DAA of the tibia is of fundamental importance during the performance of many measuring procedures, including the AMA-angle and digital surgical planning. Due to this, future comparisons between healthy and affected patients are recommended to determine whether there are significant differences that may increase the accuracy of this angle as a predictive risk factor for the occurrence of this condition.

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