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CLINICAL RESEARCH

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Computed tomographic measurements of the femoral trochlea in dogs with and without medial patellar luxation

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Abstract

Objectives: To determine cutoff values in small (SB) and medium/large (MLB) breed dogs with and without medial patellar luxation (MPL) for identifying abnormal femoral trochlea morphology.

Study design: Original research.

Animals: A total of 80 computed tomographic (CT) scans from client-owned dogs

Methods: Four groups of 20 dogs were created: (1) control SB, (2) control MLB, (3) MPL-SB, and (4) MPL-MLB. Two authors measured the femoral trochlear groove angle (FTGA), femoral trochlear angle (FTA), and femoral trochlear ridge inclination angle (FTRIA) in two points with CT. ANOVA and ROC-analysis were tested to the control and MPL groups to assess sensitivity, specificity, and cutoff values. Statistical significance was set to $p < .05$. Intraclass correlation coefficients evaluated the inter-rater agreement.

Results: FTGA ($\pm$ SD) in control SB (128.8° $\pm$ 4.7°) and control MLB (119.2° $\pm$ 5.6°), was smaller ($p < .0001$) than in MPL-SB (139.4° $\pm$ 4.4°) and MPL-MLB (133.7° $\pm$ 5.1°). FTA and FTRIA were decreased ($p = .12$, $p = .23$) in MPL-SB (2.1° $\pm$ 6.8; −0.3° $\pm$ 3.3°) and MPL-MLB (3.8° $\pm$ 5.6°; 1.7° $\pm$ 4.5°) compared to control SB (0.2° $\pm$4.1; −0.1° $\pm$ 2.6°) and control MLB (5.3° $\pm$ 2.8°; 3.1° $\pm$ 1.3°). Cutoff values for FTGA, FTA, and FTRIA were > 134°, < −5.9°, < −2 ° (SB), and > 128.3°, < −0.4°, < −0.4° (MLB). Sensitivity, specificity, and inter-rater agreement were superior for FTGA than FTA and FTRIA.

Conclusions: Dogs without MPL had a deeper femoral trochlear groove than MPL dogs. SB had a shallower groove than MLB. The measurement of FTA and FTRIA was not reliable.

Clinical relevance: A FTGA <134° (SB) and < 128° (MLB) may be considered as a cutoff for trochleoplasty decision-making.

1 | INTRODUCTION

A shallow femoral trochlear groove is a common finding in dogs affected by medial patellar luxation (MPL).[1] It

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has been suggested that the patellofemoral congruency may affect the femoral trochlear groove depth (FTGD) during the skeletal development of dogs.[2] In most of the cases, a decreased FTGD is secondary to a patellar maltracking and subsequent MPL.[2] More rarely, an abnormal trochlear morphology characterized by a shallow femoral trochlear groove, hypoplasia of the femoral trochlear ridges, and loss of bony restraints of the patella may be primarily associated with a recurrent patellar luxation.[3–6] In people, these trochlear abnormalities are referred as femoral trochlear dysplasia.[7]

Traditionally, the FTGD has been assessed intraoperatively by subjective visual inspection to evaluate whether the femoral groove requires a trochleoplasty to provide a deeper accommodation for the patella.[1] Radiographs,[8] ultrasound,[9,10] and computed tomographic (CT)[11–13] examinations were described for measuring the FTGD preoperatively. Radiographs are rarely reported in dogs to evaluate the FTGD, and neither inter- and inter-rater agreement nor accuracy were evaluated.[8]

Ultrasound has shown some benefits for FTGD measurement, as it allows for the simultaneous evaluation of the whole femoral trochlear groove and detection of the cartilage. However, US showed some pitfalls due to the dynamic nature of the examination.[9]

Computed tomography has lately shown a better measurement consistency for FTGD in terms of inter-and intra-rater agreement.[11,12] Specifically, a recent CT-study introduced a standardized protocol for measuring the FTGD in five trochlear points equally distributed along trochlear sagittal length.[11] In this study, the deepest FTGD was found in the proximal trochlear half, specifically in-between the 25% (point P25) and 50% (point P50) of the trochlear sagittal length. Additionally, it was reported that P25 and P50 were the most precise points for measuring the FTGD.[11]

The association between femoral trochlear dysplasia and MPL has been poorly described in dogs. As a result, little information concerning the trochlear morphology in dogs with and without MPL is available. To the authors' knowledge, CT was used in two studies to evaluate the FTGD and trochlear ridge orientation using angular measurements in SB.[14,15] A shallower femoral trochlear groove in MPL dogs compared to dogs without MPL, was observed proportionally to the MPL grade. Both studies were performed in small breed (SB) dogs. Reportedly, patellar luxation is a common disease of the canine hindlimbs also in medium/large breed (MLB) dogs.[2] To date no studies have compared the femoral trochlear morphology in these two distinct canine populations to assess whether differences in terms of FTGD of femoral trochlear ridge inclination may be present. Additionally, no inter-rater agreement was evaluated to assess the reproducibility of the femoral trochlear angle measurements.

The femoral trochlear groove angle (FTGA), femoral trochlear angle (FTA), and femoral trochlear ridge inclination angle (FTRIA) are described in human literature to assess the angular depth of the femoral trochlear groove and the inclination of the trochlea relative to the femoral condyles.[3,4,16–18]

The purposes of this study were to: (1) determine the cutoff values in dogs with and without MPL for identifying abnormal femoral trochlear morphology by means of CT measurement of the FTGA, FTA, and FTRIA; and (2) measure the above angles in a population of dogs, selected based on the breed size (SB vs. MLB).

We hypothesized that: (1) the FTGA measured in dogs without MPL would be smaller compared to MPL dogs, (2) the FTGA measured in SB dogs would be greater (shallower) compared to MLB, and (3) the FTA and the FTRIA in dogs without MPL would be greater than in MPL dogs.

2 | MATERIALS AND METHODS

2.1 | Medical record review and inclusion criteria

The medical records and CT of clinical cases affected or unaffected by MPL were reviewed by one author (LF) in the computerized databases of two institutions.

Information about dog signalment, bodyweight, orthopedic examination, absence or presence of MPL were recorded. In MPL dogs, the degree of luxation was recorded according to Putnam classification.[19]

Each CT was assigned to one out of four groups: (1) control SB; (2) control MLB; (3) MPL-SB; (4) MPL-MLB dogs. Only one hindlimb per patient was analyzed.

Inclusion criteria for groups 1 and 2 were: absence of MPL, absence of stifle degenerative joint disease (DJD), bodyweight <9 kg for group 1, between 10 and 36.5 kg for group 2,[20,21] and not clinically relevant femoral or tibial limb deformity. A not clinically relevant femoral deformity was defined when the anatomic lateral distal femoral angle ranged from 94° to 100°, and the femoral torsion angle ranged from 20° to 35°.[22–24] A not clinically relevant tibial deformity was defined when the mechanical medial proximal tibial angle ranged from 92° to 98°, and the tibial torsion angle from 10° to 5°.[25–27]

Dogs with grade 1 MPL, no femoral trochlear groove (convex trochlear groove surface), and severe stifle DJD were excluded from groups 3 and 4. In addition, chondrodystrophic dogs were excluded from this study.

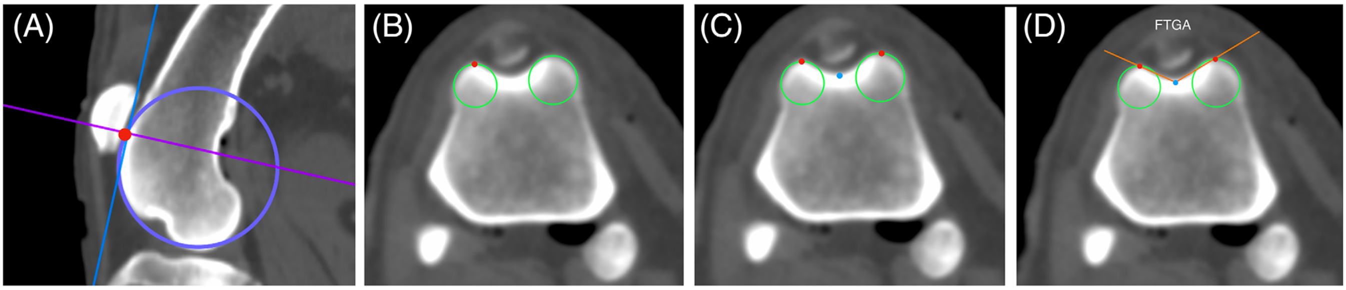

FIGURE 1 Measurement of the femoral trochlear groove angle (FTGA) at P25 point in a right femoral trochlea of a Labrador Retriever. The sagittal view of the multiplanar reconstruction function is selected and an osculating circle superimposing to the lateral femoral trochlear ridge and tangent to P25 (red dot) is drawn (A). On the transverse view, two best-fit circles of the trochlear ridges are drawn (B). The two apexes of the trochlear ridges (red dots) and the deepest point of the femoral trochlear groove (blue dot) are found (C). The FTGA (124°) is measured (D). In transverse view images, medial is on the right side and lateral is on the left

2.2 | Computed tomographic measurements

Contiguous CT images were obtained in a distoproximal direction, with the dog in dorsal recumbency, using a four multidetector row CT scanner. The CT slice thickness ranged from 0.8 to 1 mm (reconstruction interval 0.6–0.8 mm) according to the institutions' CT machine (Institution 1: Toshiba Asteion S4, Toshiba Medical Systems Europe, Amsterdam, Holland; Institution 2: Philips 16 Brilliance; Philips AG, Zurich, Switzerland). CT images were reconstructed with a high-resolution filter bone (window length 1000 Hounsfield units, HU; window width 4000 HU).

All CT images were retrieved and organized by one author (XX). The measurements were performed in a blind fashion by two authors (LF, MP). The selected CTs were sent to a collaborator (CB) who anonymized the CTs using a legend. The collaborator sent the anonymized CTs to the two authors who performed the CT measurements, indicating, for each CT, which side (right vs. left femoral trochlea) had to be assessed. The two authors calculated the FTGA, FTA, and FTRIA in two trochlear points, one-time, using a commercially available DICOM software (Osirix version 2.7, Pixmeo SARL, Geneva, Switzerland).

2.2.1 | Femoral trochlear groove angle

The CT methodology previously presented[11] was used to identify two points onto the lateral femoral trochlear ridge in the proximal half of the femoral trochlea using the 3D volume rendered function. These points were labeled as P25 and P50. The 3D curved multiplanar reconstruction function was selected and the FTGA was measured as follows:

1. The sagittal reconstructed images were scrolled until P25 was visualized.
2. On the sagittal view, an osculating circle was superimposed to lateral femoral trochlear ridge. The vertical axis of the 3D Bezier path was positioned tangentially to P25 (Figure 1A).
3. The curved multiplanar reconstruction function transverse view was selected. Two best-fit circles were superimposed on the lateral and medial trochlear ridges (Figure 1B).
4. The apexes of the trochlear ridges were identified along with the deepest point of the femoral trochlear groove (Figure 1C).
5. Two segments (angle rays) connecting the groove point (angle vertex) to the ridge apexes were drawn and the FTGA measured (Figure 1D).
6. The same procedure was repeated for P50.

2.2.2 | Femoral trochlear angle

1. The curved multiplanar reconstruction function sagittal view was selected.
2. The most distocaudal point of the lateral femoral condyle was visualized and the vertical axis of the Bezier path was positioned tangentially to an osculating circle fitting the lateral femoral condyle (Figure 2A).
3. On the curved multiplanar reconstruction function transverse view, the condylar joint orientation line (JOL) was drawn and copied (Figure 2B).
4. On the curved multiplanar reconstruction function sagittal view, the reconstructed images were scrolled until P25 was observed. Once localized, the MPR transverse view was again selected.
5. Two best-fit circles of the trochlear ridges were drawn and the condylar JOL pasted (Figure 2C).
6. A line tangent to the apex of the trochlear ridges was drawn (trochlear ridge axis) (Figure 2D).
7. The FTA formed by the trochlear ridge axis and the condylar JOL was measured (Figure 2D). The author

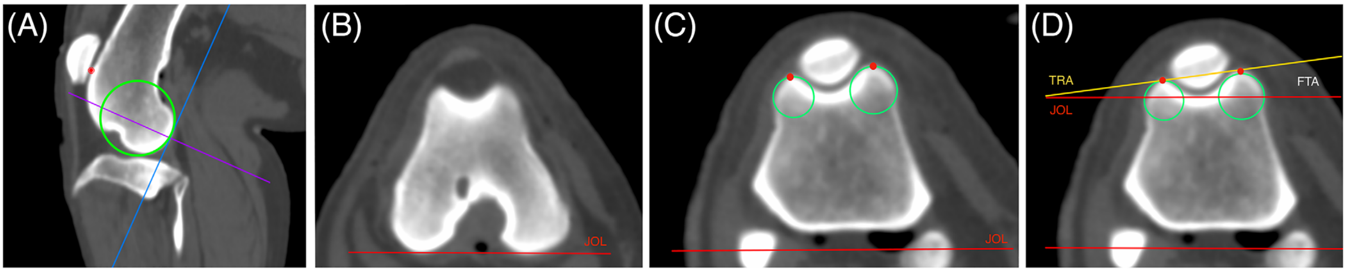

FIGURE 2 Measurement of the femoral trochlear angle (FTA) at P25 point in a right femoral trochlea of a Labrador Retriever. On the sagittal view of multiplanar reconstruction function, the vertical axis of the Bezier path is moved onto the most distocaudal aspect of the lateral femoral condyle tangent to an osculating circle best-fit the condyle (A). On the transverse view, the joint orientation line (JOL) is drawn (B). Two best-fit circles of the trochlear ridges are found along with their two apexes (red dots, C). A trochlear ridge axis (TRA) is drawn and an FTA with a medial opening angle (7.4°) is measured (D). In transverse view images, medial is on the right side and lateral is on the left

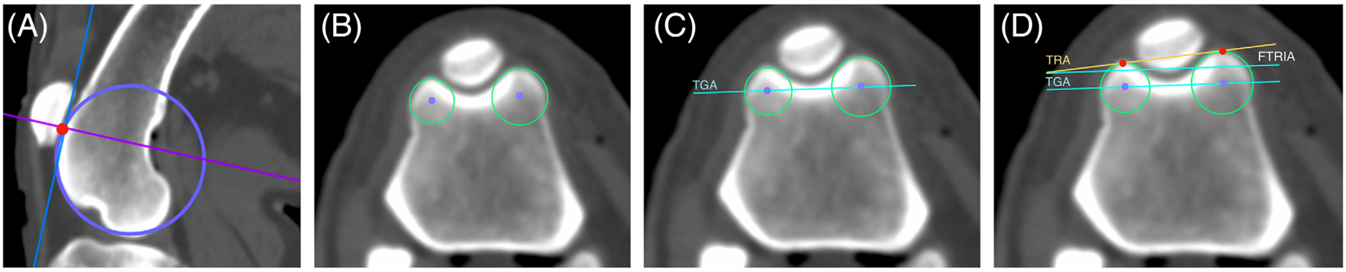

FIGURE 3 Measurement of the femoral trochlear ridge inclination angle (FTRIA) at P25 point in a right femoral trochlea of a Labrador Retriever. On the sagittal view of multiplanar reconstruction function, the vertical axis of the Bezier path is moved tangential to the osculating circle (A). On the transverse view, two best-fit circles of the trochlear ridges are found along with their two centers (B). A line connecting the two centers and parallel to the trochlear groove is drawn (TGA), (C). A trochlear ridge axis (TRA) is drawn and an FTRIA with a medial opening angle (4.2°) is measured (D) In transverse view images, medial is on the right side and lateral is on the left.

recorded whether the opening of the angle was medial or lateral. A medial opening angle had a positive value and implied that the trochlea was externally oriented, while a lateral opening angle had negative value, suggesting an internal orientation of the trochlea.

8. The procedure was repeated for P50.

2.2.3 | Femoral trochlear ridge inclination angle

1. The curved multiplanar reconstruction function sagittal view was selected and P25 found as above (Figure 3A).
2. The curved multiplanar reconstruction function transverse view was selected.
3. Two best-fit circles of the trochlear ridges were drawn (Figure 3B).
4. A line connecting the center of two circles and parallel to the femoral trochlear groove was drawn (trochlear groove axis) (Figure 3C).
5. A line tangent to the most cranial points of the trochlear ridges was drawn (trochlear ridge axis) (Figure 3D). A medial opening angle had a positive value and suggested an increased height of the medial trochlear ridge, while a lateral opening angle had negative value, meaning that the lateral trochlear ridge was higher than the medial ridge.
6. The procedure was repeated for P50.

2.3 | Statistical analysis

All data were collected in a standard spreadsheet program (Excel version 14.7.8, Microrsoft, Redmont, Washington). The statistical analysis was performed with two software packages, SAS 9.4 (SAS Institute, Cary, North Carolina) and MedCalc Statistical Software version 17.3 (MedCalc Software, Ostend, Belgium).

A power analysis was performed to assess the sample size. Data from a pilot study conducted in 40 femoral trochleae (10 animals per group). At least eight samples per

TABLE 1 Demographic data of the patients included in the study

	Breed	Bodyweight (kg)	Age (years)	Patellar luxation (degree and direction)
Group 1 Control SB	Toy Poodle ($n = 5$)	Mean: **4.5**	Mean: **2.1**	
	Maltese ($n = 4$)	SD: ± **1.3**	SD: ± **0.9**	
	Mixed-breed ($n = 4$)	Median: **4.2**	Median: **2**	
	Pinscher ($n = 4$)	Interq. 25%: **3.6**	Interq. 25%: **1.4**	
	Yorkshire ($n = 3$)	Interq. 75%: **4.9**	Interq. 75%: **3**	
Group 2 Control MLB	Labrador R. ($n = 8$)	Mean: **26.8**	Mean: **2.9**	
	Mixed-breed ($n = 5$)	SD: ± **5**	SD: ± **1.5**	
	Segugio ($n = 4$)	Median: **26.6**	Median: **2.8**	
	Bernese MD ($n = 2$) Irish Setter	Interq. 25%: **24.9**	Interq. 25%: **2**	
	($n = 1$)	Interq. 75%: **29.3**	Interq. 75%: **3.2**	
Group 3 MPL-SB	Mixed-breed ($n = 5$)	Mean: **4.3**	Mean: **1.9**	Grade 2 MPL ($n = 8$)
	Pinscher ($n = 5$)	SD: ± **1.1**	SD: ± **0.8**	Grade 3 MPL ($n = 6$)
	Toy Poodle ($n = 4$)	Median: **4.2**	Median: **1.9**	Grade 4 MPL ($n = 6$)
	Yorkshire ($n = 4$)	Interq. 25%: **3.4**	Interq. 25%: **1.4**	
	Maltese ($n = 2$)	Interq. 75%: **4.9**	Interq. 75%: **2.2**	
Group 4 MPL-MLB	Labrador R ($n = 7$)	Mean: **28.4**	Mean: **2.3**	Grade 2 MPL ($n = 8$)
	Mixed-breed ($n = 7$)	SD: ± **5.6**	SD: ± **1.9**	Grade 3 MPL ($n = 6$)
	English Setter ($n = 3$)	Median: **27.9**	Median: **1.8**	Grade 4 MPL ($n = 6$)
	Rottweiler ($n = 2$)	Interq. 25%: **25.2**	Interq. 25%: **1**	
	Drahthaar ($n = 1$)	Interq. 75%: **33.5**	Interq. 75%: **2.9**	

Abbreviations: Interq, interquartile; MD, mountain dog; MLB, medium/large breed; MPL, medial patellar luxation; SB, small breed; SD, standard deviation.

group were sufficient for a type I error of 0.05 and a power of 90% considering a significant difference between healthy and pathological calculated on the FTGA.

Descriptive statistics (means, SD, and medians) were calculated for the three femoral trochlear angles in both trochlear points. For each angle, an average of the measurements performed by the two authors at P25 and P50 was calculated to condense the data.

ANOVA analysis with least square means was performed on the four groups to compare the mean angle measurements, applying Bonferroni's adjustment for multiple comparisons, and evaluate whether mean differences within healthy and pathological groups were significantly different ($p < .05$).

Receiver operating curve (ROC) analysis was used to compare CT measurements within the SB and MLB groups, evaluate sensitivity and specificity of each femoral trochlear angle, and define a cutoff value based on Youden criterion within control and MPL populations.

To evaluate inter-rater agreement, the inter-rater intraclass coefficients (ICC) with 95% confidence intervals were calculated. The ICC score ranged from 0 (no agreement) to 1 (complete agreement). The inter-rater agreement was classified as fair (ICC <0.8), good (0.8 < ICC ≤0.9), and excellent (ICC >0.9).[26]

3 | RESULTS

The CTs of 80 dogs were equally distributed in four groups, with 20 dogs each, elected for measuring the femoral trochlear angles. The breed, median age, and bodyweight of the study dogs are summarized in Table 1. Toy poodle ($n = 9$), mixed-breed dogs ($n = 9$), and Pinscher ($n = 9$) were the most represented breeds in the SB groups, while Labrador ($n = 15$) and mixed-breed dogs ($n = 12$) were the most represented breeds in MLB groups. The degree of MPL for groups 3 and 4 are shown in Table 1. Overall, there were $n = 8$ grade 2 MPL, $n = 6$ grade 3 MPL, and $n = 6$ grade 4 MPL in each of these groups.

3.1 | Femoral trochlear groove angle

The control SB and MLB had an overall FTGA mean (± SD) of 128.8° (± 4.7°) and 119.2° (± 5.6°), while the FTGA

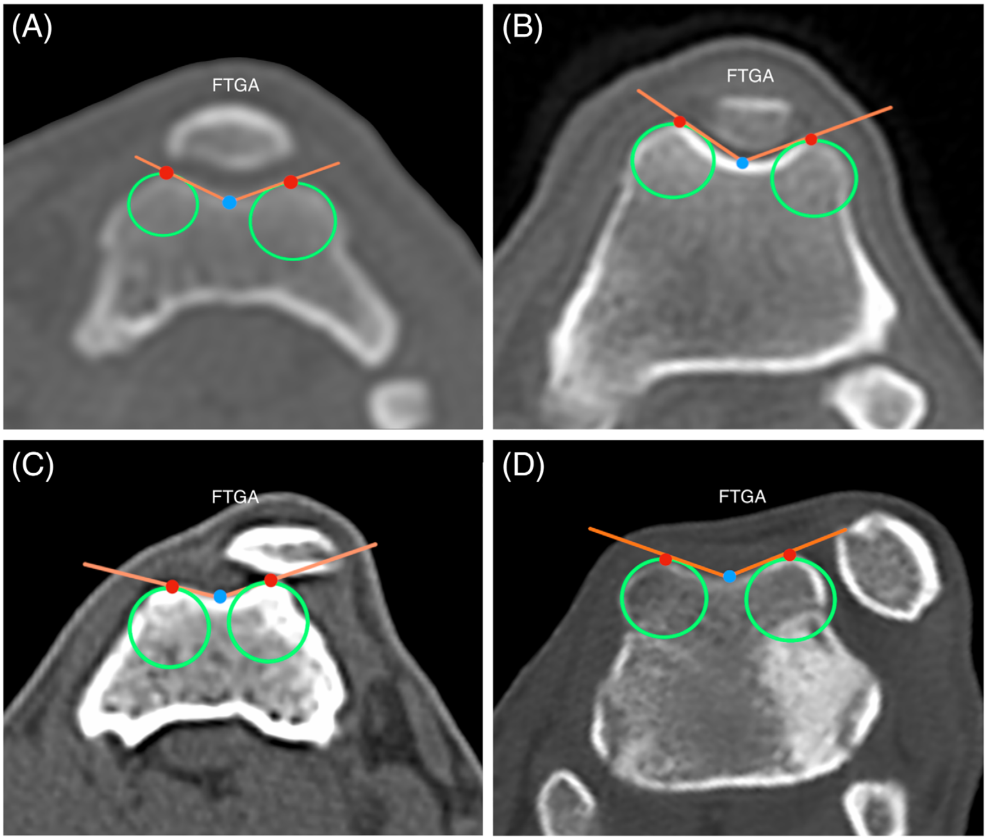

FIGURE 4 Normal (A, B) and pathological (C, D) femoral trochlear groove angle (FTGA) measured at P50 point. In a healthy Yorkshire Terrier and Labrador Retriever. The FTGA is 130°(A) and in 125°(B), respectively. The FTGA measured in a Maltese and a Drahthaar affected by grade 3 medial patellar luxation is equal to 147° (C) and 136°(D). Medial is on the right side and lateral is on the left

TABLE 2 Mean, standard deviation (SD), and median of computed tomographic measurements of the femoral trochlear groove angle (FTGA), femoral trochlear angle (FTA), and femoral trochlear ridge inclination angle (FTRIA) performed by the two observers in healthy dogs

		FTGA° (P25–P50)	FTA° (P25–P50)	FTRIA° (P25–P50)
Control SB				
Ob 1	Mean ± SD	129.4 ± 5.3	0 ± 3.8	−0.1 ± 2.8
	Median	130	−2.1	−0.8
Ob 2	Mean ± SD	128.1 ± 4.8	0.4 ± 5.4	−0.1 ± 2.4
	Median	129.4	−0.6	−0.6
Ob 1,2	Mean ± SD	128.8 ± 4.7	0.2 ± 4.1	−0.1 ± 2.6
	Median	130.2	−1.3	−0.7
	ICC	0.98	0.88	0.81
Control MLB				
Ob 1	Mean ± SD	119.9 ± 5.7	5.7 ± 2.6	3.4 ± 1.1
	Median	119.5	5.2	3.3
Ob 2	Mean ± SD	118.5 ± 5.4	5 ± 3.1	2.9 ± 1.4
	Median	117	5.1	3
Ob 1,2	Mean ± SD	119.2 ± 5.6	5.3 ± 2.8	3.1 ± 1.3
	Median	119	5.2	3.2
	ICC	0.98	0.9	0.84

Note: The intraclass correlation coefficients (ICC) with 95% confidence interval are included.
Abbreviations: MLB, medium/large breed; MPL, medial patellar luxation; SB, small breed.

TABLE 3 Mean, standard deviation (SD), and median of computed tomographic measurements of the femoral trochlear groove angle (FTGA), femoral trochlear angle (FTA), and femoral trochlear ridge inclination angle (FTRIA) performed by the two observers in pathological dogs

			FTGA° (P25-P50)	FTA° (P25-P50)	FTRIA° (P25-P50)
MPL-SB					
	Ob 1	Mean ± SD	140.8 ± 4.2	−1.5 ± 7.2	−0.1 ± 3.4
		Median	142.5	−3.6	−2
	Ob 2	Mean ± SD	138.8 ± 4.6	−2.7 ± 5.4	−0.5 ± 3.1
		Median	140.7	−3.7	−1.5
	Ob 1,2	Mean ± SD	139.8 ± 4.4	−2.1 ± 6.8	−0.3 ± 3.3
		Median	141.4	−3.7	−1.6
		ICC	0.93	0.83	0.8
MPL-MLB					
	Ob 1	Mean ± SD	134.8 ± 5.3	4 ± 5.9	1 ± 3.9
		Median	137.5	4.5	3.2
	Ob 2	Mean ± SD	132.7 ± 4.9	3.6 ± 5.4	1.8 ± 5
		Median	134.6	2.9	1.9
	Ob 1,2	Mean ± SD	133.7 ± 5.1	3.8 ± 5.6	1.7 ± 4.5
		Median	134.8	4.1	2.2
		ICC	0.96	0.82	0.81

Note: The intraclass correlation coefficients (ICC) with 95% confidence interval are included.
Abbreviations: MPL, medial patellar luxation; MPL-MLB, MPL medium/large breed; MPL-SB, MPL-small breed.

TABLE 4 Analysis of the variance and least squares means ± standard error (SE) for the three femoral trochlear angles for each group

	Control SB	Control MLB	MPL-SB	MPL-MLB	*p*-value
FTGA	128.8°[b] ± 1.62	119.2°[c] ± 1.62	139.8°[a] ± 1.62	133.2°[b] ± 1.62	<.0001
FTA	0.2°[b,c] ± 1.1	5.3°[a] ± 1.1	−2.1°[c] ± 1.1	3.8°[a,b] ± 1.1	<.0001
FTRIA	−0.1°[b] ± 0.62	3.1°[a] ± 0.62	−0.3°[b] ± 0.62	1.7°[a,b] ± 0.62	.000

Note: Statistical significance at *p*-value < .05. Different letters correspond to statistically significant differences in means ($p < .05$) after Bonferroni adjustment.
Abbreviations: FTGA, femoral trochlear groove angle; FTA, femoral trochlear angle; FTRIA, femoral trochlear ridge inclination angle; MLB, medium/large breed; MPL, medial patellar luxation; SB, small breed.
[a,b,c]Different letters correspond to statistically significant differences in means ($p < 0.05$) after Bonferroni adjustment.

mean in MPL-SB and MPL-MLB was 139.8° (± 4.4°) and 133.7° (± 5.1°), respectively (Figure 4, Tables 2 and 3).

Table 4 shows that a difference ($p < .0001$) either when comparing for condition (i.e., control-MLB vs. MPL-MLB) or for the breed size (i.e., control SB vs. control MLB) was observed. Additionally, no difference ($p = .055$) was found when comparing control SB to MPL-MLB.

Both trochlear points were accurate with ROC analysis for measuring the FTGA (Table 5). The cutoff values for SB and MLB groups were 134° and 128°, respectively. In SB and MLB groups, the sensitivity and specificity were 80% and 100%, respectively (Table 5). There was excellent inter-rater agreement for the FTGA measurement (ICC >0.9; Tables 2 and 3).

3.2 | Femoral trochlear angle

The control SB and MLB had an overall FTA mean (± SD) of 0.2° (± 4.1°) and 5.3° (± 2.8°), while FTA mean in MPL-SB and MPL-MLB was −2.1° (± 6.8°) and 3.8° (± 5.6°), respectively (Figure 5, Tables 2 and 3).

Although a difference ($p = .002$) was found with ANOVA between breed sizes (MPL-SB and MPL-MLB, Table 4), no difference ($p = 0.12$) was identified across

TABLE 5 ROC analysis for the comparisons of the femoral trochlear groove angle (FTGA), femoral trochlear angle (FTA), and femoral trochlear ridge inclination angle (FTRIA) measurement within small breed (SB) and medium/large breed (MLB) groups

	ROC	FTGA (P25–P50)	FTA (P25–P50)	FTRIA (P25–P50)
Control SB versus MPL-SB	Area under ROC curve (*p*-value)	88% ($p = .0001$)	61% (p .2)	55% ($p = .7$)
	Cutoff	>134°	< − 5.9°	< − 2°
	Sensitivity	80%	45%	50%
	Specificity	100%	95%	80%
Control MLB versusMPL-MLB	Area under ROC curve (*p*-value)	86% ($p < .0001$)	62% (p 0.2)	62% (p .2)
	Cutoff	>128.3°	< − 0.4°	< − 0.4°
	Sensitivity	80%	40%	50%
	Specificity	100%	100%	100%

Abbreviations: FTGA, femoral trochlear groove angle; FTA, femoral trochlear angle; FTRIA, femoral trochlear ridge inclination angle; MLB, medium/large breed; MPL, medial patellar luxation; SB, small breed; ROC, receiver-operating characteristic.

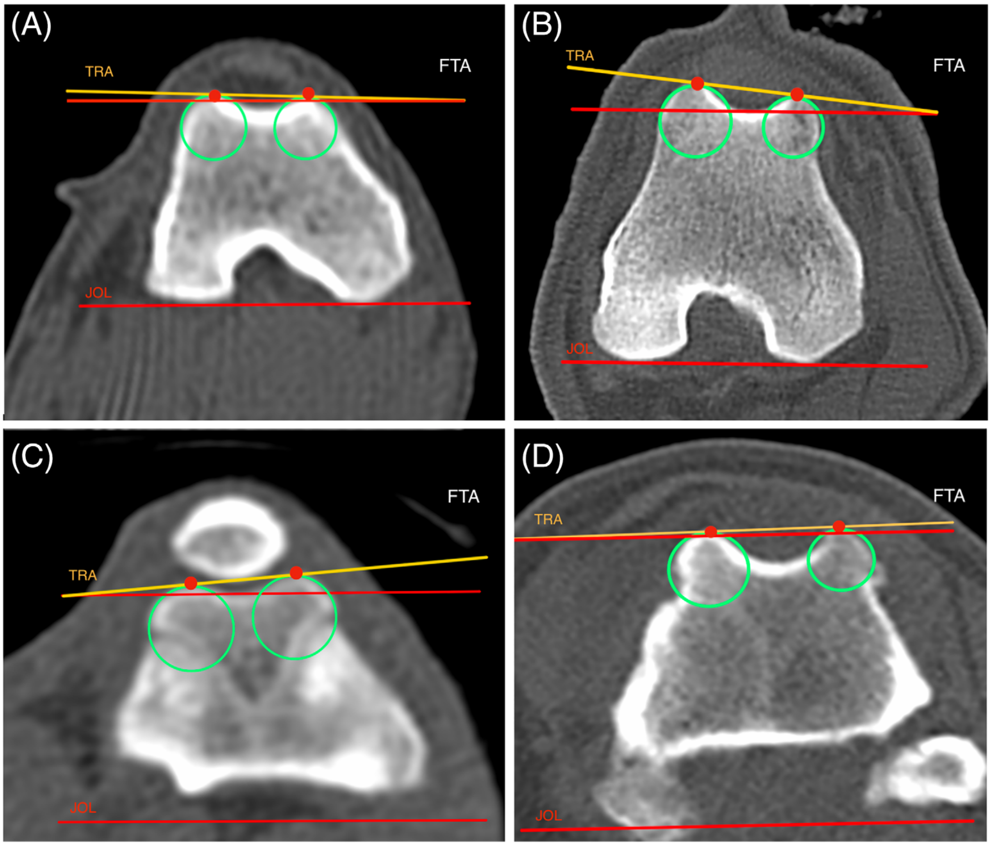

FIGURE 5 Normal (A, B) and pathological (C, D) femoral trochlear angle (FTA) measured at P50 point. In a healthy toy Poodle (A) and Rottweiler (B), the FTA is 1.7° and 6.7°, respectively. The FTA measured in a toy Poodle (C) and Bernese (D) affected by grade 2 MPL is—2.7° (C) and °- 0.5°(D), respectively. Medial is on the left side and lateral is on the right

the conditions within the same breed group (i.e., control SB vs. MPL-SB, Table 4).

Both trochlear points were inaccurate ($p > .1$) with ROC analysis for measuring the FTA (Table 5). The cutoff values were < − 5.9° and < − 0.4° for SB and MLB groups, respectively. The sensitivity and specificity in SB groups were 45% and 95%, respectively, while they were and 40 and 100%, in MLB groups (Table 5). There was a good to excellent inter-rater agreement for the FTA measurement (0.8 > ICC >0.9; Tables 2 and 3).

3.3 | Femoral trochlear ridge inclination angle

The control SB and MLB had an overall FTRIA mean (± SD) of −0.1° (± 2.6°) and 3.1° (± 1.3°), while FTGA mean in MPL-SB and MPL-MLB was $-0.3°$ ($\pm$ 3.3°) and 1.7° ($\pm$ 4.5°), respectively (Tables 2 and 3).

FTRIA was different ($p < .000$) when comparing the control groups in (i.e., control SB vs. control MLB, Table 4), but no difference ($p = 0.23$) was observed in the comparison of the condition (i.e., control MLB vs. MPL-MLB).

Both trochlear points were inaccurate ($p > 0.2$) with ROC analysis in either SB or MLB groups for measuring the FTRIA (Table 5). The cutoff values were $< -2°$ and $< -0.4°$ for SB and MLB groups respectively. The sensitivity and specificity in SB groups were 50% and 80%, while they were 40% and 100% in MLB groups (Table 5). There was a good inter-rater agreement for the FTRIA measurement (0.8 > ICC >0.9; Tables 2 and 3).

4 | DISCUSSION

In this study we provided cutoff values to identify the presence of an abnormal trochlea morphology in MPL dogs compared to dogs without MPL. We assessed the femoral trochlear morphology by performing three CT angular measurements to evaluate the angular depth of the femoral trochlear groove (FTGA), the orientation of the femoral trochlea relative to the femoral condyles (FTA), and the inclination of the trochlear ridges relative to the femoral trochlear groove (FTRIA). We performed these measurements in two distinctive canine populations to assess whether the breed size (SB vs. MLB) differences may have an impact on the femoral trochlear morphology.

In this study, we have also evaluated the inter-rater agreement two evaluate whether the measurements performed on the femoral trochlea were reproducible.

We accept our first hypothesis, as in this study the overall FTGA in dogs without MPL was smaller compared to MPL dogs, similarly to what other authors have recently reported.[8,14,15] Among SB and MLB populations, we discovered a mean FTGA of 128° $\pm$ 4.7° in SB and 119° $\pm$ 5.6° in MLB with cutoff values of 134° and 128° respectively. These data slightly differ from human literature, which suggests that a normal trochlea has an average sulcus angle of 138° $\pm$ 6°, while dysplastic trochleae have a sulcus angle >145°.[4,28]

When comparing our results with the radiographic study of Garnoeva,[8] similar data in terms of mean FTGA in SB dogs without MPL were found, as Garnoeva reported a mean FTGA value of 125°. On the contrary, in the CT study of Sasaki and coauthors,[15] a greater FTGA (135° $\pm$ 8°) was found in SB dogs without MPL. We believe that a plausible explanation to such discrepancy relies on the trochlear position where the FTGA measurement was performed. In our study, the FTGA was measured in two trochlear points in the proximal half of the trochlea, that did not include the very proximal part of the femoral trochlea. Similarly, Sasaki and colleagues[15] measured the FTGA in the proximal half of the femoral trochlea, but in a more proximal position. Nicetto et al.[11] and Yasukawa and coauthors[14] showed that the FTGD is decreased in the very proximal area of the proximal trochlear half. Additionally, the CT measurements in this specific position were less precise and accurate.[11]

In human orthopedics, a great research focus has been dedicated to the analysis of femoral trochlear morphology, as trochlear dysplasia is a common finding in people affected by patellar instability syndrome.[6,7,29] The sulcus angle, here named FTGA, was described to investigate the angular relationship between the deepest point of the trochlear groove and the apexes of the trochlear ridges.[4–6]

In people, the sulcus angle is usually assessed via radiographic skyline projection.[4,16,30] In veterinary medicine, this projection has been described to evaluate the FTGD,[8,31] but it is not routinely used. In this study, we opted for CT rather than radiographs, since a CT standardized methodology to accurately perform measurements on the femoral trochlear groove has been established.[11,12] The benefits of the broad availability of radiographs and ease for performing a skyline view of the femoral trochlea are counteracted by the three-dimensional complexity of the trochlea morphology, which changes in proximodistal direction.[7,14,15]

Moreover, from the authors' perspective, when performing the skyline radiographic projection, it is difficult to select and analyze one specific point of the trochlear groove. As a result, it would be necessary to perform multiple radiographs with a different degree of stifle flexion, although this will probably increase the sedation time and costs. Contrariwise, CT allows for a three-dimensional evaluation of the femoral trochlea, with the benefits of precisely localizing the femoral trochlear points when performing the angular measurements.

Trochleoplasty has been suggested as a successful surgical technique to treat patellar luxation in both humans[32,33] and dogs,[34–36] but it has been also associated with complications.[37–39] Additionally, the authors of a previous study reported that the trochleoplasty may not be always required for the treatment of patellar luxation in dogs.[40]

The cutoff values reported in this study may help to elucidate how deep should the femoral trochlear groove be in MPL-SB and MPL-MLB. This may imply that dogs having MPL with a sufficiently deep femoral trochlear groove (FTGA smaller than the reported cutoff) may require a different surgical technique rather than a trochleoplasty.

The good results in terms of inter-rater agreement support also the use of the FTGA as a reliable measurement among different evaluators.

We hypothesized that FTGA would have been different in SB and MLB. We accept this hypothesis as we found that the angular femoral trochlear groove depth of SB is significantly higher than MLB dogs (Figure 4).

Although we cannot assume this as a definitive statement, due to the heterogeneity of breeds included in the study, the shallower groove in SB than MLB may be an anatomical factor that could be investigated to explain the reported higher prevalence of MPL in SB dogs.[21,41]

In people, the FTA is assessed to evaluate the orientation of the trochlea relative to the femoral condyles.[6,18,42] The FTA has been reported to be slightly smaller in dysplastic knees (9.4°) than in normal knees (11.4°).[18] In another large multicenter study (566 osteoarthritic knees) the average FTA was (3.1°).[6]

We measured the FTA to investigate whether dogs affected by MPL may have a trochlea that is not coaxial to the condylar JOL (Figure 5). Additionally, we measured the FTRIA to assess the inclination of the trochlear ridges relative to the femoral trochlear groove, to evaluate whether a hypoplastic trochlear ridge may be a significant finding in dogs affected by MPL. The FTRIA is similar to the lateral and medial trochlear inclination angles described in people.[6,17]

In this study, we found a decrease of either FTA or FTRIA in MPL dogs, but we failed to find a significant difference, thus we reject our third hypothesis. Additionally, although we found a good to excellent inter-rater agreement, the results in terms of sensitivity and specificity suggested that the measurement of both FTA and FTRIA was not as reliable as for FTGA.

Extrapolating from our data, we observed that the trochlea in the control SB group is approximately coaxial with the JOL, while control MLB group had a mild medial opening angle and, therefore, an external orientation of the trochlea.

Similarly, dogs without MPL had either an equal trochlear ridge height (SB) or a medial ridge that is slightly more prominent than the lateral (MLB). In MPL-SB and MPL-MLB, either FTA or FTRIA decreased likely due to chondromalacia and subchondral bone sclerosis of the medial trochlear ridge, which typically occurs in case of MPL.

This study has some limitations that should be mentioned. First, being a retrospective study, certain information on the patient signalment, history, and medical records could be inaccurate. Second, unlike other imaging techniques (US and MRI), CT is unable to accurately identify the cartilage thickness. The slight under or overestimation of the femoral trochlear angles may have resulted in a less-than perfect measurement of trochlear angles with small proportions of errors.

In conclusion, dogs with MPL had a different femoral trochlear morphology, especially in terms of FTGD. We found that the FTGD changes according to the breed size, as SB had an averagely greater or shallower FTGA compared to the MLB dogs.

The good outcomes in terms of sensitivity, specificity, and inter-rater agreement suggest that the FTGA can be used as a reliable CT measurement to quantify groove depth prior to surgery and determine whether a femoral trochlear groove deepening is required.

We also conclude that the orientation of the trochlea and the inclination of the femoral trochlear ridges may be less clinically relevant when evaluating the trochlear morphology.

To validate or reject the findings of this study, a prospective clinical study using CT femoral trochlear measurements and intraoperative assessment of the FTGD is warranted.

AUTHOR CONTRIBUTIONS

Longo F, DVM, PhD: Conceived and designed the study, performed the measurements, reviewed the medical records, collected data, analyzed and interpreted the data, drafted the manuscript; Memarian P, DVM: Performed the measurements, revised, read and approved the final manuscript; Knell SC, DVM, PhD, DECVS: Interpreted the data, revised the manuscript, read and approved the final manuscript; Contiero B, MsS: Statistical analysis, organized and provided CTs, read and approved the final manuscript; Pozzi A, DVM, DACVS, DECVS, DACVSMR: Participated in the design of the study, interpreted the data, revised the manuscript, read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare neither proprietary interest nor funding for this study.

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