Article published online: 2024-07-26

Computed Tomographic Measurement Method for Morphoanatomical Comparison of Femur, Tibia, and Patella in Cats with and without Medial Patellar Luxation

Bruno Santos[1] Eimear Shorten[1] Alexandre Caron[2] Gareth Arthurs[3] Marie-Pauline Maurin[1]

[1] Section of Small Animal Clinical Studies, University College Dublin, Belfield, Dublin 4, Ireland
[2] AniCura-TRIOVet, Rennes, France
[3] Arthurs Veterinary Specialists, Northampton, United Kingdom

Address for correspondence Marie-Pauline Maurin, DVM, DVMS, Dip. ECVS, University College Dublin, Belfield, Dublin 4, Ireland (e-mail: marie-pauline.maurin@ucd.ie).

Vet Comp Orthop Traumatol 2025;38:1–10.

Abstract

Objectives The aims of this study are to describe a computed tomographic (CT) measurement method of feline femoral, tibial, and patellar conformation, and to compare these measurements between a cat population diagnosed with medial patellar luxation (MPL) and cats without MPL.

Materials and Methods Eleven measurements were performed by two observers, including anatomical lateral distal femoral angle (aLDFA), femoral trochlear width (FTW) and femoral trochlear depth (FTD), anteversion angle of the femoral neck, patellar length, patellar width, patellar height, patellar volume, mechanical medial proximal tibial angle, tibial torsion angle, and tibial tuberosity displacement. Mean and standard deviation differences between the groups were statistically assessed. Intra-observer and interobserver interclass correlation coefficients (ICCs) were calculated.

Results The aLDFA was significantly higher in the MPL II compared with the control and MPL III. The FTW was significantly larger in the MPL III than in the control or the MPL II group. The FTD in the control group was significantly larger than in the MPL II and III groups. The TTA of the control group was significantly smaller than the MPL II and III. The intraobserver ICC was high at 64%, and the interobserver ICC was high at 36% of the measurements.

Clinical Significance This study identified shallower FTD and increased TTA in cats diagnosed with MPL. The TTA difference was less than 5 degrees and FTD was less than 1 mm. The findings provide information on feline pelvic limb morphology. However, the differences between the two populations are small.

Keywords
- computed tomography
- feline orthopaedics
- cats
- patellar luxation

Introduction

Medial patellar luxation (MPL) in cats is less commonly reported than in dogs.[1–4] Cats are described as having more patellar laxity than dogs without causing clinical signs.[1] Usually, cats diagnosed with this condition show a range of presentations like a crouched gait, inability to jump, decreased activity, intermittent lameness or unexpected distress with vocalization, and refusal to use the affected limb after patellar luxation.[1] The cause of feline patellar luxation is poorly understood. Feline patellar luxation was

received
April 23, 2024
accepted after revision
July 12, 2024
article published online
July 26, 2024

© 2024. Thieme. All rights reserved.
Georg Thieme Verlag KG,
Rüdigerstraße 14,
70469 Stuttgart, Germany

DOI https://doi.org/10.1055/s-0044-1788732.
ISSN 0932-0814.

Downloaded by: IP-Proxy European College of Veterinary Surgeons , European College of Veterinary Surgeons. Copyrighted material.

initially believed to be caused by trauma.[3,5] However, a congenital cause has also been suggested based on an early clinical presentation with a bilateral diagnosis.[1,2,4] A weak association between MPL and hip dysplasia has also been reported in cats.[2,3] Medial luxation, as opposed to lateral, is described in most feline patellar luxation cases.[4]

Unlike in dogs, where multiple radiographic and computed tomography (CT) studies had been published identifying pelvic limb deformities associated with this condition, only one recent publication explored concurrent femoral and tibial skeletal deformities in cats using CT.[6–12] Characterization of skeletal deformities and other factors contributing to patellar malalignment allowed appropriate surgical planning and treatment for the realignment of the quadriceps mechanism in dogs.[13] Accurate radiographic measurements have shown to be challenging because of positioning variations and limitations of a three-dimensional (3D) structure translated into two-dimensional images.[6–8] Methods using CT showed better accuracy.[6–11] The study comparing femoral and tibial conformation in eight cats with and eight cats without MPL using CT suggested that cats with MPL have medialization of the tibial tuberosity and decreased trochlear depth.[12] However, the indication for corrective osteotomies based on these results remains unknown. Studies with larger sample sizes and studies comparing different luxation grades are required to further document and understand this condition in cats.

Tibial tuberosity transposition (TTT), recession trochleoplasties (wedge or block), soft tissue techniques, and patellar groove replacement have been described to treat feline patellar luxation.[1,4,14–16] Partial parasagittal patellectomy has also been described as a supplemental technique to block recession trochleoplasty, considering cats' naturally wide patella.[14,17,18] A short case series described a semicylindrical trochleoplasty alternative in five feline stifles to accommodate the wide feline patella.[16] Despite all these techniques described, there is a lack of consensus and guidelines regarding feline surgical treatment of this condition. A better understanding of pelvic limb deformities in cats diagnosed with MPL would be the first step towards an appropriate choice of surgical treatment.

This study aimed to (1) compare the femoral, tibial, and patellar morphology of cats with and without MPL, (2) compare the same morphology between MPLII and MPLIII grades, and (3) evaluate the repeatability and reproducibility of a CT measurement methodology. Based on our clinical experience, we hypothesized that (1) femoral, tibial, and patellar morphology in cats without MPL would not significantly differ from cats with MPL, (2) and would not differ between cats with MPL grade II and cats with MPL grade III, and (3) the methodology described would be repeatable and reproducible.

Materials and Methods

Ethical approval was granted by the University College Dublin Ethical Review Committee. Medical records from the University College Dublin Veterinary Hospital were retrospectively reviewed from September 2018 to December 2022, and skeletally mature cats that underwent a CT, including the pelvis and pelvic limbs, as part of diagnostic investigations, were included and used as a control group. Inclusion criteria were CT images, including full pelvic limbs from hip to tarsus. Exclusion criteria were an orthopaedic condition or hindlimb lameness recorded in the history and clinical examination. All the CT images were acquired using a 16-slice sliding gantry CT scanner (SOMATOM Scope; version Syngo CT VC40, Siemens). Slice thickness varied between 0.75 and 1 mm. For the group of cats with MPL, medical records were retrospectively reviewed from three different institutions in the same study period and skeletally mature cats presenting with pelvic limb lameness and subsequently diagnosed with MPL based on an orthopaedic examination by a board-certified specialist or supervised resident in small animal surgery. The inclusion criteria were the presence of lameness associated with MPL. The side and degree of luxation of the affected limbs were recorded.[19] As for the inclusion criteria of the control group, cats without CT images available from hip to tarsus and those with a history of previous surgery in the affected limb were excluded. Computed tomography machines were specific to each practice (Toshiba Astelion, Canon Medical Systems Europe BV and Philips MX-16-slice helical CT system, Philips Healthcare), slice thickness varied between 0.75 and 1 mm, and bone reconstruction was available. Patient positioning and sedation/anaesthesia protocol acquisition protocols were based on clinician preference.

Three-dimensional multiplanar reconstruction (MPR) and 3D volumetric reconstruction were performed for each CT using a DICOM Viewer (Horos, Purview, Annapolis, MD). Computed Tomography images of the cats from the control and affected groups were randomly reviewed by each observer using a web-based random sequence generator (www.random.org/lists/, School of Computer Science and Statistics, Trinity College, Dublin, Ireland). The two observers, a board specialist in diagnostic imaging (E.S.) and a resident in small animal surgery (B.S.) were provided with a written explanatory protocol for making different measurements. One observer repeated the measurements three times (B.S.) on different occasions with multiple weeks between sessions; the other (E.S.) did the measurements once. Eleven measurements were performed in total, including anatomical lateral distal femoral angle (aLDFA), femoral trochlear width (FTW) and femoral trochlear depth (FTD), anteversion angle of the femoral neck (AA) by axial method, patellar length (fPL), patellar width (fPW), patellar height (aPH) and patellar volume (PV), mechanical medial proximal tibial angle (mMPTA), tibial torsion angle (TTA), and tibial tuberosity displacement (TTD).[7,9–11,17,20,21]

Femoral Measurements

The aLDFA was measured in the frontal plane. Preparation of the alignment of the femur and manipulation of the MPR images was done as described by Barnes and colleagues.[9] The planes were designated frontal, sagittal, and axial and calibration of the alignment in the three planes was achieved, allowing correct identification of the anatomical landmarks.[9] The intersection of the orthogonal planes in the MPR was

Downloaded by: IP-Proxy European College of Veterinary Surgeons , European College of Veterinary Surgeons. Copyrighted material.

placed in the most caudal point of the medial femoral condyle while changing the sagittal plane orientation lines. The goal was to have the sagittal plane orientation lines tangential to the most caudal point of the proximal femur and the medial femoral condyle.[9] The same process was done in the axial plane image to the most caudal point of the lateral femoral condyle by scrolling the frontal plane orientation line.[9] The true frontal plane view was achieved when the femoral condyles and the most caudal point of the proximal femur were visualized together.[9] After this, the thickness of the slice was increased to allow identification of the femoral head, neck, diaphysis, and condyles.[9] The proximal anatomical axis was defined in the frontal plane using a bisecting axis passing in the proximal third and half of the femur length as described by Tomlinson and colleagues in dogs and Swanson and colleagues adapted for cats.[6,22] Once the proximal anatomical axis was defined, the distal femoral reference lines were also drawn in the frontal plane, connecting the most distal points of the lateral and medial femoral condyles. The lateral angle obtained between the proximal anatomical axis and the femoral line in the frontal plane intersection defined the aLDFA (►**Fig. 1A**).[21,22] On the axial plane, the AA by the axial method, the FTW and FTD were measured.[9,10,20,23] A methodology recently validated in dogs was adapted for our study's axial measurement of the AA.[10] The images were reconstructed using the 3D volume rendering function. The femur was isolated from the tibia and hip by using the cutting tool. Alignment on the axial plane from a distal perspective allowed identification of the femoral head, femoral neck, and femoral condyles. Adjustments were made to the spatial orientation of the bone until both femoral condyles were aligned in a straight horizontal line, the inverted "U" shape of the intercondylar notch was identified, and once an unobstructed view of the femoral head and neck was observed, the true distoproximal axial femoral position was confirmed. In cases where the medial luxated patella position obstructed the view of the femoral neck, the cutting tool was used to remove it, or a semitransparent bone filter (dark bone filter, 4) was applied.[24] The histogram in the chromatic toolbar was adjusted by shadowing the surrounding soft tissues and increasing the bone transparency until the cortical profiles of interest and the intramedullary femoral canal were visible.[24] The aligned femur image was copied and pasted into the software; measurements were performed on the saved calibrated image. Using the measurement tools, a best-fit circle was placed over the distal visible portion of the femoral neck, with the

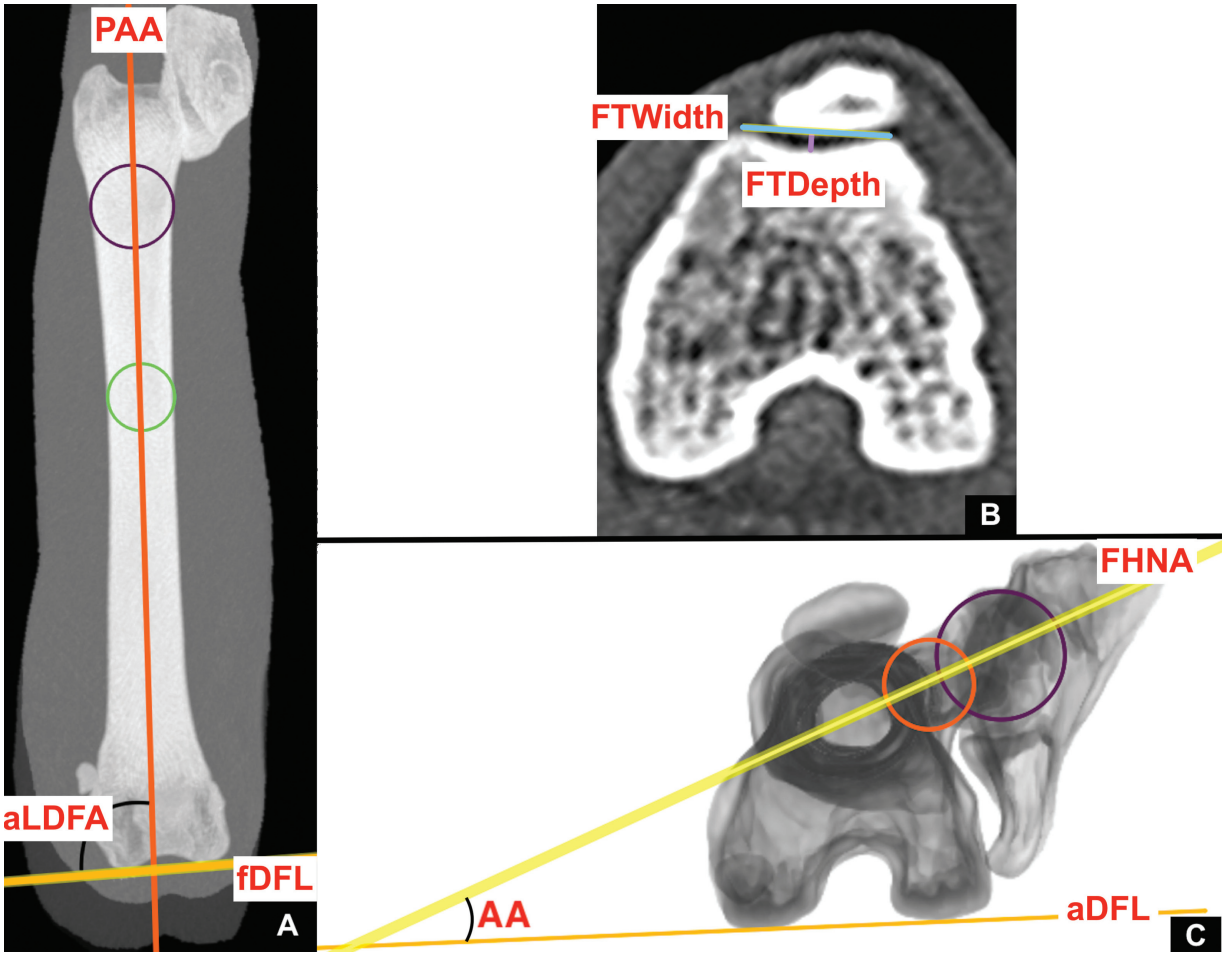


Fig. 1 Computed tomography images displaying the femoral measurements performed in the frontal (**A**) and axial plane (**B, C**). Anatomical lateral distal femoral angle (aLDFA), proximal anatomical axis (PAA), distal femoral line in the frontal plane (fDFL), distal femoral line in the axial plane (aDFL), angle of anteversion of the femur (AA), femoral head and neck angle (FHNA), femoral trochlear width (FTWidth), and femoral trochlear depth (FTDepth).

 © 2024. Thieme. All rights reserved.

Downloaded by: IP-Proxy European College of Veterinary Surgeons , European College of Veterinary Surgeons. Copyrighted material.

circle's circumference touching the cranial and caudal cortices of the femoral neck. Another best-fit circle was done on the femoral head. The connection of both centres of the circles by a line is defined as the femoral head and neck axis. A connection between the most distal and caudal points of the lateral and medial femoral condyles delineated the distal femoral line in the axial plane. The angle formed between the femoral head and neck axis and the distal femoral line in the axial plane intersection was defined as the AA (►**Fig. 1C**). The trochlear width (TW) and depth (TD) were measured as previously described in a feline *ex vivo* study.[17] The frontal plane was oriented tangential to the cranial cortex of the distal third of the femur, identifying the trochlear ridge.[23] In the midsection of the trochlea, a reference line connecting the medial and lateral trochlear ridges represents the TW. The TD was defined as the perpendicular distance from the TW line to the centre of the trochlear surface at that point (►**Fig. 1B**).

Tibial Measurements

The MPR was adjusted so that the orthogonal planes aligned correctly with the anatomical/mechanical axis of the tibia, and slice thickness was appropriately changed for the visualization of the necessary landmarks.[9] Measurements of the mMPTA were performed in the frontal plane.[21] The mechanical anatomical axis of the tibia was defined by the line passing through the centre of the tibia's intercondylar eminence to the centre of the distal tibial articular surface. The proximal tibial reference line was defined by the line passing through the two distal points of the concavities of the medial and lateral tibial condyles. The medial angle obtained between the intersection mechanical anatomical axis of the tibia and the proximal tibial reference line resulted in the mMPTA (►**Fig. 2A**). The TTA and TTD were measured in the axial plane. The alignment previously performed for the mMPTA was maintained. A methodology similar to that described by Aper and colleagues, recently adopted by Newman and Voss, was used to calculate the TTA.[11,13] A caudal tibial intercondylar line (CdTL) was defined in the axial view of the CT slice of the MPR where the most proximal caudal points of the tibial condyles were simultaneously identifiable. The horizontal line of the MPR grid was aligned with the CdTL. After scrolling distally, the distal cranial tibial line (CrTL) was located just cranioproximal to the talocrural joint, corresponding to the frontal tibial bone surface. Care was taken to keep the same alignment of the grid line while scrolling distally. The angle tool was then used to define the TTA, the angle resulting from the intersection between the CdTL and the cranial tibial line (►**Fig. 2B**). A positive TTA was defined if external tibial torsion was documented. In contrast, a negative TTA was defined if internal tibial torsion was documented.[24] If the intersection between the CdTL and the cranial tibial line resulted on the medial side of the tibia, the result would be internal tibial torsion with a negative angle value. Whereas, if the intersection resulted in the lateral side of the tibia, the result would be external tibial torsion with a positive tibial angle value.[24] The TTD was adapted from a validated method used in dogs.[9] First, the axial CT image that allowed visualization of the insertion of the patellar tendon and the caudal points of the medial and lateral tibial condyles was displayed. Hereafter, having the caudal tibial line CdTL as a reference, the TW was measured, and the tibial sagittal line (TSL) bisecting the TW and perpendicular to the CdTL was drawn. The tibial tuberosity line (TTL) bisected the insertion of the patellar tendon and intersected with the CdTL. The TTD was the angle formed by the TSL and the TTL (►**Fig. 2C**).[9] The TTD was negative when the tuberosity was medial to the TSL and positive when lateral to the TSL.[9]

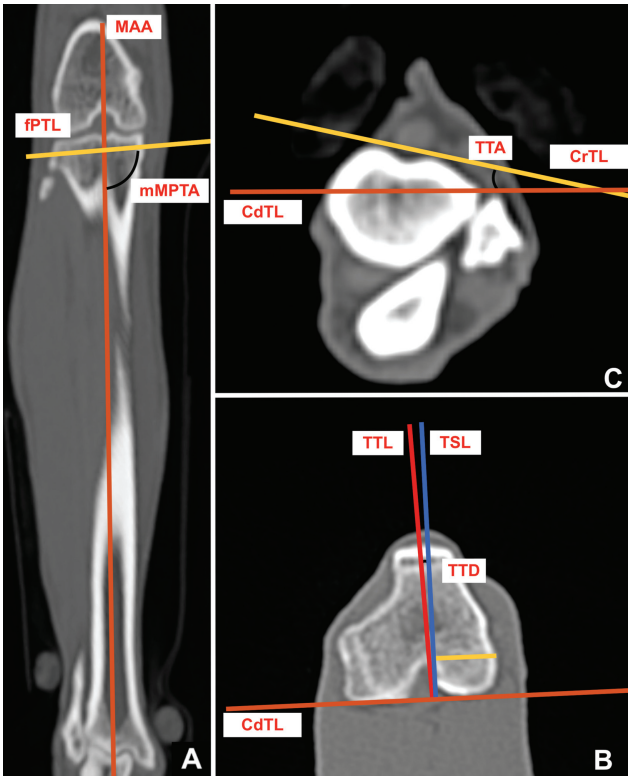


Fig. 2 Computed tomography images displaying the tibial measurements performed in the frontal **(A)** and axial plane (**B**, **C**). Mechanical medial proximal tibial angle (mMPTA), proximal tibial line in the frontal plane (fPL), mechanical anatomical axis of the tibia (MAA), tibial torsion angle (TTA), cranial tibial line (CrTL), caudal tibial intercondylar line (CdTL), tibial tuberosity displacement (TTD), tibial sagittal line (TSL), and tibial tuberosity line (TTL).

Patellar Measurements

The orthogonal planes were aligned to fit the frontal, sagittal, and axial planes using the MPR. The frontal plane was aligned with the long axis of the patella, and the maximum height point was identified in the axial plane. The fPL was defined as the longest distance of the patella and the fPW as the widest distance of the patella, both measured in the frontal plane (►**Fig. 3A**). The maximum patellar height was measured in the axial plane, perpendicular to the long axis of the patella assessed in the sagittal plane (►**Fig. 3B**). Finally, PV was assessed by the compute volume function once the edges of the patella were tracked in each slice with the "pencil" or "closed polygon" function (►**Fig. 3C**).[7,17]

 © 2024. Thieme. All rights reserved.

Downloaded by: IP-Proxy European College of Veterinary Surgeons , European College of Veterinary Surgeons. Copyrighted material.

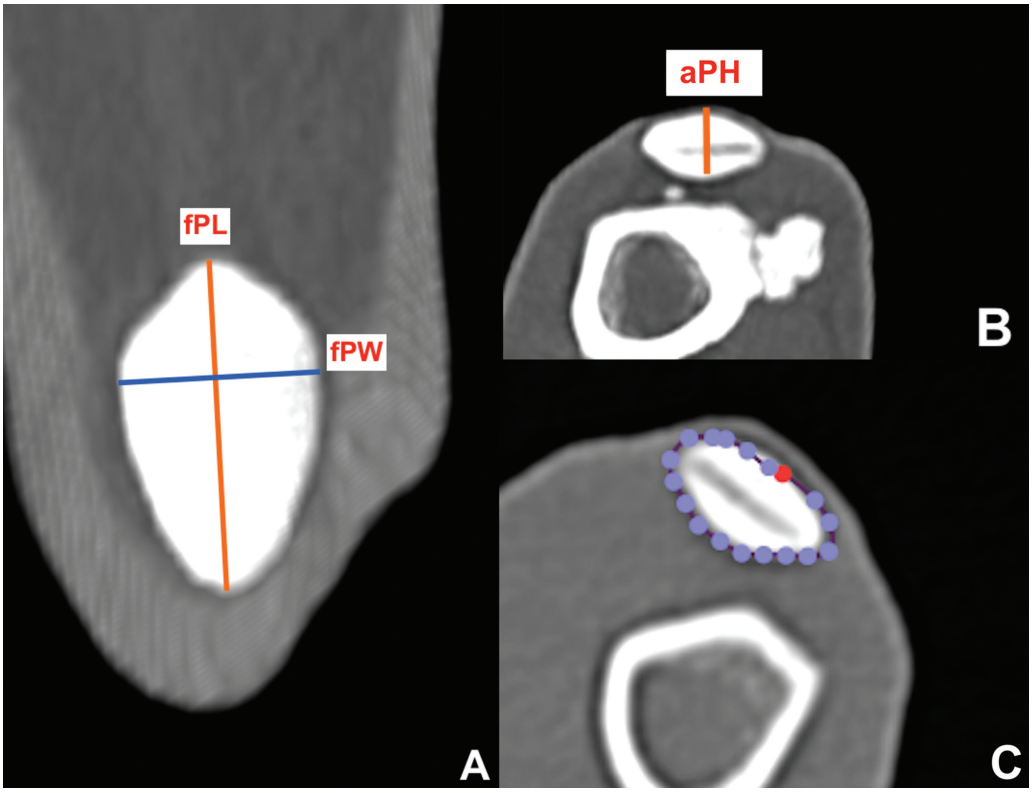


Fig. 3 Computed tomography images displaying the patellar measurements performed in the frontal (**A**) and axial plane (**B**, **C**), that is, patellar length in the frontal plane (fPL), patellar width measured in the frontal plane (fPW), and patellar height in the axial plane (aPH). (**C**) This figure represents one slice of the patellar volume being measured with the "closed polygon" function in Horos.

Statistical Analysis

Shapiro–Wilk test was performed to assess the normality of the data with less than 40 observations in total.[25] Mean and standard deviation calculations from the observers' measurements were performed (SPSS 27.0; IBM Corp., Armonk, NY). A one-way ANOVA was performed for normally distributed data, and the Kruskal–Wallis rank sum test was for non-normally distributed data. Tukey's test or pairwise comparisons were used as the post hoc test to compare control and MPLII, control and MPLIII, and MPLII and MPLIII. Intraobserver and interobserver interclass correlation coefficients (ICCs) were calculated (SPSS 27.0; IBM Corp., Armonk, NY) using an absolute-agreement, two-way, mixed-effects model.[26] A high correlation was defined as ICC above or equal to 0.75, a good correlation as ICC above or equal to 0.60 but less than 0.74, a fair correlation as ICC above or equal to 0.4 but less than 0.59, and a poor correlation as ICC below 0.40.[26]

Results

Twenty-one cats were included in this study, 10 in the control group and 11 in the affected group, with a total of 14 control limbs and 18 affected limbs. The control group images included cats with nonhealing wounds in the hindlimb, distal tarsocrural fracture, ilial fracture, laryngeal lymphoma, suspected duodenal perforation, cerebral vascular event, facial trauma, lung lobe torsion, abdominal mass, thoracic and abdominal pleural effusion. In the affected group, bilateral MPL was present in seven cats (63.64%) and unilateral MPL in four (36.26%) with two right-sided and two left-sided. Seven of the 18 affected limbs (38.89%) were medial patellar luxation grade II/IV (MPLII), and 11 of the 18 affected limbs (61.11%) were medial patellar luxation grade III/IV (MPLIII). All cats in the MPL group had a history of chronic pelvic limb lameness without a known history of trauma, and no additional orthopaedic abnormalities were identified upon orthopaedic examination.

The cats in the control group had a mean weight of 3.33 kg (2.00–5.00) and 4.53 kg (2.90–5.90) in the MPL group. The mean age of the control group was 8.40 years (1.00–16.00) and 3.70 years (0.83–10.00) in the MPL group. All cats were neutered; five were males and five females in the control group; seven were males and four females in the MPL group. The control group had nine domestic shorthaired cats and one Norwegian Forest cat. In the MPL group, there were nine domestic shorthaired cats, one Abyssinian, and one Maine Coon.

The mean and standard deviations of all pooled measurements and the calculation of differences between groups are summarized in ►**Table 1**. Normal distribution was absent for TTD and fPL for the MPLII group, and the Kruskal–Wallis rank sum test with a pairwise comparison was used in these variables. There were no significant differences between the group measurements for the AA, mMPTA, TTD, fPW, and patellar height. A significant difference ($p < 0.05$) was identified between the groups for the aLDFA, FTW, FTD, TTA, fPL, and PV measurements. The aLDFA was significantly higher in the MPLII group (91.59 degrees) compared with the control group (90.70 degrees) and the MPLIII group (90.66 degrees)

 © 2024. Thieme. All rights reserved.

Downloaded by: IP-Proxy European College of Veterinary Surgeons , European College of Veterinary Surgeons. Copyrighted material.

Table 1 Means and standard deviation of the pooled measurements of both observers and a comparison between the three groups

		N	Mean ± Std. Dev.	95% Confidence interval		*p*-Values
				Lower bound	Upper bound	
aLDFA (degrees)	Control	56	90.70 ± 1.32	90.35	91.06	0.008[a]
	MPLII	28	91.59 ± 1.60	90.97	92.21	0.014[b,c]
	MPLIII	44	90.66 ± 1.20	90.29	91.02	0.984[d]
AA (degrees)	Control	56	25.15 ± 5.45	23.69	26.61	0.717
	MPLII	28	24.52 ± 4.92	22.61	26.43	
	MPLIII	44	24.36 ± 4.62	22.95	25.76	
FTW (mm)	Control	56	7.44 ± 0.63	7.28	7.61	0.018[a]
	MPLII	28	7.46 ± 0.50	7.26	7.65	0.994[b]
	MPLIII	44	7.80 ± 0.74	7.57	8.02	0.021[d]
FTD (mm)	Control	56	1.29 ± 0.27	1.22	1.36	<0.001[a]
	MPLII	28	0.88 ± 0.25	0.78	0.98	<0.001[b]
	MPLIII	44	1.02 ± 0.27	0.93	1.10	<0.001[d]
mMPTA (degrees)	Control	56	89.87 ± 1.88	89.37	90.38	0.531
	MPLII	28	90.33 ± 0.95	89.97	90.70	
	MPLIII	44	90.07 ± 2.01	89.45	90.68	
TTA (degrees)	Control	56	−10.51 ± 3.40	−11.42	−9.60	<0.001[a]
	MPLII	28	−7.29 ± 2.80	−8.38	−6.21	<0.001[b]
	MPLIII	44	−5.06 ± 2.99	−5.97	−4.15	<0.001[c,d]
TTD (degrees)	Control	56	−2.18 ± 5.42	−3.63	−0.73	0.07
	MPLII	28	1.16 ± 6.56	−1.38	3.70	
	MPLIII	44	−1.45 ± 4.87	−2.93	0.03	
fPL (mm)	Control	56	13.95 ± 1.38	13.58	14.32	0.027[a]
	MPLII	28	13.92 ± 0.78	13.62	14.22	0.721[b]
	MPLIII	44	14.32 ± 0.83	14.06	14.57	0.010[d]
fPW (mm)	Control	56	8.80 ± 0.70	8.61	8.98	0.612
	MPLII	28	8.90 ± 0.61	8.67	9.14	
	MPLIII	44	8.99 ± 1.38	8.57	9.41	
aPH (mm)	Control	56	4.74 ± 0.35	4.64	4.83	0.07
	MPLII	28	4.54 ± 0.32	4.42	4.66	
	MPLIII	44	4.68 ± 0.41	4.56	4.81	
PV (cm^3)	Control	56	0.33 ± 0.06	0.31	0.34	0.001[a,c]
	MPLII	28	0.29 ± 0.03	0.28	0.30	0.014[b]
	MPLIII	44	0.34 ± 0.05	0.32	0.36	0.456[d]

Abbreviations: AA, angle of anteversion of femoral neck; aLDFA, anatomical lateral distal femoral angle; aPH, patellar height; fPL, patellar length; fPW, patellar width; FTD, femoral trochlear depth; FTW, femoral trochlear width; mMPTA, mechanical medial proximal tibial angle; MPL, medial patellar luxation; *N*, observations; PV, patellar volume; TTA, tibial torsion angle; TTD, tibial tuberosity displacement.
[a]*p*-Value from the ANOVA analysis or the Kruskal–Wallis rank sum.
[b]*p*-Value from the post hoc Tukey or pairwise test comparing control group and MPLII.
[c]*p*-Value from the post hoc Tukey or pairwise test comparing MPLII and MPLIII group.
[d]*p*-Value from the post hoc Tukey or pairwise test comparing control group and MPLIII group.

($p = 0.014$). The FTW was significantly higher in the MPLIII group (7.80 mm) than in the control group (7.44 mm; $p = 0.021$) but not significantly higher than in the MPL II group (7.46 mm; $p = 0.084$). The FTD in the control group (1.29 mm) was significantly larger than in the MPLII group (0.88 mm) and the MPLIII group (1.02 mm; $p < 0.001$). The TTA in the control group (−10.51 degrees) was significantly smaller than in the MPLII group (−7.29 degrees) and the MPLIII group (−5.06 degrees; $p < 0.001$). Additionally, the TTA in the MPLII group (−7.29 degrees) was significantly

 © 2024. Thieme. All rights reserved.

Downloaded by: IP-Proxy European College of Veterinary Surgeons , European College of Veterinary Surgeons. Copyrighted material.

Table 2 Intra- and interobserver correlation coefficient calculations

Measurements	Intraobserver	Interobserver
aLDFA	0.522	0.281
AA	0.721	0.451
FTW	0.922	0.595
FTD	0.873	0.374
mMPTA	0.530	−0.01
TTA	0.911	0.892
TTD	0.869	0.419
fPL	0.947	0.941
fPW	0.919	0.031
aPH	0.576	0.793
PV	0.949	0.880

Abbreviations: AA, angle of anteversion of femoral neck; aLDFA, anatomical lateral distal femoral angle; aPH, patellar height; fPL, patellar length; fPW, patellar width; FTD, femoral trochlear depth; FTW, femoral trochlear width; mMPTA, mechanical medial proximal tibial angle; PV, patellar volume; TTA, tibial torsion angle; TTD, tibial tuberosity displacement.
Note: Correlations were considered high in green (interclass correlation coefficient [ICC] ≥ 0.75), good in orange (≥ 0.60 ICC < 0.74), fair in red (≥ 0.4 ICC < 0.59), or poor in dark red (ICC < 0.40). The intraobserver ICC was calculated based on the three repetitions of observer 1. The interobserver ICC was calculated based on the first measurement of observer 1 and the single measurement of observer 2.

smaller than in the MPLIII group (−5.06 degrees; $p = 0.012$). The fPL in the control group (13.95 mm) was significantly smaller than in the MPLIII group (14.32 mm; $p = 0.010$). The PV in the control group (0.33 cm^3) was significantly higher than the MPLII group (0.29 cm^3; $p = 0.014$), and the PV for the MPLII group (0.29 cm^3) was significantly smaller than in the MPLIII group (0.34 cm^3; $p < 0.001$). The intra- and interobserver correlation coefficients (CCs) are summarized in ►**Table 2**. The intraobserver CC was high in 64% of the measurements, good in 9%, and fair in 27%. The interobserver CC was high in 36% of the measurements, fair in 27%, and poor in 36%. The measurements with poor interobserver variability between observers were the aLDFA, AA, FTD, mMPTA, and fPW.

Discussion

By comparing femoral, tibial, and patellar bone morphology through CT images between a group of cats exempted from MPL and a group of cats diagnosed with MPL grade II and III associated with lameness, this study identified several significant differences. It identified that overall, cats with MPL II and III have a shallower and wider femoral trochlear sulcus and increased external tibial torsion compared with cats exempted from MPL, rejecting our first null hypothesis. The TTA difference between groups was less than 5 degrees, while the FTD, FTW, and fPL were less than 1 mm. The comparison of the aLDFA, TTA, and PV measurements between the MPLII group and the MPLIII group also identified significant differences, rejecting our second null hypothesis. Additionally, cats with MPL grade III were found to have a marginally longer and more voluminous patella than cats in the normal group. Increasing the sample size may have resulted in accepting our null hypotheses as it would have allowed a higher level of significance and potentially avoided a type I error. As a result, the clinical significance and practical implications of these results remain unknown. The CT measurements methodology described showed good repeatability with an intraobserver ICC good or high in 75% of measurements. The interobserver ICC was fair or poor in 63% of measurements and good in 36% of measurements, partially accepting our third hypothesis. As a result, based on previously reported different measurement methods, the described methodology may need to be modified for better standardization and subsequent interobserver ICC improvement.

The diagnosis of patellar luxation is generally based on gait analysis and orthopaedic examination findings.[1,4] While radiographs can assist in excluding other joint pathologies and limb deformities in the initial line of investigations, morphologic skeletal abnormalities can be difficult to evaluate.[1,6–8,10,11,13,27–31] CT has been widely recognized as the gold standard for qualifying and quantifying limb deformities for more appropriate preoperative surgical planning.[6–8,10,11,13,28–31] Some authors reported most femoral and tibial deformities to be accurately evaluated by radiography in Toy Poodles and Chihuahuas with and without MPL.[7,28] Other authors suggested that radiographic measurements of the distal femur could be used as a screening test for considerable deformity to understand if CT could be indicated.[32] Nevertheless, radiographic evaluation of severe proximal tibial torsion or distal femoral deformity showed less precision.[7,32] Axial measurements to evaluate torsional deformities cannot be easily performed with radiographs.[7] However, they can easily be performed in 3D volume image rendering or MPR.[7,8,13,33] Additionally, different CT protocols for measuring the tibia and femur in dogs were identified as repeatable and reproducible.[9,24] Despite the variable positioning of our cat population, manipulation of CT images allowed the visualization of each bone individually. Using multiplanar and volumetric reconstructions allowed the observers to identify critical anatomical landmarks.

The femoral measurements with significant differences from the control group were aLDFA, FTW, and FTD. There was no significant difference between the AA in the three groups. The aLDFA difference between the control and both MPL groups was less than 1 degree, which makes this result more likely a type I error. In another study, the aLDFA difference between MPL and non-MPL groups was less than 3 degrees.[12] Our results support that distal femoral deformities or femoral torsional deformities did not appear to significantly contribute to luxation in these reported populations. Corrective osteotomies of the femur would not, therefore, be indicated. We did not record or investigate any cats with grade IV MPL; therefore, we cannot comment further other than to reflect that to the best of our knowledge, no guidelines exist, and previous cases described in the literature of

Downloaded by: IP-Proxy European College of Veterinary Surgeons , European College of Veterinary Surgeons. Copyrighted material.

feline MPL grade IV were treated without femoral deformity correction.[4,14]

Significant changes regarding trochlear morphology were also identified between the groups. Femoral trochleae were found to be shallower and wider in both MPL groups. Femoral trochlear and patellar morphology have been previously assessed in a recent cadaveric study, and their methodology was adapted to the current study.[17] The values of our control group were consistent with the previously published data.[17] The FTD for the control in our study was 1.29 ± 0.27 mm compared with 1.2 ± 0.1 mm, and the FTW was 7.46 ± 0.63 mm compared with 7.92 ± 0.62 mm.[17] The TD was also indirectly assessed with CT by Beer and colleagues by a combined TD/patellar height ratio, making direct comparisons with our results difficult.[12] In that study, TD was also significantly lower in cats affected by MPL.[12] However, our results showed a less than 1 mm difference between the control and the MPL groups. This small difference is difficult to interpret and could also be due to limitations of landmark identification, as the distal portion of the femoral trochlea of cats is marginally shallower and wider.[17] Even though our results did not provide evidence to suggest trochleoplasty as a "corrective" method with a TD difference of less than 1 mm, they identified a shallow groove of less than 2 mm. Trochleoplasty techniques have been described in cats with intraoperative quantification of the appropriate trochlear groove depth and width.[4,12,14] The aim of these techniques, which is to improve patellar tracking and femoral–patellar contact, is understandable and seems to have been indicated based on their clinical benefit. For instance, the largest published cohort study of surgically treated cats with MPL showed, even though not significant, a reduced rate of reluxation (9% reduced to 4%).[14] A lack of objective guidelines for trochleoplasty is also present in dogs. A canine study, suggesting that trochleoplasty techniques are not always necessary, identified a reluxation rate of 20%.[34] A recent alternative method for trochlear morphology assessment has been suggested in dogs, evaluating the femoral trochlear groove angle, instead of depth.[35] To the authors' knowledge, this measurement has not yet been evaluated in cats, and further studies are needed to clarify in which cases trochleoplasty is truly indicated in both dogs and cats.

The TTA was the only tibial measurement that significantly differed between groups in this study. No difference was identified in the TTD and the mMPTA. Cats clinically affected with MPL showed increased external tibial torsion and no other associated proximal tibial deformities. These results agree with previously published data.[12] Our results showed that cats in the control group have approximately 10 degrees of physiological internal tibial torsion. Interestingly, more than 3 to 6 degrees of internal tibial torsion were reported in medium to large dogs.[11,24] In comparison, cats with MPL II and III have increased external tibial torsion by 3 and 5 degrees, respectively, compared with the control group. In our population, the tibial tuberosity position was not different between groups, contradicting the results of a previous publication.[12] However, our study did not contain cats diagnosed with a grade IV MPL. It is possible that significant TTD can only be identified in severe cases. Compared to the canine literature, a study found significant differences in tibial external torsion and medial tibial displacement, in Toy Poodles affected with an MPL grade IV, not in the ones diagnosed with a grade II.[7] Our results suggest that TTT may not be indicated in cats suffering from MPL grade II or III, as no excessive tibial tuberosity medialization was identified.[4,12,14,17] Based on previous studies, the clinical benefit of TTT in cats might be less than in dogs.[4,14] TTT was reported to be associated with major complications in 20 to 28% of feline cases, with iatrogenic lateral patellar luxation being one of the reported complications, requiring revision surgery.[4,14,16] Detorsional osteotomies have not been reported in cats for the treatment of MPL. A recent study reported clinical outcomes of dogs undergoing torsion correction osteotomies of the femur and tibia to treat patellar luxation. Internal tibial torsion of <10 degrees and external tibial rotation of >2 degrees were defined as normal, and all detorsional tibial osteotomies performed were to correct MPL cases with increased external tibial torsion.[36] Our findings identified a maximum of 5 degrees torsion in cats with grade III MPL compared with the control group and only 3 degrees in grade II MPL cats; this suggests surgical intervention to correct tibial torsion in cats may not be necessary.

To our knowledge, this is the first CT anatomical study that includes measurements of the patella in cats affected by MPL compared with normal cats. Our results showed similar measurements to those previously reported in normal cats.[17] We found a patellar length of approximately 13 to 14 mm, a width of approximately 8 to 9 mm, a height of 4.5 mm, and a volume of 0.29 to 0.33 cm^3. We also identified that the patellar width was 1 mm wider than the trochlea width in all groups. This finding is similar to that of the previously reported healthy cat population.[17] The most significant difference found was a patellar length increased by 1 mm in the grade III MPL group compared with the control group. These measurements suggest that feline MPL is unrelated to a larger patella.

As with all studies, our study findings are constrained by several limitations. Even though the intraobserver CCs were good at 64% and fair at only 27%, the interobserver CCs were equally good and poor in 36% of our results, making the repeatability between the two observers overall weak. However, the relevance of the differences between the measurements obtained with poor ICC scoring between observers was minimal, a few millimetres or degrees and would be unlikely to influence surgical planning. Computed tomography positioning may also have influenced these disparities, resulting in greater difficulty in identifying anatomical landmarks. The CT measurement protocol used in our study was assessed by calculating the inter- and intraobserver ICC.[26] A fair-to-excellent intraobserver ICC score was observed in all measurements. It can, therefore, be inferred that an experienced observer can repeat the described measurements. However, when another observer reproduced the measurements, aLDFA, FTD, mMPTA, and fPW, there were poorer interobserver ICC scores. Multiple reasons can be listed for this poor score. It could be related to a true low rate of agreement but also a lack of variability of the sample with standard deviations of less than 1 unit (millimetres

 © 2024. Thieme. All rights reserved.

Downloaded by: IP-Proxy European College of Veterinary Surgeons , European College of Veterinary Surgeons. Copyrighted material.

or degrees) in most measurements. It could be a statistical method error related to the small number of hindlimbs or observers included.[26] The CT methodology itself could also be a reason for the poor application by the observers, including a lack of detail in the methodology description and a loss of 3D reconstruction details with the use of different CT terminals. Further studies are needed to define a more reproducible CT methodology for these parameters in cats, especially concerning trochlear morphology. Another limitation of our study was that soft tissue structures and their influence on the MPL were not evaluated. Soft tissue techniques, such as lateral imbrication and medial release, are often used to treat patellar luxation.[4,14,16] Considering the relative lack of pelvic limb morphological abnormalities found in cats with MPL compared with those without, soft tissues may play a bigger role in MPL in cats than in dogs. Soft tissue-only techniques have been recommended as the sole treatment for cases of traumatic feline patellar luxation.[1] However, there are no clinical studies assessing the treatment of nontraumatic feline MPL using soft tissue techniques alone. Another limitation of our study was the relatively low prevalence of cats with MPLII and MPLIII, as well as the absence of MPL IV, which is reflected by the small number of cases in this study and the overall low number of studies assessing this condition in cats. A larger number of cats in the affected group could allow us to statistically consider unilateral versus bilateral cases by considering individual variation. A multi-institutional study gathering a larger number of clinical cases could further clarify the suspected type I error present in our study regarding our first two hypotheses. In our population, only 2 of the 11 cats presented with lameness were purebred, while the others were domestic shorthaired cats. Therefore, we cannot comment specifically on this or any differences between normal cats and purebreds, especially considering a recent screening study, including a pedigree population of cats, that documented an MPL prevalence of 32.7%.[37] Interestingly, despite the high prevalence of patellar luxation in this population, they were mostly grade I, bilateral, and no mobility changes were noted by their breeders.[37]

Our results demonstrated that cats clinically affected with a grade II and III MPL have significant differences in pelvic limb morphology compared with cats free from this orthopaedic condition. They have marginally shallower femoral trochlear grooves and increased external tibial torsion. However, these differences should be interpreted with caution. Despite a very good intraobserver correlation, the interobserver correlation was high in only a third of the measurements. Given the minimal differences in measurements between the different groups, we suggest that angular deformity correction is unlikely to be indicated in these patients. Techniques focusing on improving patellar tracking aided by retinacular techniques warrant more investigation in cats with MPL grade II or III. Further studies are required with a larger population for a deeper understanding of the MPL condition in cats.

Authors' Contribution

The authors confirm their contributions to the paper as follows: study conception and design: B.S., M-P.M., and G.A.; data collection: all authors; analysis and interpretation of results: B.S., M-P.M., A.C., and G.A.; draft manuscript preparation: B.S. and M-P.M. All authors reviewed the results and approved the final version of the manuscript.

Funding

University College Dublin - OIP Early Career Grant - R22059.

Conflict of Interest

None declared.

References

1 Voss K. Stifle joint. In: Montavon PM, Voss K, Langley-Hobbs SJ, eds. Feline Orthopedic Surgery and Musculoskeletal Disease. Edinburgh: W.B. Saunders; 2009:475–490
2 Smith GK, Langenbach A, Green PA, Rhodes WH, Gregor TP, Giger U. Evaluation of the association between medial patellar luxation and hip dysplasia in cats. J Am Vet Med Assoc 1999;215(01): 40–45
3 Houlton JEF, Meynink SE. Medial patellar luxation in the cat. J Small Anim Pract 1989;30(06):349–352
4 Loughin CA, Kerwin SC, Hosgood G, et al. Clinical signs, and results of treatment in cats with patellar luxation: 42 cases (1992-2002). J Am Vet Med Assoc 2006;228(09):1370–1375
5 Umphlet RC. Feline stifle disease. Vet Clin North Am Small Anim Pract 1993;23(04):897–913
6 Tomlinson J, Fox D, Cook JL, Keller GG. Measurement of femoral angles in four dog breeds. Vet Surg 2007;36(06):593–598
7 Yasukawa S, Edamura K, Tanegashima K, et al. Evaluation of bone deformities of the femur, tibia, and patella in Toy Poodles with medial patellar luxation using computed tomography. Vet Comp Orthop Traumatol 2016;29(01):29–38
8 Lusetti F, Bonardi A, Eid C, Brandstetter de Belesini A, Martini FM. Pelvic limb alignment measured by computed tomography in purebred English Bulldogs with medial patellar luxation. Vet Comp Orthop Traumatol 2017;30(03):200–208
9 Barnes DM, Anderson AA, Frost C, Barnes J. Repeatability and reproducibility of measurements of femoral and tibial alignment using computed tomography multiplanar reconstructions. Vet Surg 2015;44(01):85–93
10 Serck BM, Karlin WM, Kowaleski MP. Comparison of canine femoral torsion measurements using the axial and biplanar methods on three-dimensional volumetric reconstructions of computed tomography images. Vet Surg 2021;50(07):1518–1524
11 Aper R, Kowaleski MP, Apelt D, Drost WT, Dyce J. Computed tomographic determination of tibial torsion in the dog. Vet Radiol Ultrasound 2005;46(03):187–191
12 Beer AJC, Langley-Hobbs S, Belch A. Comparison of hindlimb conformation in cats with and without medial patellar luxation. Vet Comp Orthop Traumatol 2023;36(01):10–20
13 Newman M, Voss K. Computed tomographic evaluation of femoral and tibial conformation in English Staffordshire Bull Terriers with and without congenital medial patellar luxation. Vet Comp Orthop Traumatol 2017;30(03):191–199
14 Rutherford L, Langley-Hobbs SJ, Whitelock RJ, Arthurs GI. Complications associated with corrective surgery for patellar luxation in 85 feline surgical cases. J Feline Med Surg 2015;17(04):312–317
15 Jaworski J, Krukowski M, Gosling M, Burton N. Patellar groove replacement in a cat. VCOT Open 2022;5(02):e71–e77

Downloaded by: IP-Proxy European College of Veterinary Surgeons , European College of Veterinary Surgeons. Copyrighted material.

16 Deom K, Conzemius MG, Tarricone J, Nye C, Veytsman S. Short-term outcomes for surgical correction of feline medial patellar luxations via semi-cylindrical recession trochleoplasty. J Feline Med Surg Open Rep 2023;9(02):20551169231179543
17 Brioschi V, Rutherford L, Newell K, Trotter C, Arthurs GI. Computed tomographic assessment of block recession trochleoplasty and partial parasagittal patellectomy in cats. Vet Comp Orthop Traumatol 2020;33(02):102–109
18 Rutherford L, Arthurs GI. Partial parasagittal patellectomy: a novel method for augmenting surgical correction of patellar luxation in four cats. J Feline Med Surg 2014;16(08):689–694
19 Singleton WB. The surgical correction of stifle deformities in the dog. J Small Anim Pract 1969;10(02):59–69
20 Nunamaker DM, Biery DN, Newton CD. Femoral neck anteversion in the dog: its radiographic measurement. Vet Radiol 1973;14 (01):45–48
21 Palumbo Piccionello A, Salvaggio A, Volta A, et al. Good inter- and intra-observer reliability for assessment of radiographic femoral and tibial frontal and sagittal planes joints angles in normal cats. Vet Comp Orthop Traumatol 2020;33(05):308–315
22 Swanson EA, Tomlinson JL, Dismukes DI, Fox DB. Measurement of femoral and tibial joint reference angles and pelvic limb alignment in cats. Vet Surg 2012;41(06):696–704
23 Petazzoni M, De Giacinto E, Troiano D, Denti F, Buiatti M. Computed tomographic trochlear depth measurement in normal dogs. Vet Comp Orthop Traumatol 2018;31(06):431–437
24 Longo F, Nicetto T, Pozzi A, Contiero B, Isola M. A three-dimensional computed tomographic volume rendering methodology to measure the tibial torsion angle in dogs. Vet Surg 2021;50(02): 353–364
25 Ghasemi A, Zahediasl S. Normality tests for statistical analysis: a guide for non-statisticians. Int J Endocrinol Metab 2012;10(02): 486–489
26 Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 2016;15(02):155–163
27 McLaughlin RM. Surgical diseases of the feline stifle joint. Vet Clin North Am Small Anim Pract 2002;32(04):963–982
28 Phetkaew T, Kalpravidh M, Penchome R, Wangdee C. A comparison of angular values of the pelvic limb with normal and medial patellar luxation stifles in chihuahua dogs using radiography and computed tomography. Vet Comp Orthop Traumatol 2018;31 (02):114–123
29 Aghapour M, Bockstahler B, Vidoni B. Evaluation of the femoral and tibial alignments in dogs: a systematic review. Animals (Basel) 2021;11(06):1804
30 Dudley RM, Kowaleski MP, Drost WT, Dyce J. Radiographic and computed tomographic determination of femoral varus and torsion in the dog. Vet Radiol Ultrasound 2006;47(06):546–552
31 Apelt D, Kowaleski MP, Dyce J. Comparison of computed tomographic and standard radiographic determination of tibial torsion in the dog. Vet Surg 2005;34(05):457–462
32 Clark EA, Condon AM, Ogden DM, Bright SR. Accuracy of caudocranial canine femoral radiographs compared to computed tomography multiplanar reconstructions for measurement of anatomic lateral distal femoral angle. Vet Comp Orthop Traumatol 2023;36 (03):157–162
33 Nicetto T, Longo F, Contiero B, Isola M, Petazzoni M. Computed tomographic localization of the deepest portion of the femoral trochlear groove in healthy dogs. Vet Surg 2020;49(06):1246–1254
34 Linney WR, Hammer DL, Shott S. Surgical treatment of medial patellar luxation without femoral trochlear groove deepening procedures in dogs: 91 cases (1998-2009). J Am Vet Med Assoc 2011;238(09):1168–1172
35 Longo F, Memarian P, Knell SC, Contiero B, Pozzi A. Computed tomographic measurements of the femoral trochlea in dogs with and without medial patellar luxation. Vet Surg 2023;52(03): 395–406
36 Longo F, Nicetto T, Knell SC, Evans RB, Isola M, Pozzi A. Three-dimensional volume rendering planning, surgical treatment, and clinical outcomes for femoral and tibial detorsional osteotomies in dogs. Vet Surg 2022;51(07):1126–1141
37 Černá P, Timmermans J, Komenda D, Nývltová I, Proks P. The prevalence of feline hip dysplasia, patellar luxation and lumbosacral transitional vertebrae in pedigree cats in The Czech Republic. Animals (Basel) 2021;11(09):2482

Downloaded by: IP-Proxy European College of Veterinary Surgeons , European College of Veterinary Surgeons. Copyrighted material.