Lateral and medial tibial plateau angles in normal dogs
An osteological study

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Keywords
Lateral plateau angle, dog, medial tibial plateau angle, cranial cruciate ligament

Summary
Objectives: To measure lateral and medial tibial plateau angle values in isolated canine tibiae and to compare lateral and medial tibial plateau angle values between dogs based on sex and breed.

Methods: Tibiae of 90 dogs from 24 different breeds were used. Photographs were taken of the medial and lateral aspects of the tibiae for measurement of the medial and lateral tibial plateau angles. Additionally, the medial tibial plateau angle was measured from radiographs of the tibiae. Two-way analysis of variance was used to test the effects of side, sex and breed on the medial and lateral tibial plateau angles as measured from photographs as well as the medial tibial plateau angles as measured from radiographs. The photographic and radiographic medial tibial plateau angles were compared by paired t-test, whereas the medial and lateral photographic tibial plateau angles were compared by t-test.

Results: When all dogs were included in the analysis, the difference between the mean medial tibial plateau angle (24.0 ± 3.19°) and the mean lateral tibial plateau angle (25.5 ± 3.84°) as measured from photographs was significant (p < 0.05). The difference in the photographic medial tibial plateau angle between male and female dogs was significant (p < 0.05), whereas the difference in the photographic lateral tibial plateau angle between sexes was not significant. There was a significant difference between the medial and lateral tibial plateau angles as measured from photographs in male dogs (p < 0.05) but not in female dogs. Breed comparisons also showed significant differences for the photographic lateral tibial plateau angle (p < 0.05).

Clinical significance: The axial rotation of the femoral condyles on the tibial plateau is probably affected by the discrepancy between the medial and lateral tibial plateau angles, and this difference in certain breeds might influence the prevalence of cranial cruciate ligament disease.

Introduction
The stifle joint is a complex joint from both a morphological and functional perspective (1–3). This joint is comprised of the femorotibial, femoropatellar, and proximal tibiofibular joints in dogs. The femorotibial joint forms between the roller-like condyles of the femur and the nearly flattened condyles of the tibial plateau (4–5). The cranial cruciate ligament acts as an important joint stabilizer by limiting cranial translation of the tibia relative to the femur, medial rotation of the tibia, and hyperextension of the stifle joint (6–8). One cause of excessive steepness of the tibial plateau is premature or retarded closure of the caudal and cranial aspects of the tibial physis, respectively (9–13). Steepness of the tibial plateau may lead to an increase in cranial tibial thrust, and the cranial cruciate ligament is prone to injury in some breeds (6, 13–17). Several studies have focused on the relationship between cranial cruciate ligament rupture incidence and tibial plateau angle (11, 18–22). In contrast to humans, there is no consensus on this relationship for dogs. The tibial plateau angle is a cardinal parameter in planning tibial osteotomy procedures and in the evaluation of cranial cruciate ligament deficiency (6, 23). The tibial plateau angle is measured from mediolateral radiographs in dogs and reflects the medial tibial plateau angle because the cranial and caudal margins of the medial condyle are two reference points of the tibial plateau axis (6, 24–29). In addition to the medial tibial plateau angle, the lateral tibial plateau angle on the tibial plateau can also be measured. In a recent study of human tibiae, a significant difference was found between the medial tibial plateau angle (5.02 ± 3.02°) and the lateral tibial...
plateau angle (6.38 ± 3.04°) (30). Men with anterior cruciate ligament rupture were also reported to have greater lateral tibial plateau angles (7.52 ± 3.39°) than those without cruciate ligament injury (4.36 ± 2.26°) (31). In another study, median lateral tibial plateau angle values were six degrees (range: 0°-14°) for uninjured control subjects, and nine degrees (range: 0°-12°) for anterior cruciate ligament injured subjects (32). The authors are unaware of any study measuring lateral tibial plateau angle in dogs. We hypothesized that i) the lateral tibial plateau angle is different from the medial tibial plateau angle, ii) there are no sex-related differences in these angles, and iii) the lateral tibial plateau angle differs among dog breeds.

Material and methods

Materials

In total, 228 tibiae from 114 medium and large-breed dogs obtained from the Veterinary Anatomy Department Collections of Adnan Menderes and Istanbul Universities were used. The soft tissues around the bone were removed, and they were cleaned by boiling in tap water. The absence of gross pathological changes and presence of proximal tibial growth plate fusion were determined by visual inspection of the bone and were used as the two inclusion criteria for the study. The breed and sex of each animal were recorded.

Measurements

Photographs incorporating a ruler were taken from the medial and lateral aspects of the tibiae for measurement of the medial and lateral tibial plateau angles, respectively. Special attention was given to provide the standard position of the bone; specifically, the cranial margins of the femoral and medial tibial condyles were superimposed. The camera was placed at the level of the proximal aspect of the tibia at a fixed distance from the bone, and the photograph was centred on the tibial eminence. Mediolateral radiographs of the tibia were also obtained in the aforementioned position, and the beam was again centred on the tibial eminence. The radiographs were then photographed with a ruler, and JPEG image files were produced. The distance between the camera and radiographs was 40 cm, and the camera was centred on the tibial eminence. These images were used to measure the radiographic medial tibial plateau angle.

For measurements, the radiographic and photographic images were transferred to a computer as JPEG formats using a fixed scale and resolution (3456×2304 pixels). First, all reference points on the proximal tibia were marked using a custom software program. These reference points included the central point of the intercondylar tubercles for the proximal point of the reference line (Figure 1, point a), the cranial and caudal margins of the medial femoral condyle for the joint orientation line of the medial tibial plateau (Figure 1, line f-e), the caudal margins of the extensor groove (corresponding to the cranial margin of the lateral condyle) and the lateral condyle for the joint orientation line of the lateral tibial plateau (Figure 1, line c-d). These images were subsequently transferred to a software program, and the images were calibrated. Using this software, two parallel lines were drawn tangential to the periosteal margins of the distal tibia, and the midpoint between these parallel lines was used as the distal point of the reference line (Figure 1, point b).

In both the photographic and radiographic images, the reference line was drawn from the central point of the intercondylar tubercles to the central point of the distal extremity of the tibia in the medial and lateral aspects. The angles between the line perpendicular to the reference line and the medial and the lateral joint orientation lines were measured as the photographic medial tibial plateau angle, radiographic medial tibial plateau angle and photographic lateral tibial plateau angle, respectively (Figure 1). All angles were measured only once in the aforementioned sequence from each tibia by one observer (SSS).

Figure 1  Measurements of the photographic lateral and medial tibial plateau angles (lTPA-P and mTPA-P, respectively) and the radiographic medial tibial plateau angle (mTPA-R). The reference line (a-b) as well as the joint orientation lines of the lateral tibial plateau (c-d) and medial tibial plateau (e-f) are shown.
**Statistical analysis**

The data were evaluated for normality by the Shapiro–Wilk one-sample test. A two-way analysis of variance (ANOVA) was used to test the effects of side (left/right) and sex, and the interaction of these two factors, on the photographic medial tibial plateau angle, radiographic medial tibial plateau angle, and photographic lateral tibial plateau angle. An ANOVA was also used to test the effect of breeds in which the sample size was five or more dogs on the photographic medial and lateral tibial plateau angles. The Bonferroni test was used as a post hoc test to determine whether differences were significant. The arithmetic mean of the values for the right and left sides was used for the paired t-test after determining a lack of significant difference between the two sides. The paired t-test was also used for the comparisons of the medial and lateral photographic tibial plateau angles as well as for the comparison of the photographic and radiographic medial tibial plateau angles in all dogs, whereas the difference between male and female dogs in the photographic medial and lateral tibial plateau angles were compared by the unpaired t-test. Observed power calculations were focused on two-tailed test.

Statistical analyses were performed using commercially available software. Summary statistics are reported as the mean, standard deviation (SD) and 95% confidence interval. The level of significance was set at p < 0.05 for all the analyses.

**Results**

A total of 48 tibiae of 24 dogs were excluded from the study because of the presence of an open proximal tibial growth plate (n = 21) and osteophyte formations (n = 3) on the tibial plateaux. In total, 90 dogs from 24 different breeds, including German Shepherd Dog (n = 19), Anatolian Shepherd (n = 13), mixed breed (n = 13), Boxer (n = 6), Rottweiler (n = 6), Doberman (n = 5), Pointer (n = 4), Siberian Husky (n = 3), Collie (n = 2), Setter (n = 2), St. Bernard (n = 2), Golden Retriever (n = 2), Kopov Slovensky (n = 2), and one of each Akbash, American Staffordshire Terrier, Canaan, Caucasian Shepherd, Chow Chow, Clumber Spaniel, Great Dane, Malamute, Mastiff, Pitbull and Shar-Pei, were used in the study.

Data for 180 tibiae from 90 dogs were used for the study. The proportions of males and females were 46/90 (51%) and 44/90 (49%), respectively. The photographic medial tibial plateau angles (\( p = 0.215 \)), radiographic medial tibial plateau angles (\( p = 0.139 \)) and photographic lateral tibial plateau angles (\( p = 0.168 \)) for the right and left tibias were not significantly different. No differences were found between the mean photographic medial tibial plateau angle and mean radiographic medial tibial plateau angle (\( p = 0.605 \)). In evaluating tibiae from all 90 dogs together, the difference between the photographic medial tibial plateau angle and the photographic lateral tibial plateau angle was significant (\( p = 0.001 \)) (Table 1).

Also, the difference between male and female dogs in the photographic medial tibial plateau angle was significant (\( p = 0.032 \)), but not in the photographic lateral tibial plateau angle (\( p = 0.800 \)). Furthermore, the difference between the medial and lateral photographic tibial plateau angles was significant for males (\( p = 0.001 \)) but not females (\( p = 0.238 \)) (Table 2). The medial and lateral photographic tibial plateau angles were compared among the six breeds, each of which were represented by five or more dogs. There were significant differences between breeds for the lateral photographic tibial plateau angle (\( p = 0.001 \)), whereas no difference was found for the medial photographic tibial plateau angle (\( p = 0.098 \)) among the six breeds (Table 3). The two highest lateral photographic tibial plateau angle values were found in Anatolian Shepherds and mixed breeds, whereas the two lowest values were found in Rottweilers and Dobermanns. A significant difference between the medial and lateral photographic tibial plateau angles was only found in Anatolian Shepherds (\( p < 0.05 \)), but not in mixed breeds (power = 0.267), Rottweilers (power

<table>
<thead>
<tr>
<th>Breed</th>
<th>Male Proportion</th>
<th>Female Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>German Shepherd</td>
<td>19 (21%)</td>
<td></td>
</tr>
<tr>
<td>Anatolian Shepherd</td>
<td>13 (14%)</td>
<td></td>
</tr>
<tr>
<td>Mixed breed</td>
<td>13 (14%)</td>
<td></td>
</tr>
<tr>
<td>Boxer</td>
<td>6 (7%)</td>
<td></td>
</tr>
<tr>
<td>Rottweiler</td>
<td>6 (7%)</td>
<td></td>
</tr>
<tr>
<td>Doberman</td>
<td>5 (6%)</td>
<td></td>
</tr>
<tr>
<td>Pointer</td>
<td>4 (5%)</td>
<td></td>
</tr>
<tr>
<td>Siberian Husky</td>
<td>3 (3%)</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1** The side comparison of the variables and the comparison among mean values of the radiographical (R) medial tibial plateau angle (TPA) and the photographic (P) medial TPA and lateral TPA.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Right</th>
<th>Left</th>
<th>p</th>
<th>Mean ± SD (Range; 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial TPA-R</td>
<td>24.3 ± 3.31°</td>
<td>23.9 ± 3.31°</td>
<td>NS</td>
<td>24.1 ± 3.10°a (18.2° to 33.4°; %CI, 23.4° to 24.7°)</td>
</tr>
<tr>
<td>Medial TPA-P</td>
<td>24.2 ± 3.30°</td>
<td>23.9 ± 3.43°</td>
<td>NS</td>
<td>24.0 ± 3.19°a (18.3° to 32.7°; %CI, 23.4° to 24.7°)</td>
</tr>
<tr>
<td>Lateral TPA-P</td>
<td>25.4 ± 3.80°</td>
<td>25.7 ± 4.12°</td>
<td>NS</td>
<td>25.5 ± 3.84°a (18.4° to 34.9°; %CI, 24.7° to 26.3°)</td>
</tr>
</tbody>
</table>

Values with different superscript letters in the same column are significantly different (p < 0.05). NS: Not significant; CI = confidence interval.

**Table 2** The comparison of the photographic (P) medial and lateral tibial plateau angles (TPA) between the male and female dogs.

<table>
<thead>
<tr>
<th>TPA</th>
<th>Male (n = 44)</th>
<th>Female (n = 46)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial TPA-P</td>
<td>23.3 ± 2.52°a (18.5° to 27.9°)</td>
<td>24.7 ± 3.60°(18.3° to 32.7°)</td>
<td>*</td>
</tr>
<tr>
<td>Lateral TPA-P</td>
<td>25.6 ± 4.12°b (19.2° to 34.9°)</td>
<td>25.4 ± 3.58°(18.4° to 33.9°)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values with different superscript letters in the same column are significantly different (p < 0.01). * indicates that p < 0.05; NS: not significant.

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Values with different superscript letters in the same line are significantly different (p<0.05). ** indicates that p <0.01, NS: Not significant.

### Discussion

The medial tibial plateau angle values obtained from the photographic images were not significantly different from the radiographic images. Similar to the findings of a previous study, the lack of difference in the medial tibial plateau angle values obtained by the two methods made the comparison possible (33). All measured variables were considered to be symmetrical because of a lack of significant difference between the right and left sides. The difference in the photographic medial tibial plateau angle between male and female dogs was significant, but not in photographic lateral tibial plateau angle. When all of the dogs were grouped together, there was a significant difference between the medial and lateral photographic tibial plateau angles. Breed comparisons showed significant differences for the lateral but not for the medial photographic tibial plateau angles.

Tibial plateau angle measurements are affected by the beam centring used when obtaining radiographs as well as positioning of the limb, especially tibial rotation and selection of subjective landmarks (24–26, 34, 35). Superimposition of the tibial condyles is suggested for true tibial positioning in tibial plateau angle measurements (34). The superimposition of the cranial margin of tibial condyles and the beam or focus centre were standardized as much as possible, albeit the intra- and interbreed variation in the length of the tibial condyles (36). The measurement reference points were marked using software to minimize discrepancies between the subjects, as manipulating the image allows better identification of anatomic landmarks (37). Tibial plateau angle measurements are also affected by the presence of degenerative changes and individual anatomic variation in stifles (24–25, 38). However, tibiae for which osteophyte formation on the tibial plateau was found by visual inspection were excluded from the study. Additionally, to prevent inter-observer measurement variation, only one observer determined all the measurement landmarks (SSS) (21).

For tibial plateau angle measurement, the cranial and caudal margins of the medial condyle are considered the two joint orientation line reference points. The cranial point selection is easily identified; the caudal aspect of the medial condyle has a curvilinear appearance and shows anatomical variations, which cause difficulties in caudal point selection (13, 24–26, 39–42). The lateral condyle is shorter than the medial condyle, and the articular surface of the lateral condyle is concave (36). Therefore, the lateral condyle was totally superimposed by the medial condyle on the radiographic images. Measuring the lateral tibial plateau angle from radiographs appears to be almost impossible; the aforementioned anatomical characteristics lead to a lack of any distinct structure defining the cranial and caudal points of the lateral condyle. Computed tomography or magnetic resonance imaging are suggested to provide an accurate characterization of the whole tibial plateau since radiographs alone may be inadequate for preoperative assessment of the lateral tibial plateau angle.

In dogs, the tibial plateau angle does not change from 90 days of age until physeal maturity, and proximal tibial growth plate fusion occurs between six and 11 months of age depending on the breed (43, 44). Therefore, it appears that the dogs in the present study were older than 11 months of age, and the tibial plateau angle was assumed to have reached to its constant shape. The measurement of tibial plateau angle is not affected by the size of a dog, but cranial cruciate ligament deficiency is mostly seen in medium to large breed dogs, similar to the studied dogs (25, 45–49).

There were no differences in the medial and lateral photographic tibial plateau angles between the right and left tibias observed, which is similar to previous reports on tibial plateau angle (22, 35, 43). The mean, range and 95% confidence interval of the medial photographic tibial plateau angles were also similar to reported tibial plateau angle values in healthy dogs (12, 18, 20, 21, 24, 35, 50–53).

The medial tibial plateau angle is an important anatomical characteristic for angular assessment of the tibial plateau. Characterizing the tibial plateau by a single angle may be inadequate, which may partly explain the wide tibial plateau angle range (12.0° to 46.0°) in dogs with cranial cruciate ligament deficiency (25, 30, 54). In the dogs of the present study, there was a significant difference between the photographic medial and lateral tibial plateau angles. However, contrary to the findings in humans, a significant difference between the photographic medial and lateral tibial plateau angles was only found in male dogs; no difference was observed in female dogs of the present study.
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Conflict of interest

None of the authors of this article has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

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Online supplementary material

Dot plots showing the photographic medial and lateral tibial plateau angles for each dog of the six breeds are presented in Ap-
pendix Figure 1 and the difference between the medial and lateral photographic tibial plateau angles for the 90 dogs is recorded in Appendix Table 1, both of which are available online at www.vcot-online.com.

S. S. Sabanci, M. K. Ocal: Lateral tibial plateau angle in dogs

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