Use of the proximal portion of the tibia for measurement of the tibial plateau angle in dogs

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Objective—To determine whether the canine tibial plateau angle (TPA) can be accurately measured from lateral radiographic views of the stifle joint that include only the proximal portion of the tibia.

Sample Population—282 lateral radiographic views of the stifle joint from 128 dogs.

Procedure—236 radiographs were obtained from 102 dogs with no stifle joint disease, and 46 were obtained from 26 dogs with cranial cruciate ligament rupture. Radiographs were digitized. Tibial plateau angles were determined by measuring the angle between the intersection of the tibial plateau slope line and perpendiculars to 4 tibial axes. The gold standard TPA was based on a reference axis that used the entire length of the tibia and was determined by the line connecting the mid-point of the tibial intercondylar eminence and the center of the talus. Tibial plateau angle1, TPA2, and TPA3 were based on tibial axes that were determined by use of only the proximal portion of the tibia.

Results—TPA determined on the basis of the shortest proximal reference axis (TPA1) was not accurate. However, as the length of the reference axis increased, reliability of the TPAs obtained from proximal reference axes improved, and their correlations with the gold standard TPA increased (r = 0.78, 0.86, and 0.92 for TPA1, TPA2, and TPA3, respectively). Equations obtained by regression analysis allowed estimation of the gold standard TPA with some degree of accuracy.

Conclusions and Clinical Relevance—Use of a proximal reference axis to calculate TPA may be an alternative to a calculation based on the full-length axis. (Am J Vet Res 2003;64:1117–1123)

Although countless procedures designed to repair the cranial cruciate ligament of dogs have been described, they all attempt to passively control cranial translation of the proximal portion of the tibia with reference to the distal femur. Henderson and Milton1 and Slocum and Devine3 showed how various forces on the canine stifle joint create cranial tibial translation in the cranial cruciate ligament deficient joint. Cranial tibial thrust is defined as the cranially directed force generated during weight-bearing and is responsible for tibial translation. Slocum and Devine3 theorized that excessive cranial tibial slope, as measured in the sagittal plane on mediolateral radiographic views, generates significantly more cranial tibial thrust, thereby producing greater stress on the cranial cruciate ligament. The leveling or correction of this caudal tibial slope to eliminate or reduce cranial translation is the basis for Slocum's and Devine's cranial tibial plateau leveling osteotomy.1,3

Correction of this caudal tibial slope requires its measurement from radiographs by use of a reference axis from which a tibial plateau angle (TPA) can be measured. Generally, a line tangent to the articular surface of the medial tibial condyle is used to represent the caudal tibial plateau slope. Most authors use the intersection of the cranial cruciate ligament near the cranial aspect of the medial condylar articular surface as the cranial point of the slope angle on the basis of a standard lateral radiographic view of the stifle joint. Different landmarks for the caudal point along the medial condylar surface as well as the fibular head have been published.4,5,9 In the current veterinary literature, the most widely used reference axis of the tibia used to obtain an angle is created by a line drawn between the mid-point of the intercondylar eminence and the center of the talus. Most methods define the TPA as the angle formed by the intersection between the tangent to the articular surface of the proximal portion of the tibia and the perpendicular to this reference axis of the tibia.5,7,9

In clinical practice, measurement of the TPA by use of this method has the drawback of requiring full-length tibial radiographs. If accurate and reliable TPA measurements could be obtained from collimated mediolateral radiographic views of the proximal portion of the canine tibia, substantial savings in cost and effort, as well as reduced morbidity, might be possible. The primary purpose of this study was to compare the most widely accepted TPA measurement (the gold standard) with TPA measurements obtained from a shorter reference axis with only landmarks of the proximal portion of the tibia. Our hypothesis is that accurate and reliable TPA measurements can be obtained by use of a proximal reference axis. In addition, the effect of faulty positioning (rotation) on TPA measurements was investigated. If rotation could be shown to have little or no effect on TPA measurement, the need for repeating radiography would be reduced, thereby decreasing cost and effort.

Materials and Methods

Sample collection—A total of 282 lateral radiographic views of the stifle joint was obtained from 128 patients during February 2001 through August 2001. Two hundred thirty-six lateral radiographic views of stifle joints were obtained from 102 dogs with no history of stifle joint injury as follows: 6 radiographs were from 6 dogs that had 1 radiograph obtained of a single stifle joint, 152 were from 76 dogs that included only the proximal portion of the tibia.
had 1 radiograph obtained of each stifle joint, 24 were from 8 dogs that had 2 radiographs obtained of 1 stifle joint and 1 of the other stifle joint, 36 were from 9 dogs that had 2 radiographs obtained of each stifle joint, and 18 were from 3 dogs that had 3 radiographs obtained of each stifle joint. Forty-six lateral radiographic views of stifle joints were obtained from 26 dogs with a confirmed diagnosis of cranial cruciate rupture as follows: 7 radiographs were from 7 dogs that had 1 radiograph obtained of a single stifle joint, 36 were from 18 dogs that had 1 radiograph obtained of each stifle joint, and 3 were from 1 dog that had 2 radiographs obtained of 1 stifle joint and 1 of the other stifle joint. Only radiographs of stifle joints with no radiographic evidence of osteoarthrosis were included in the study.

Each dog was given an IV injection of ketamine hydrochloride (5.5 mg/kg) with diazepam (0.275 mg/kg) and then intubated and maintained under anesthesia with isofluorane. All dogs were radiographed in lateral recumbency with the fibular malleolus and the lateral proximal portion of the tibial condyle in contact with the film cassette. Full-length mediolateral views of the tibia (including the stifle and tarsal joints) centered at the mid-diaphysis were obtained by use of radiographic film, with settings of 300 mA and 120 kVp on the X-ray machine. Superimposition of the femoral condyles and, to a lesser extent, tibial condyles were subjectively evaluated by 1 author (SBA) to determine whether a true mediolateral view was obtained. Because of anatomic variation and differences in personnel expertise, not all radiographs had perfect mediolateral alignment. When this occurred, the stifle joint was reredographed, and both the original radiograph and correctly positioned radiograph were retained for inclusion in the study.

Radiographic measurements—All radiographs were digitized and then randomized and coded so that observers were blinded to the identity of each patient's radiograph. A computer software program was used to import each radiograph into a format allowing the observer to easily magnify the picture, create a line between 2 points, bisect a line, form a perpendicular, and calculate the angle of intersection between 2 lines to the nearest 0.01°.

Circles that best fit each femoral condyle were digitally drawn over the lateral radiographic view, and the amount of overlap was recorded. When the condyles did not allow for a near fit, the degree of overlap was subjectively scored. Radiographs were scored on a 4-point system for accuracy of alignment as follows: 1 = perfect superimposition of femoral and tibial condyles, 2 = mild rotation of femoral condyles with >85% overlap, 3 = 70 to 85% overlap, and 4 = <70% overlap. In addition, for radiographs scored 2, 3, or 4, a notation as to whether the rotation was primarily in an axial plane, a transverse plane (rotation in the cross-sectional plane of the long axis of the body), or in both an axial and transverse planes was made. One observer (SBA) scored all radiographs. Thirty days elapsed between scoring and all other radiograph measurements.

In this study, the tibial plateau slope line was defined as the line formed by joining the point of insertion of the cranial cruciate ligament near the cranial articular surface of the tibia with the point of the caudal-most articular surface of the medial tibial condyle. The perpendiculars to 4 different reference axes formed the 4 TPA measurements where they intersected acutely with the tibial plateau slope line. The reference axis (ie, Rg) was created by a line drawn between the mid-point of the intercondylar eminence and the center of the talus (Fig 1). This axis was used as the reference standard, because it is the most widely used reference axis in the current veterinary literature. The other 3 axes (R1, R2, and R3) were constructed in an attempt to use a collimated radiograph of the stifle joint with-
out the tarsal joint or distal portion of the tibia. In a manner similar to the method by Read and Robbins\(^8\) that uses the anatomic axis, the cranial border of the tibial plateau was used as the proximal point of these axes. Because there are no consistent landmarks present in the proximal tibial diaphysis, the distal points were derived by bisecting the width of the tibia at 3 different levels. The levels were determined by the proximal width of the tibia, which was measured between the proximal-most aspect of the tibial crest and caudal-most aspect of the articular surface of the medial tibial condyle. This measured value, multiplied by 1, 1.5, and 2, served as the distances distal from the proximal point at which an arc was drawn through the diaphyseal cortices. The tibia was bisected at the midpoint between the intersections of the arc and each cortex. The resultant axes were formed by connecting each of the bisection points to the original proximal point as follows: \(R1 = \text{proximal width of tibia, } R2 = 1.5 \times \text{proximal width of tibia, } \text{and } R3 = 2 \times \text{proximal width of tibia}\) (Fig 2 and 3). The corresponding TPAs for the reference axis and
Tibial plateau angles 1, 2, and 3 are denoted by TPAg, TPA1, TPA2, and TPA3, respectively.

Two authors who are veterinarians (SBA and DLH) and 1 experienced trained veterinary technician evaluated the radiographs. The first author (SBA) obtained the 4 TPA measurements for all radiographs. Because the first author had the most experience with TPA measurement, the TPAg determined by this investigator was used as the gold standard. The other 2 observers determined the 4 reference axes for 100 radiographs that were randomly selected from radiographs of dogs with no history of stifle joint injury. To eliminate extraneous variation as a result of differences in the tibial plateau slope lines, the first author mathematically calculated the TPAs for the 2 other observers, using their reference axes and the angles formed with an external arbitrary line that had been previously drawn on the margin of each radiograph. A separate data file was used by each observer to ensure that all observers were blinded to each other’s measurements and the radiograph alignment scores.

Data analysis—A computer software program was used for data management, generation of random numbers for random selection of radiographs, and statistical analysis. Histograms were used to assess normality before applying parametric methods. Because multiple radiographs from the same dog cannot be considered statistically independent, 1 radiograph was randomly selected for analysis from each dog with more than 1 radiograph whenever P values were determined, resulting in a sample size of 128 radiographs.

An association between the gold standard TPA versus TPA1, TPA2, and TPA3 was initially evaluated with scatterplots. Because these scatterplots were consistent with linearity and histograms were consistent with normality, Pearson correlations were obtained to evaluate relationships between the gold standard TPA and TPA1, TPA2, and TPA3 for each observer and between corresponding TPAs measurements for different observers. Bivariate regression was used to obtain equations relating the gold standard TPA to TPA2 and TPA3, which were then used individually to estimate the gold standard TPA. These regression analyses were determined on the basis of the random subsample of 128 radiographs from 128 dogs to avoid biased TPA estimates.

A 2-factor repeated-measures ANOVA was performed with the following 2 within-subject factors: observer (observers 1, 2, and 3) and TPA type (TPAg, TPA1, TPA2, and TPA3). These analyses tested for differences between the gold standard TPA and TPA1, TPA2, and TPA3 and among corresponding TPAs for different observers. Because a significant TPA type main effect was found, post hoc tests were conducted by use of 1-factor repeated-measures ANOVA and paired t tests to determine which means of the TPAs were different. The multivariate approach was used for repeated-measures ANOVA, because the Mauchly test results indicated that the sphericity assumption needed for the univariate approach did not hold.

Relationships between the gold standard TPA of observer 1 and the radiograph alignment score were assessed with scatterplots, Pearson correlations, and a 1-way ANOVA. To compare radiographs with no rotation, axial rotation only, transverse rotation only, and both axial and transverse rotation with respect to the observer 1 TPA, a 1-way ANOVA was used. Comparison of the means of the TPAs of observer 1 for rotated and nonrotated radiographic views was also done by use of the paired t test for a subset of 12 dogs with rotated and nonrotated radiographs of the same limb. The Levene test was used to test the assumption of equal variances needed for a 1-way ANOVA and the pooled-variance t test.

A significance level of P ≤ 0.05 was used for all tests. No 1-sided statistical tests were done. Values are presented as means (± SD). A fairly large sample of radiographs from 128 dogs was selected to obtain adequate power for detecting differences between observers and between TPA types.
Inclusion of radiographs from 128 dogs insured 90% power for detecting an effect size of 0.29 on the basis of a 2-sided paired t test with a significance level of \( P \leq 0.05 \). Because the purpose of the study was to assess the equivalence of different methods for measuring the TPA, adjustments for multiple comparisons were not made. Such adjustments would have reduced the statistical power of the study, thereby decreasing the chance of detecting differences between the gold standard TPA and other TPA measurements.

**Results**

Of the 128 dogs, 57 were spayed females, 8 were sexually intact females, 44 were castrated males, and 18 were sexually intact males. The gender and neuter status of 1 dog could not be determined, because most of the medical records for that dog were missing. Mean body weight was 29.5 kg (± 12.5), and mean age was 6.8 years (± 3.6). Forty-one (32%) of the dogs were of mixed breed, followed by 16 (12.5%) Labrador Retrievers. The remaining dogs were of various breeds.

Mean (± SD) values for TPA measurements were determined (Table 1). For each observer, substantial differences were found between the mean gold standard TPA and the mean TPAs obtained by use of proximal reference lines. All of these differences were significant (\( P < 0.001 \)). For each observer, the mean TPA2 was closest to the mean gold standard TPA.

Although differences between means must be considered, correlations are even more important. A discrepancy between means can be adjusted for if a high correlation is present. Pearson correlations between the gold standard TPA and the TPAs determined on the basis of proximal reference lines were determined for each observer (Table 2). As expected, the correlations between the gold standard TPA and other TPAs improved as the length of the proximal reference axis used to obtain the TPA increased. The highest correlations with the gold standard TPA were obtained for TPA3 (\( r = 0.91 \) to 0.92). The correlations between TPA1 (which was determined on the basis of the shortest reference line) and the gold standard TPA were too low (\( r = 0.69 \) to 0.78) to permit an accurate estimation of the gold standard TPA by use of TPA1.

Of the 3 TPAs calculated by use of proximal reference axes, TPA2 had the shortest reference axis that produced TPA measurements with fairly strong correlations with the gold standard TPA. For this reason, bivariate regression was done with the gold standard TPA of observer 1 as the dependent variable and observer 1 TPA2 as the independent variable to determine whether an equation could be obtained that would allow estimation of the gold standard TPA from TPA2 within 3 or 5° of error. The following regression equation was obtained:

Estimated gold standard TPA = \(-7.34 + 1.19 \times \text{(TPA2)}\)

For this regression line, a scatterplot of the observer 1 TPA2 versus the gold standard TPA was produced with 95% prediction bands (Fig 4). The regression equation was applied to the TPA2 values of observer 1, and the resulting estimated gold standard TPA values were compared with the actual gold standard TPAs of observer 1 (Fig 5). Almost 80% (79%) of the differences (errors) between the actual and estimated gold standard TPA values were within 3°, and 96% were within 5°.

The regression equation was then applied to the TPA2 values of observers 2 and 3, and their estimated gold standard TPA values were compared with their actual gold standard TPA values. For observer 2, 73% of the errors were within 3°, and 91% were within 5°. For observer 3, 83% of the errors were within 3°, and 95% were within 5°.

To determine whether use of a slightly longer reference axis would improve accuracy, TPA3, which had the longest proximal reference axis, was used to esti-
mate the gold standard TPA. Bivariate regression was done with the gold standard TPA of observer 1 as the dependent variable and observer 1 TPA3 as the independent variable, resulting in the following regression equation:

\[ \text{Estimated gold standard TPA} = -10.00 + 1.19 \times \text{TPA3} \]

When this equation was applied to the TPA3 values of observer 1 and the estimated gold standard TPA values were compared with the actual gold standard TPA of observer 1, 90% of the errors were within 3°, and 98% were within 5° (Fig 6 and 7). The regression equation was also applied to the TPA3 values of observers 2 and 3 to compare their estimated and actual gold standard TPA values. For observer 2, 86% of the errors were within 3°, and 97% were within 5°. For observer 3, 88% of the errors were within 3°, and 98% were within 5°. Use of a slightly longer reference axis substantially improved accuracy for all 3 observers.

To assess the reliability of TPA measurements determined on the basis of short reference lines, the differences between the mean TPAs for different observers were tested for significance. No significant interaction was found between the observer and TPA type \((P = 0.093)\). However, significant main effects were found for the observer \((P = 0.007)\) and TPA type \((P < 0.001)\). Further testing found no significant differences between observers with respect to the gold standard TPA \((P = 0.27)\). However, significant differences were found between observers 1 and 3 with respect to TPA1 \((P = 0.003)\), TPA2 \((P = 0.001)\), and TPA3 \((P < 0.001)\). No other significant differences were found between observers.

Although significant differences were found between observers 1 and 3 with respect to all of the mean TPAs that were determined on the basis of proximal reference axes, examination of these means (Tables 1 and 3) makes it clear that these differences are so small that they are not clinically important. Significance was achieved because the variability was small (ie, small SD values) and the statistical power was adequate.

Reliability was further assessed by obtaining Pearson correlations between the corresponding TPAs for different observers (Table 4). As expected, all of the correlations for the gold standard TPA are extremely high \((r = 0.99)\). The correlations for TPA1 are unacceptably low \((r = 0.60 \text{ to } 0.81)\). However, the correlations improve as the length of the reference axis increases, with acceptable correlations for TPA2 and good correlations for TPA3.

Mean TPAs were determined on a random subsample of radiographic views of the stifle joint by the 3 observers (Table 3). The subsample of radiographs consisted of 128 radiographs (1 radiograph/dog) for observer 1; 38 of these radiographs served as the subsample for observers 2 and 3. The descriptive statistics for these subsamples are similar to those for the entire sample of radiographs (Table 1).

The relationship between TPA and positioning (ie, radiograph alignment score and rotation) was also evaluated (Table 5). No significant relationship was...
Table 3—Mean (± SD) reference (gold standard) TPA (observer 1) and TPAs 1, 2, and 3 of 128 dogs as determined on a random subsample of radiographic views of the stifle joint by 3 observers.

<table>
<thead>
<tr>
<th>Radiographs evaluated (No.)</th>
<th>Investigator</th>
<th>Observer 1</th>
<th>Observer 2</th>
<th>Observer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPAg (°)</td>
<td></td>
<td>27.8 ± 4.6</td>
<td>27.3 ± 3.5</td>
<td>27.1 ± 3.4</td>
</tr>
<tr>
<td>TPA1 (°)</td>
<td></td>
<td>23.9 ± 3.2</td>
<td>23.6 ± 5.0</td>
<td>24.9 ± 3.7</td>
</tr>
<tr>
<td>TPA2 (°)</td>
<td></td>
<td>29.5 ± 3.2</td>
<td>29.3 ± 4.4</td>
<td>30.1 ± 3.6</td>
</tr>
<tr>
<td>TPA3 (°)</td>
<td></td>
<td>31.7 ± 3.9</td>
<td>31.2 ± 3.9</td>
<td>31.9 ± 3.5</td>
</tr>
</tbody>
</table>

Superscript letters in the same row that differ indicate mean values that are significantly (P < 0.05) different from each other.

See Table 1 for key.

Discussion

Use of a proximal reference axis to calculate the TPA has considerable potential clinical value. It allows centering of the X-ray beam over the stifle joint rather than over the mid-diaphysis of the tibia. This enables better determination of pathologic changes of the stifle joint without obtaining additional radiographic views. In addition, use of a proximal reference axis allows for added collimation of the X-ray beam. Many lateral radiographic views of the stifle joint routinely collimate out the distal portion of the tibia, especially in large dogs. Review of previously taken standard lateral radiographic views of the stifle joint may allow determination of a TPA prior to the development of degenerative joint changes.

Results of our study indicate that use of a short reference axis to calculate the TPA has sufficient merit to warrant further research. The best candidates for further study are the TPA measurements that are determined on the basis of longer proximal reference axes (ie, TPA2 and TPA3), because the TPA determined on the basis of the shortest proximal reference axis (ie, TPA1) was inaccurate and had poor reliability. These results are consistent with those obtained for humans. Julliard et al found that in humans, greater TPA accuracy was obtained with longer axes, largely as a result of the magnification of smaller errors with short axes. In addition, we found that rotation of the tibia, as determined on the basis of position of the femoral condyles, did not appear to alter the TPA, which is also consistent with results for TPA measurements in humans.

References


Table 4—Pearson correlations between observers for the corresponding TPAs as determined on 100 selected lateral radiographic views of the stifle joint from 128 dogs.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Investigator</th>
<th>Observer 1 vs 2</th>
<th>Observer 1 vs 3</th>
<th>Observer 2 vs 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPAg</td>
<td></td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>TPA1</td>
<td></td>
<td>0.68</td>
<td>0.81</td>
<td>0.60</td>
</tr>
<tr>
<td>TPA2</td>
<td></td>
<td>0.86</td>
<td>0.94</td>
<td>0.84</td>
</tr>
<tr>
<td>TPA3</td>
<td></td>
<td>0.91</td>
<td>0.97</td>
<td>0.90</td>
</tr>
</tbody>
</table>

See Table 1 for key.

Table 5—Mean (± SD) reference (gold standard) TPAs (observer 1) for each radiographic alignment score and rotation category as determined on all 228 lateral radiographic views of the stifle joint from 128 dogs.

<table>
<thead>
<tr>
<th>Radiographic alignment score</th>
<th>Rotation</th>
<th>No. of radiographs (%)</th>
<th>Observer 1 gold standard TPA (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>56 (19.9)</td>
<td>26.3 ± 4.9</td>
</tr>
<tr>
<td>2</td>
<td>Axial</td>
<td>85 (30.1)</td>
<td>27.4 ± 4.6</td>
</tr>
<tr>
<td>2</td>
<td>Transverse</td>
<td>56 (19.9)</td>
<td>26.5 ± 4.0</td>
</tr>
<tr>
<td>3</td>
<td>Axial and transverse</td>
<td>3 (1.1)</td>
<td>33.0 ± 2.2</td>
</tr>
<tr>
<td>3</td>
<td>Transverse</td>
<td>25 (8.9)</td>
<td>27.5 ± 6.4</td>
</tr>
<tr>
<td>3</td>
<td>Axial and transverse</td>
<td>16 (5.7)</td>
<td>27.8 ± 3.3</td>
</tr>
<tr>
<td>4</td>
<td>Axial</td>
<td>14 (5.0)</td>
<td>28.3 ± 6.5</td>
</tr>
<tr>
<td>4</td>
<td>Transverse</td>
<td>2 (0.7)</td>
<td>28.7 ± 12.9</td>
</tr>
<tr>
<td>4</td>
<td>Axial and transverse</td>
<td>0 (0)</td>
<td>NA</td>
</tr>
</tbody>
</table>

NA = Not applicable. See Table 1 for key.