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Determination of Femoral and Tibial Joint Reference Angles in Small-breed Dogs

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Abstract : The present study determined the normal reference ranges for the femoral and tibial joint orientation angles of small-breed dogs. For this purpose, 60 each of cadaveric canine femurs and tibias from normal small-breed dogs (Maltese, Poodle, Shih Tzu, Yorkshire Terrier) were examined with radiographs and photographs. Axial and frontal radiographs and photographs of each bone were obtained, from which anteversion and inclination angles, anatomic lateral proximal and distal femoral angles (aLPFA and aLDFA), mechanical lateral proximal and distal femoral angles (mLPFA and mLDFA), and mechanical medial proximal and distal tibial angles (mMPTA and mMDTA) were measured. The 95% CI for radiographic values of all femurs and tibiae were anteversion angle, 23.4-27.4°; inclination angle, 128.4-130.4°; aLPFA, 117.8-122.1°; aLDFA, 93.7-95.2°; mLPFA 113.8-117.3°; mLDFA 99.2-100.5°; mMPTA 96.8-98.5°; mMDTA 89.4-90.7°. The Maltese had a larger anteversion angle than the Poodle and the Yorkshire Terrier and a larger mLPFA than the Poodle. In the comparison between the radiographs and the photographs, significant differences were found in the anteversion angle, mLPFA, mMPTA, and mMDTA. The established normal reference values might be useful for determining whether a valgus or varus deformity of the femur or the tibia is present and if so, the degree of angular correction needed.

***Key words* :** limb alignment, angular deformity, joint reference angles, corrective osteotomy, small-breed dog.

Introduction

Angular deformities of the femur and tibia are defined as varus or valgus bending to the body midline (14,20). Dogs with femoral and tibial limb deformities can present with bow-legged appearance, possibly accompanied by pain or lameness. Such deformities can result in maldistribution of forces across the adjacent joints, joint malalignment, patellar luxation, cranial cruciate ligament (CrCL) insufficiency, and meniscal injury, which can result in osteoarthritis, lameness, and pain (3).

These deformities often occur as femoral torsion, varus deformity of the distal femur, and varus/valgus deformity of the proximal or distal tibia. Femoral torsion is the result of alteration in the angles formed by the axis of the femoral neck and the axis of the femoral shaft, the anteversion and inclination angles (11). Femoral torsion exacerbates hip joint-related disease, such as osteoarthritis or luxation (4). It can also influence the pathogenesis of patellar luxation and CrCL insufficiency, although controversy on that subject remains (4,6,8,12). Varus deformity of the distal femur moves the long axis of the quadriceps femoris muscles medially (20) and leads to patellar luxation or CrCL insufficiency (4,5). In skeletally immature dogs, abnormal pressure on the distal femoral physis generated by patellar luxation can also cause angular deformity of the femur (21). Like femoral deformity, a proximal tibial varus/valgus deformity leads to abnormal contact stresses (22). Stress generated intra-articularly can produce excessive force on the CrCL (19). A previous study reported that proximal tibial varus/valgus was present in 68.4% and medial patellar luxation was present in 57.9% dogs with CrCL instability (22).

In the surgical management of patellar luxation or CrCL insufficiency, correction of the deformities prevents complications such as patellar reluxation, inadequate stabilization of CrCL, and late medial meniscal injuries. Furthermore, appropriate alignment of the quadriceps mechanism is essential for optimal function and minimization of osteoarthritis (4). Deformities are corrected by applying a supportive implant such as a dynamic compression plate or a hybrid external fixator following femoral closing or opening-wedge ostectomy (15,17).

Reference ranges for the anatomic and mechanical angles of the femur and tibia are needed to for accurate diagnosis, appropriate surgical planning, and assessment of treatment outcome. Previous studies have reported reference ranges for the anteversion and inclination angles of the canine femur and joint orientation angles of the femur and tibia (3,4,7,11, 20,21). However, these previous reports studied only large-breed dogs; the reference ranges of small-breed dogs have not yet been reported. The reference ranges for large-breed dogs might not be appropriate in the assessment of small-breed dogs. Therefore, the purpose of this research is to

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determine and report reference values for femoral and tibial joint orientation angles in small-breed dogs.

Materials and Methods

Specimen Inclusion Criteria

Small adult canine cadavers were collected after euthanasia for reasons unrelated to this study. Cadavers were similar in size and body weight (~6 kg) and had no apparent orthopedic abnormalities. Cadavers were examined in order to evaluate extension and flexion movements of the hip, stifle, and tarsal joints using gross and palpable observation of the alignment of the frontal plane of the entire pelvic limb when in an extended position. The position of the patella and CrCL sufficiency were noted, and the cadaver was excluded if any abnormalities were present. Cadavers were also excluded if open physis, patellar luxation, tibial rotation, or angular deformity was seen on radiographic examination. Body weight (kg), sex, and breed were recorded for each dog, and both left and right femoral and tibial bones were isolated and dissected free of soft tissues. Thirty canine cadavers (60 femurs and 60 tibias) were analyzed.

Radiographic and Photographic Technique

All radiographs were acquired using a digital radiographic machine (CM-150, Comed Medical Co., Ltd. Korea), and all photographs were acquired with a digital camera (HDR-CX500, Sony Corporation, Japan). The anteversion angle can be quantified from the axial view of the femur. To obtain the axial view, each femur was mounted in a customized orthogonal frame in order to secure proximodistal positioning, and the radiographic or photographic beam center was positioned along the center of the femoral diaphysis. Inclination and joint orientation angles can be measured from frontal views of the femur and tibia. The diaphysis of each femur or tibia was positioned parallel to the table, and a frontal aspect position was considered acceptable. The radiographic or photographic beam center was placed at the midpoint of the total length of the bone.

Measurement Technique

A digital image measurement program (Infinitt Vet PACS, Infinitt Healthcare Co., Ltd. Korea) was used for all lines, angles, and measurements. On the image of the axial view of the femur, a line was drawn from the center of the femoral head to a point that bisected the mid-diaphysis of the femoral neck. Another line was drawn to abut the caudal aspect of the femoral condyles. Those lines determined the anteversion angle (Fig 1). On the image of the frontal view of the femur, the distal femoral joint center point was determined at the most proximal aspect of the top of the intercondylar fossa. The femoral length was measured from the most distal point of the dorsal aspect of the femoral neck to the distal femoral joint center point. The line passing through two points located at 33% and 50% of the femoral length below the proximal aspect of the femoral neck in the middle of the femur was determined as the anatomic axis. Another line was

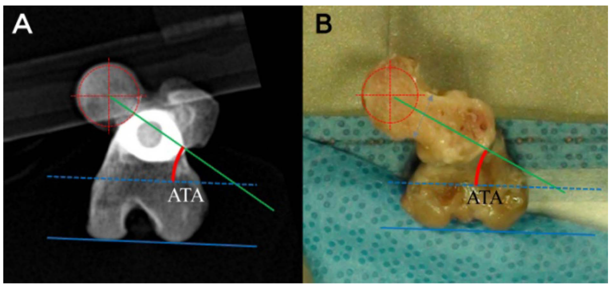

Fig 1. Axial radiograph (A) and photograph (B) of a small-breed dog femur. ATA, anteversion angle.

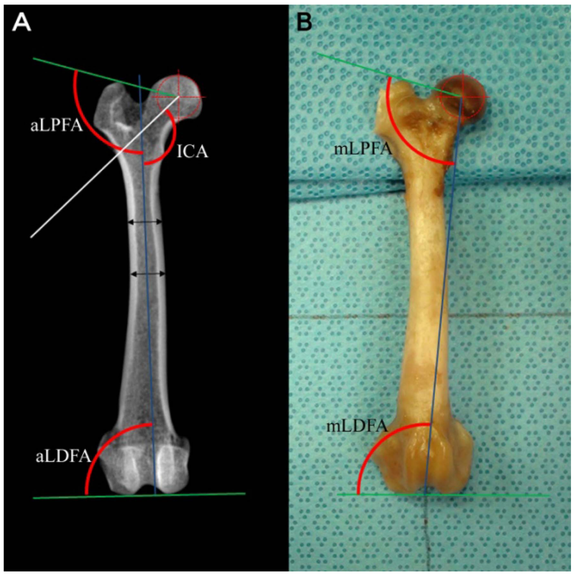

Fig 2. Frontal radiograph (A) and photograph (B) of a small-breed dog femur. ICA, inclination angle; aLPFA, anatomic lateral proximal femoral angle; aLDFA, anatomic lateral distal femoral angle; mLPFA, mechanical lateral proximal femoral angle; mLDFA, mechanical lateral distal femoral angle.

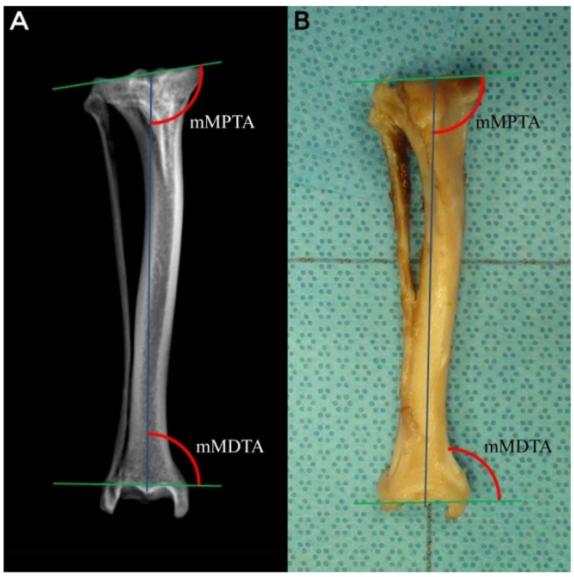

Fig 3. Frontal radiograph (A) and photograph (B) of a small-breed dog tibia. mMPTA, mechanical medial proximal tibial angle; mMDTA, mechanical medial distal tibial angle.

drawn using the center of the femoral head and a point that bisected the mid-diaphysis of the femoral neck. The angle formed by the intersection of those two lines was defined as the inclination angle (Fig 2). The joint orientation lines of the proximal and distal femur were determined from the center of the femoral head to the top of the greater trochanter and from the convexity of the medial and lateral femoral condyles, respectively. The angles formed by the intersection of the anatomic axis and the proximal or distal joint orientation line were defined as the anatomic lateral proximal femoral angle (aLPFA) and the anatomic lateral distal femoral angle (aLDFA), respectively (Fig 2). The mechanical axis of the femur was determined as a line from the center of the femoral head to the distal femoral joint center points. The mechanical axis of the femur and the proximal or distal femoral joint orientation line formed the mechanical lateral proximal femoral angle (mLPFA) and the mechanical lateral distal femoral angle (mLDFA), respectively (Fig 2). On the image of the frontal view of the tibia, the joint orientation lines of the proximal and distal tibia were defined by a line connecting the most distal points of the subchondral bone concavities of the medial and lateral tibial condyles and a line that abuts the most proximal points of the subchondral bone of the two arciform grooves of the cochlear tibia, respectively. The mechanical axis of the tibia was determined by a line from a point in the center of the tibial spines to the most-distal point of the subchondral bone of the distal intermediate tibial ridge. The mechanical axis of the tibia, and the proximal or distal tibial joint orientation line formed the mechanical medial proximal tibial angle (mMPTA) and the mechanical medial distal tibial angle (mMDTA), respectively (Fig 3). The anteversion and inclination angles and the joint orientation angles of each femoral and tibial bone were measured and recorded.

Statistical Analysis

Data from each variable were combined and means ± SD and 95% CI were determined. A paired t-test and the Wilcoxon-signed rank test were performed to determine the outcome variables differences between limbs from male and female dogs and results from radiographic and photographic images. An ANOVA was performed, and values of $P < 0.05$ were accepted as significant for determining differences among breeds. All analyses were performed with commercial statistical software (GraphPad Prism v5.0, GraphPad Software Inc., USA).

Results

Femurs (n = 60) and tibias (n = 60) from 30 adult small-breed dogs were analyzed. The mean weight of the cadavers was 2.90 ± 1.21 kg (mean ± SD, range 1.32-5.89 kg), and no limbs were excluded because of weight (> 6 kg). There were 28 male dogs and 32 female dogs. The breeds of the specimens were Maltese (n = 24), Shih Tzu (n = 18), Poodle (n = 10), and Yorkshire Terrier (n = 8).

Anteversion and Inclination Angles

The anteversion and inclination angles obtained from the radiographs and photographs of small-breed dogs were normalized and reported in Table 1. The mean anteversion angle of all dogs was 25.4 ± 7.7º from the radiographs and 22.6 ± 7.6º from the photographs, demonstrating a significant difference ($P < 0.001$). No significant difference was found between male and female dogs. In radiographic comparison of the four breeds, Maltese had a significantly larger anteversion angle than Poodles and Yorkshire Terriers ($P < 0.05$). There were no other significant differences among breeds in the radiograph or photographs. The mean inclination angle of all dogs was 129.4 ± 3.8º from the radiographs and 128.5 ± 6.2º from the photographs, which was not a significant difference. No significant differences were found between male and female dogs or among the four breeds.

Anatomic Femoral Angles: aLPFA and aLDFA

Table 2 summarizes the data for the anatomic femoral angles obtained from the radiographs and photographs of small-breed dogs. The mean aLPFA of all dogs was 120.0 ± 8.3º from the radiographs and 119.0 ± 7.0º from the photographs, which was not a significant difference. No signifi-

Table 1. Anteversion and inclination angles from radiographs and photographs

	Anteversion Angle (º)		Inclination Angle (º)	
	Radiograph	Photograph	Radiograph	Photograph
	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)
Overall	25.4 ± 7.7* (23.4-27.4)	22.6 ± 7.6* (20.6-24.6)	129.4 ± 3.8 (128.4-130.4)	128.5 ± 6.2 (126.9-130.1)
Male	24.7 ± 9.1 (21.2-28.3)	22.1 ± 7.4 (19.2-25.0)	129.8 ± 3.1 (128.7-131.0)	128.4 ± 8.2 (125.2-131.6)
Female	26.0 ± 6.3 (23.7-28.2)	23.0 ± 7.8 (20.2-25.9)	129.1 ± 4.3 (127.5-130.6)	128.6 ± 3.8 (127.2-130.0)
Maltese	29.7 ± 4.7[a,b] (27.7-31.7)	22.9 ± 6.8 (20.1-25.8)	130.3 ± 3.2 (129.0-131.7)	127.7 ± 8.8 (124.0-131.4)
Poodle	21.2 ± 8.3[a] (14.2-28.1)	22.5 ± 4.8 (18.6-26.5)	126.6 ± 4.5 (122.8-130.4)	128.3 ± 3.0 (125.8-130.8)
Shih Tzu	24.8 ± 7.5 (21.1-28.5)	24.5 ± 8.9 (20.1-28.9)	129.4 ± 4.1 (127.3-131.4)	128.5 ± 3.9 (126.6-130.5)
Yorkshire	19.6 ± 8.2[b] (13.7-25.4)	18.4 ± 8.1 (12.7-24.2)	129.6 ± 3.4 (127.1-132.0)	130.5 ± 3.2 (128.2-132.8)

The data are reported as the mean ± SD and lower and upper 95% CIs for the femoral torsional angles.
*Significantly different ($P < 0.001$).
Means with the same alphabet in a column are different from each other by the Tukey's test at 5% significance.

Table 2. Anatomic femoral angles from radiographs and photographs

	aLPFA (°)		aLDFA (°)	
	Radiograph	Photograph	Radiograph	Photograph
	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)
Overall	120.0 ± 8.3 (117.8-122.1)	119.0 ± 7.0 (117.2-120.8)	94.5 ± 2.9 (93.7-95.2)	94.8 ± 3.3 (94.0-95.7)
Male	120.6 ± 7.4 (117.8-123.5)	119.5 ± 7.5 (116.6-122.4)	93.9 ± 2.3 (93.0-94.7)	94.5 ± 2.7 (93.4-95.5)
Female	119.4 ± 9.1 (116.1-122.7)	118.6 ± 6.6 (116.2-121.0)	95.0 ± 3.3 (93.8-96.2)	95.2 ± 3.8 (93.8-96.5)
Maltese	122.5 ± 8.4 (119.0-126.1)	121.0 ± 7.9 (117.6-124.3)	95.2 ± 3.2 (93.9-96.6)	94.9 ± 3.9 (93.3-96.5)
Poodle	117.5 ± 5.3 (113.0-121.9)	114.6 ± 4.6 (110.7-118.4)	94.2 ± 2.6 (92.0-96.4)	95.3 ± 2.9 (92.8-97.7)
Shih Tzu	120.3 ± 6.3 (117.2-123.5)	117.9 ± 6.5 (114.6-121.1)	93.7 ± 2.7 (92.3-95.0)	94.7 ± 2.9 (93.2-96.2)
Yorkshire	115.2 ± 11.2 (107.2-123.3)	120.1 ± 5.7 (116.0-124.1)	94.1 ± 2.8 (92.1-96.2)	94.6 ± 3.5 (92.1-97.1)

The data are reported as the mean ± SD and lower and upper 95% CIs for anatomic femoral angles.
aLPFA, anatomic lateral proximal femoral angle; aLDFA, anatomic lateral distal femoral angle.

Table 3. Mechanical femoral angles from radiographs and photographs

	mLPFA (°)		mLDFA (°)	
	Radiograph	Photograph	Radiograph	Photograph
	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)
Overall	115.6 ± 6.8* (113.8-117.3)	113.2 ± 7.8* (111.2-115.3)	99.9 ± 2.5 (99.2-100.5)	100.0 ± 2.6 (99.3-100.7)
Male	115.8 ± 7.8 (112.7-118.8)	114.1 ± 7.9 (111.0-117.1)	99.4 ± 2.2 (98.6-100.3)	99.8 ± 2.1 (99.0-100.6)
Female	115.4 ± 6.0 (113.3-117.6)	112.5 ± 7.8 (109.7-115.3)	100.3 ± 2.8 (99.3-101.3)	100.2 ± 3.0 (99.1-101.3)
Maltese	118.0 ± 8.1[a] (114.6-121.4)	115.2 ± 8.2 (111.8-118.7)	99.7 ± 2.6 (98.6-100.8)	99.6 ± 2.8 (98.4-100.8)
Poodle	111.4 ± 4.3[a] (107.8-114.9)	106.4 ± 9.2 (98.7-114.1)	99.7 ± 2.9 (97.3-102.1)	100.9 ± 2.5 (98.9-103.0)
Shih Tzu	114.9 ± 6.6 (111.6-118.2)	112.6 ± 6.5 (109.3-115.8)	100.0 ± 2.8 (98.6-101.4)	100.3 ± 2.2 (99.2-101.4)
Yorkshire	114.3 ± 2.7 (112.4-116.3)	115.2 ± 5.2 (111.4-118.9)	100.2 ± 1.7 (98.9-101.4)	99.8 ± 3.1 (97.6-102.0)

The data are reported as the mean ± SD and lower and upper 95% CIs of the mechanical femoral angles.
mLPFA, mechanical lateral proximal femoral angle; mLDFA, mechanical lateral distal femoral angle.
*Significantly different ($P < 0.001$).
Mean with the same alphabet in a column is different from each other by the Tukey's test at 5% significance.

Table 4. Mechanical tibial angles from radiographs and photographs

	mMPTA (°)		mMDTA (°)	
	Radiograph	Photograph	Radiograph	Photograph
	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)
Overall	97.6 ± 3.3* (96.8-98.5)	95.2 ± 3.5* (94.3-96.1)	97.4 ± 3.0* (96.6-98.1)	90.1 ± 2.5* (89.4-90.7)
Male	97.7 ± 3.7 (96.3-99.1)	95.3 ± 3.9 (93.8-96.8)	97.8 ± 3.6 (96.4-99.2)	89.7 ± 2.4 (88.8-90.6)
Female	97.6 ± 2.9 (96.5-98.6)	95.1 ± 3.1 (94.0-96.3)	97.0 ± 2.4 (96.1-97.8)	90.4 ± 2.5 (89.5-91.3)
Maltese	98.6 ± 2.7 (97.4-99.7)	95.9 ± 2.4 (94.9-96.9)	96.7 ± 2.0 (95.9-97.6)	89.6 ± 2.2 (88.7-90.5)
Poodle	96.3 ± 2.4 (94.3-98.3)	93.9 ± 2.3 (92.0-95.8)	97.0 ± 3.0 (94.5-99.5)	89.6 ± 2.2 (87.8-91.5)
Shih Tzu	96.8 ± 2.8 (95.3-98.2)	94.1 ± 3.5 (92.4-95.9)	96.6 ± 3.3 (95.0-98.2)	90.5 ± 2.6 (89.2-91.9)
Yorkshire	98.0 ± 5.0 (94.4-101.6)	96.5 ± 5.4 (92.6-100.3)	100.5 ± 2.9 (98.4-102.6)	90.6 ± 3.2 (88.4-92.9)

The data are reported as the mean ± SD and lower and upper 95% CIs for the mechanical tibial angles.
mMPTA, mechanical medial proximal tibial angle; mMDTA, mechanical medial distal tibial angle.
*Significantly different ($P < 0.001$).

cant differences were found between male and female dogs or among the four breeds. The mean aLDFA of all dogs was 94.5 ± 2.9° from the radiographs and 94.8 ± 3.3° from the photographs, which was not a significant difference. No significant differences were found between male and female dogs or among the four breeds.

Mechanical Femoral Angles: mLPFA and mLDFA

Table 3 summarizes data for the mechanical femoral angles obtained from the radiographs and photographs of small-breed dogs. The mean mLPFA of all dogs was 115.6 ± 6.8° from the radiographs and 113.2 ± 7.8° from the photographs, which was a significant difference ($P < 0.001$). No significant difference was found between male and female dogs. In radiographic comparison of the four breeds, Maltese had a significantly larger mLPFA than Poodles ($P < 0.05$). No other significant differences were found in the radiographs or photographs. The mean mLDFA of all dogs was 94.5 ± 2.9° from the radiographs and 94.8 ± 3.3° from the photographs, which was not a significant difference. No significant differences were found between male and female dog or among four breeds.

Mechanical Tibial Angles: mMPTA and mMDTA

The mechanical tibial angles obtained from the radiographs and photographs of small-breed dogs are summarized in Table 4. The mean mMPTA of all dogs was 97.6 ± 3.3° from the radiographs and 95.2 ± 3.5° from the photographs, which was a significant difference ($P < 0.001$). No significant differences were found between male and female dogs or among the four breeds. The mean mMDTA of all dogs was 97.4 ± 3.0° from the radiographs and 90.1 ± 2.5° from the photographs, which was a significant difference ($P < 0.001$). No significant differences were found between male and female dogs or among the four breeds.

Discussion

The present study provides reference values for the anteversion and inclination angles of the femoral head and femoral and tibial joint orientation angles of small-breed dogs. It also provides mean values for each angle in a population of Maltese, Poodles, Shih Tzu, and Yorkshire Terriers. Patellar luxation is common in these small-breed dogs, and reports of CrCL insufficiency in small-breed dogs have increased. Dogs with patellar luxation and CrCL insufficiency may have angular deformities of femur and tibia (9,16,18,20). The present reference values for small-breed dogs will allow surgeons to evaluate the alignment of the femur and tibia in small-breed dogs, and to determine the amount of correction required to improve alignment. The CI suggests that 95% of the dogs in each breed should fall within the reference range shown for each measured angle.

All values were measured using morphologic images obtained by radiographic and photographic methods. Morphometric measurement using a radiograph is technically challenging and is associated with distortions that result from inaccurate positioning of the patient and locations of landmarks (1,4,10). The magnitude of femoral varus is accentuated by external rotation and diminished by internal rotation of the femur during radiographic positioning because of the natural recurvatum of the canine femur. Distal elevation of the femur also alters the radiographic measurement (4,7). Thus, it has been reported that standard radiography is not as accurate as anatomic preparation, whereas CT and MRI are more accurate than radiography and as accurate as anatomic preparation (4). However, those modalities are often limited by availability and cost and are not routinely performed. Therefore, to obtain reliable, accurate measurement in the present study, we used methods and landmarks already validated in previous studies: reliable radiography of the femur depends on accurate identification of the center of the patella on the distal aspect of the femur, and proper centering of the fabellae on the respective cortices (3,21). Also, the values measured using radiography were compared to those using photographs of isolated bones.

The anteversion angle of large-breed dogs has been reported in the range of 16-31.3° (1,4,11,13). All anteversion angles measured in the present study were within that range. However, the radiographic value of all dogs was significantly larger than those from the photographs particularly in Maltese. The present study found no significant difference in inclination angle between the radiographs and photographs or among the four breeds. However, the mean values for small-breed dogs in this study were lower than those reported for large-breed dogs (131-138°) and Pomeranians (134-138°) (20,21). Also, the inclination angle can be used to determine the rotational position of the femur (21). External rotation of the femur will significantly increase the angle of inclination (2). The consistency of inclination angles in the present study indicates the appropriate positioning of the femur.

The mean values of anatomic femoral angles, aLPFA and aLDFA, showed no significant differences between the radiographs and the photographs or among the four breeds. The values of aLPFA in small-breed dogs in the present study were much higher than those reported for large-breed dogs (95-104°). On the other hand, the mean values of aLDFA in small-breed dogs reported here within the ranges reported for large-breed dogs (94-98°) and Pomeranians (94-96°) (20,21). The mean mLPFA in the present study varied significantly between the radiographs and the photographs, unlike the mLDFA, which did not vary. The ranges of mLPFA and mLDFA in large-breed dogs were previously reported to be 92-101° and 97-101°, respectively (21). The value of mLPFA in small-breed dogs was higher than that of large-breed dogs, whereas the value of mLDFA found here was within the range for large-breed dogs. Both mMPTA and mMDTA, which represent the alignment of the tibia varied significantly between the radiographs and the photographs, but similar values were found among the breeds. The values of those angles were slightly higher those reported for large-breed dog (3).

Although the values for the anteversion and inclination angles and the anatomic and mechanical LDFA are similar to those for large-breed dogs, the aLPFA and mLPFA values are much higher in small-breed dog than in large-breed dogs, which suggest variations in femoral angle among dog sizes and breeds and supports the need for reference values for joint orientation angles in small-breed dogs.

Because this is the first report of normal reference ranges in small-breed dogs, the true clinical relevance remains unknown; however, future studies evaluating the incidence and prevalence of stifle pathology in relation to joint orientation angles will help with this understanding.

Conclusion

Femoral and tibial limb deformities result in maldistribution of forces across the adjacent joints and joint malalignment, which lead to patellar luxation, CrCL insufficiency, and meniscal injury with clinical presentation of osteoarthritis, pain, and lameness.

This study provides information about the angular alignment of the normal femur and tibia in the frontal plane of small-breed dogs. The normal reference values established here may be useful for determining whether a valgus or varus deformity of the femur and tibia is present and, if so, the degree of angular correction needed. The accurate diagnosis of angular deformity may allow for prevention of complications such as patellar reluxation, inadequate stabilization, and postliminary medial meniscal injuries following CrCL stabilization.

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