Sequential measurements of the tibial plateau angle in large-breed, growing dogs

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**Objectives**—To determine the earliest age that canine tibial plateau angles (TPAs) can be reliably measured and determine whether TPAs change during long bone growth.

**Animals**—10 Labrador Retrievers and 20 Labrador Retriever-hound crossbreeds.

**Procedure**—Stifle joints were radiographed every 2 months from 8 weeks of age to radiographic closure of the tibial physes. Four examiners radiographically evaluated TPA, physeal closure status (ie, complete or incomplete) of the proximal and distal tibial physis, and whether anatomic TPA measurement landmarks were sufficiently visible (LSV) or insufficiently visible (LIV) for accurate measuring. Linear regression analysis was performed to detect change in TPAs over time. Mean ages with 95% confidence intervals (CIs) were determined for dogs with radiographs classified as LIV and LSV.

**Results**—TPAs did not change from 90 days of age to physeal closure. Mean age for dogs with radiographs classified as LIV was 70.2 days (95% CI, 68.12 to 72.28 days), with no dog with LIV radiographs over 81 days of age. Mean age for dogs with radiographs classified as LSV was 85.5 days (CI, 76.73 to 94.27 days).

**Conclusions and Clinical Relevance**—TPAs in Labrador Retrievers and Labrador Retriever-hound crossbreeds can be measured accurately after 90 days of age, and earlier attempts to measure result in falsely low TPA measurements. Measuring TPAs in growing dogs may allow earlier detection of premature physeal closures. As more is learned about the role of the TPA in cranial cruciate ligament injury, early treatment may be possible for growing dogs with cruciate ligament injuries and excessive tibial slope.

With the recent introduction of the tibial plateau leveling osteotomy technique, much attention has been directed to the role of the tibial plateau angle (TPA) in cruciate ligament injury. Morris and Lipowitz and Rooney et al demonstrated a tendency toward greater TPAs in dogs with CCL rupture, compared with dogs without CCL rupture. In a similar study by Reif and Probst, no difference was found in TPAs in Labrador Retrievers with and without cruciate ligament injury. Wilke et al evaluated both traditional TPAs (obtained by lateral radiography) and standing TPAs (obtained by standing position radiography) for Greyhounds and Labrador Retrievers. That study group found no difference in standing TPAs between clinically normal Greyhounds and Labrador Retrievers without CCL rupture and found that Labrador Retrievers with cruciate ligament injury had smaller traditional TPAs than Labradors without CCL injury. Although the overall effect the TPA has on cruciate ligament injury is not fully understood, it does have an effect on cranial tibial thrust.

Warzee et al and Reif et al have demonstrated the role of the TPA in generating cranial tibial thrust, with steeper TPAs producing greater degrees of tibial thrust and presumed greater strain on the CCL. A number of dogs with excessive tibial plateau slope secondary to premature closure of the caudal aspect of the proximal tibial physis have sustained CCL tears at young ages, a condition that is supported by information in the human literature. Results of a human study looking at the anterior cruciate ligament forces with different ligament orientations indicated that ligament strain increases as the angle of the anterior cruciate ligament increases toward 80° relative to tibial plateau. Although the angle of the CCL could vary depending upon the location of its proximal attachment to the distal femur, results of both veterinary and human studies have revealed standard points of attachment of the CCL. With little variability in cruciate ligament attachment sites, the TPA would play a major role in the angle of the CCL and would thereby have an effect on the forces experienced by the CCL.

With CCL injury occurring in younger dogs, surgeons are limited in their options for repair. Tibial plateau leveling osteotomy is not recommended before 8 to 9 months of age because of potential injury to the proximal tibial physis and the lack of knowledge about the growth of the tibial plateau. Several cases of partial epiphysiodesis of the cranial aspect of the proximal tibial physis have been described for the treatment of CCL tears in juvenile dogs with variable success. Again, more information about tibial plateau development would be necessary for such procedures to be investigated more thoroughly. Radiographic...
development of the tibia and the time of radiographic closure of the tibial physes have been investigated. To our knowledge, however, no one has investigated the development of the tibial plateau. The purposes of the study reported here were to determine the age at which the TPA can be reliably measured and determine whether the TPA changes during growth of the tibia. We hypothesize that the TPA does not change during growth of the tibia and can be accurately measured at 2 months of age.

Materials and Methods

Study protocol—The University of Minnesota Institutional Animal Care and Use Committee approved this prospective study. Ten Labrador Retrievers and 20 Labrador Retriever-hound crossbreeds between 8 and 15 weeks of age were enrolled in the study. A complete physical examination was performed, and sex, age, and body weight were recorded for each dog at each visit. Each dog was observed for lameness, and hip, stifle, and tibiotarsal joints were palpated for instability or pain. Puppies were excluded from the study if any traumatic or congenital stifle abnormalities, tibiotarsal abnormalities, or abnormalities that would preclude safe sedation were observed.

Radiographic images of the right and left tibia were taken under sedation approximately every 2 months from 8 to 52 weeks of age. Dogs were sedated with either medetomidine hydrochloride (5 µg/kg) or a combination of acetylprimazine maleate (0.01 to 0.05 mg/kg) and hydromorphone hydrochloride (0.1 to 0.2 mg/kg) injected IV in the cephalic or lateral saphenous veins. After radiographic examination, the sedative effect of medetomidine was reversed with atipamezole hydrochloride given IM at an equal volume to that of the medetomidine, and hydromorphone was reversed with nalbuphine hydrochloride (0.1 mg/kg) administered IV in the cephalic or lateral saphenous vein.

Radiographic projections included a lateral view of both stifle joints by use of the tibial plateau view as determined by Slocum and a standard caudocranial view. For the lateral projection, the x-ray beam was centered over the stifle joint with the stifle and tibiotarsal joints in 90° of flexion. The film cassette was in contact with the lateral malleolus, fibular head, and greater trochanter. The caudocranial view was taken with the stifle joint locked in extension. The radiographic beam was centered over the stifle joint with the entire tibia and the tibiotarsal joint included in the radiograph. The patella was centered in the trochlear groove, and each fabella was split by the corresponding femoral cortex. In addition, 1 lateral radiographic view and 1 ventrodorsal radiographic view of the pelvis were taken of each puppy between 6 months and 1 year of age.

Tibial plateau angles were measured on all lateral radiographic views by 4 veterinarians who were certified in the technique of tibial plateau leveling ostotomy (Fig 1). Examiners 1, 2, and 3 had 3, 4, and 5 years, respectively, of experience measuring TPAs, and examiner 4 had 8 months. Each examiner was given only 1 set of films for each dog during each measurement session and was blinded to the current age and previous measurements for that dog. Each examiner evaluated TPA, physeal closure status (ie, complete or incomplete) of the proximal and distal tibial physis on lateral and caudocranial views, radiographic positioning and quality of the films (ie, sufficient for measuring or insufficient for measuring), and whether the anatomic landmarks used for TPA measurements (ie, cranial aspect of tibial plateau, caudal aspect of tibial plateau, and intercondylar eminences) were sufficiently visible for accurate measuring (landmarks sufficiently visible for accurate measuring [LSV]) or landmarks insufficiently vis-

Figure 1—True lateral radiographic view of the stifle joint as described by Slocum, with cranial extent of the medial tibial plateau (A), caudal extent of the medial tibial plateau (B), and intercondylar eminences (C) clearly visible. The tibial plateau angle (TPA) is measured by drawing a line connecting the cranial and caudal extents of the tibial plateau (A and B), which identifies the tibial slope, and a vertical line between the intercondylar eminences and the center of the talocrural joint (C and D), which marks the long axis of the tibia. The TPA is the angle between a perpendicular to line C and D and the tibial plateau slope (θ).
To determine the age at which the TPA can be reliably measured and to evaluate interobserver variability, all data were sorted by the age of the dog in days at the time of each radiographic examination. Seven groups were created as follows: group 1 (60 to 100 days old), group 2 (101 to 140 days old), group 3 (141 to 180 days old), group 4 (181 to 220 days old), group 5 (221 to 260 days old), group 6 (261 to 320 days old), and group 7 (≥321 days old). Age category size (ie, age range for each group) was selected at 40-day intervals, but to prevent elimination of any data and in an attempt to include a final measurement after physeal closure for each dog, size was adjusted for the last 2 categories to ensure that no dog was measured more than once for any age group. Although no biological reason existed for this age-category-size selection, it was used to identify any points during which examiner variability increased.

Data analysis—The median age, age range, and mean TPA in each age group were calculated. The mean TPA for left and right stifle joints was compared for each age group by use of the independent sample t test. A 1-way ANOVA was used to evaluate the TPA measurements of the 4 examiners followed by post hoc t tests (by use of a Bonferroni adjusted α level) to evaluate the differences in examiner measurements for each age group.

The mean, median, and range of values for age for all dogs with radiographs classified as LIV were determined. Any dog with radiographs classified as LIV by any observer was eliminated. The mean age of group-1 dogs with radiographs classified as LIV by any observer was 64 days (range, 61–100 days). The mean age of group-2 dogs with radiographs classified as LIV by any observer was 105 days (range, 101–140 days). The mean age of group-3 dogs with radiographs classified as LIV by any observer was 148 days (range, 141–180 days). The mean age of group-4 dogs with radiographs classified as LIV by any observer was 190 days (range, 181–220 days). The mean age of group-5 dogs with radiographs classified as LIV by any observer was 248 days (range, 221–260 days). The mean age of group-6 dogs with radiographs classified as LIV by any observer was 315 days (range, 261–320 days). The mean age of group-7 dogs with radiographs classified as LIV by any observer was 441 days (range, ≥321 days). Age category size (ie, age range for each group) was selected at 40-day intervals, but to prevent elimination of any data and in an attempt to include a final measurement after physeal closure for each dog, size was adjusted for the last 2 categories to ensure that no dog was measured more than once for any age group. Although no biological reason existed for this age-category-size selection, it was used to identify any points during which examiner variability increased.

No significant differences in TPAs were found between group-1 and group-2 dogs. Significant differences were found between group-2 and group-3 dogs (P < 0.001) for the left TPA; significant differences were found between examiners 1 and 2 (P = 0.013) for the left TPA; significant differences were found between examiners 2 and 3 (P = 0.013) for the left TPA; and significant differences were found between examiners 2, 3, and 4 (P = 0.007) for the right TPA.

Results of linear regression analysis to evaluate changes in TPAs over time for the entire study population revealed a slope (slope, −0.002) that did not deviate significantly (P > 0.480) from 0. Likewise, results of linear regression analysis to evaluate changes in examiner on physeal closure status (ie, complete or incomplete) of the proximal and distal physes for each group.

All null hypotheses were evaluated. A value of P < 0.05 was considered significant, and the null hypotheses were rejected. Equality of variance was not assumed whenever the independent sample t test was performed.

Results

Thirty dogs met the study criteria. Of the 30 dogs, 10 (33.3%) were client-owned purebred Labrador Retrievers, and 20 (66.7%) were Labrador Retriever-hound crossbreeds that were part of a separate study at the University of Minnesota College of Veterinary Medicine. Labrador Retriever-hound crossbreeds consisted of 7 litters with 2 to 4 dogs/litter enrolled in the study. All 20 of the Labrador Retriever-hound crossbreeds and 6 of the 10 Labrador Retrievers were males. Four female Labrador Retrievers were enrolled in the study (Table 1). No dog developed any illness that required withdrawal from the study. The mean number of measurements for each dog was 4, with a median of 4, minimum of 2, maximum of 6, and range (difference between minimum and maximum) of 4.

At least 1 set of radiographs after closure of the distal tibial physis was available for 22 of 30 dogs. Radiographs after closure of the proximal tibial physis were available for 13 dogs. Only 1 discrepancy in classification of proximal physeal closure status was found between examiners, with 3 of 4 examiners classifying the proximal physis as incomplete (open) for that dog.

No significant differences in TPAs were found between observers for dogs at any age, except for group-5 dogs (Fig 2). In group-5 dogs, significant differences were found between examiners 2 and 3 (P < 0.013) for the left TPA; significant differences were found between examiners 2 and 3 (P < 0.043) and between examiners 2 and 3 (P < 0.007) for the right TPA.

Mean TPAs for the right and left stifle joints were not significantly different for dogs at any age. However, significant (P < 0.001) changes in both the right and left TPAs were found between group-1 and group-2 dogs.

Results of linear regression analysis to evaluate changes in TPAs over time for the entire study population revealed a slope (slope, −0.002) that did not deviate significantly (P > 0.480) from 0. Likewise, results of linear regression analysis to evaluate changes in

<table>
<thead>
<tr>
<th>Groups</th>
<th>Ages (d)</th>
<th>No. of dogs</th>
<th>Min</th>
<th>Max</th>
<th>Difference*</th>
<th>Medium BW (kg)</th>
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<th>Right</th>
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<td>239</td>
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*Difference between minimum and maximum age. Mean TPA = Tibial plateau angle.
TPAs over time for Labradors and Labrador Retriever-hound crossbreeds independently failed to reveal significant ($P < 0.368$ and $P < 0.092$, respectively) changes. Worthy of mentioning, however, is that the slope of the linear regression line for Labrador Retrievers was 0.006, whereas the slope of the linear regression line for Labrador Retriever-hound cross-breeds was –0.005.

The mean age for all dogs with radiographs classified as LIV was 70.2 days, with a median of 70.0 days, range of 18 days, minimum of 63 days, maximum of 81 days, and SD of 4.3 days.

Table 2—Summary of physeal closure data for 30 dogs followed over 7 age groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean age (d)</th>
<th>% Proximal phys*</th>
<th>% Distal phys*</th>
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<tr>
<td>1</td>
<td>76</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
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<td>156</td>
<td>0</td>
<td>0</td>
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<tr>
<td>4</td>
<td>189</td>
<td>0</td>
<td>2.4 (200)</td>
</tr>
<tr>
<td>5</td>
<td>238</td>
<td>1.3 (236)</td>
<td>68.4 (238)</td>
</tr>
<tr>
<td>6</td>
<td>282</td>
<td>57.7 (284)</td>
<td>100 (282)</td>
</tr>
<tr>
<td>7</td>
<td>393</td>
<td>100 (393)</td>
<td>100 (393)</td>
</tr>
</tbody>
</table>

*Data are presented as the percentage of examiners who classified the physes as closed for each age group. The actual number of dogs with closed physes was not reported because examiners occasionally varied in their responses for the same dog. Values in parentheses represent mean age in days of dogs at physeal closure.
for the mean age was 68.12 to 72.28 days. The mean age for group-1 dogs with radiographs classified as LSV was 85.3 days, with a median of 86 days, range of 35 days, minimum of 65 days, maximum of 100 days, and SD of 10.5 days. The 95% confidence interval for the mean age for group-1 dogs with radiographs classified as LSV was 76.73 to 94.27 days. Dogs with radiographs classified as LIV were significantly \( (P < 0.001) \) younger than dogs with radiographs classified as LSV. All radiographs classified as LIV were from group-1 dogs.

A significant \( (P < 0.001) \) difference was found among examiners in the classification of radiographs as LIV or LSV. The mean TPA of group-1 dogs with radiographs classified as LIV was 21.25° for the left stifle joint and 21.05° for the right stifle joint, and the mean TPA for dogs with radiographs classified as LSV was 25.83° and 25.44° for the left and right stifle joints, respectively. The mean TPA of dogs with radiographs classified as LIV was significantly \( (P < 0.004) \) lower than the mean TPA of dogs with radiographs classified as LSV. For dogs \( (n = 18) \) with radiographs classified as LIV, TPAs increased significantly \( (P < 0.001) \) from age groups 1 to 2, whereas the same comparison for dogs \( (8) \) with radiographs classified as LSV revealed no significant difference in TPAs from age groups 1 to 2. No significant differences were found among the responses of examiners concerning the status of physeal closure of dogs at any age (Table 2).

**Discussion**

Results of our study do not identify an exact age at which TPAs can be accurately measured. Overlap was found among age groups, with dogs as young as 65 days old having radiographs with a classification of LSV by all examiners and dogs as old as 81 days having radiographs with a classification of LIV by 1 examiner. The mean age of dogs with radiographs classified as LSV by all examiners was 85.3 days with a 95% confidence interval of 76.73 to 94.27 days. No group-2 dogs had radiographs with a classification of LIV, and the youngest dog in group 2 was 108 days old. Although the exact age at which the landmarks used for measuring TPAs become radiographically visible cannot be determined by the results of our study, our data indicate that TPAs can be accurately measured at about 90 days of age, and by 108 days of age, there is strong evidence that measurements are accurate and repeatable. We feel this inability to accurately measure the TPAs of younger dogs is further supported by the significant \( (P < 0.001) \) change in TPAs from group-1 to group-2 dogs with radiographs classified as LIV. No significant change in TPAs was found at any age for dogs with radiographs classified as LSV.

A summary of the comments on why examiners classified radiographs as LIV suggests that the youngest dogs in our study had no radiographically visible intercondylar eminences and that the measuring points on the cranial and caudal aspects of the medial tibial plateau could not be identified. As age increased, the eminences became radiographically visible, followed by the point on the cranial aspect of the tibial plateau, and finally the point on the caudal extent of the tibial plateau became identifiable (Fig 3). Although the inability to identify landmarks for measuring TPAs appeared to be age related in our study, results of another study indicate similar difficulties in adult dogs resulting from slight radiographic positioning inconsistencies, occasional sloping of the cranial and caudal extent of the tibial plateau, and osteoarthritis.

No significant change in TPAs was found over time for Labrador Retrievers, Labrador Retriever-hound crossbreeds, or the entire study population. Analysis of TPAs from Labrador Retrievers resulted in a linear regression line with a positive slope \( (0.006) \), whereas analysis of TPAs from Labrador Retriever-hound crossbreeds resulted in a linear regression line with a negative slope \( (-0.005) \). Although the slopes of these lines were not significantly \( (P < 0.16) \) different from each other, we feel that this finding may be influenced by the breed distribution in our study, with twice as many Labrador Retriever-hound crossbreeds as Labrador Retrievers.

We found no difference between right and left mean TPAs in dogs at any age. This finding is in agreement with that of a previous study in which no difference between right and left TPAs for adult Labrador Retrievers was found.

No significant difference in mean TPAs was found among examiners for any age group, except for group-5 dogs. We have no explanation for this difference in TPA measurements among examiners for group-5 dogs. We could not identify any errors in radiographic technique or positioning that would explain this difference. However between any 2 examiners, a difference of \( > 3.2^\circ \) in mean TPA measurements for any age group was not found in our study (Fig 2). Our maximum interexaminer difference in TPA measurements is \( 1.6^\circ \) less than the interexaminer variability reported by Caylor et al. Our data are based on the mean TPAs for all responses by each examiner for each age group, which may have resulted in lower variability.

The design of our study did not allow identification of the exact time of closure of the proximal or distal tibial physes. However, approximately 70% of examiners classified the distal tibial physis as closed by 238 days (8.5 month) of age, with the earliest closure at 200 days (7 months) and 100% closed by 282 days (10 months). The proximal physis closed later, with the first reported closure at 236 days (8 months) of age and 100% closure by 393 days (13 months) of age. These results are consistent with closure ranges from a previous study.

The mean TPA for Labrador Retrievers at the time of closure of the proximal and distal physes was 24.73° in our study. Morris and Lipowitz, and Reif and Probst have suggested TPAs of 18.87°, 27.97°, and 23.60° for clinically normal Labradors and 23.21°, 25.55°, and 23.50° for Labradors with CCL tears, respectively. Although we have no means of differentiating between dogs at low or high risk for CCL tears in our study, our TPA data fall somewhere within the range of these previously reported values.

The results of our study indicate that TPAs can be accurately measured at approximately 90 days of age. Our null hypothesis was rejected, as TPA measurements
were rarely accurate before this age. Any attempts at earlier measurements often lead to an underestimation of the actual TPA. Knowing when the TPA can be measured is important because the age at the time of CCL injury appears to be decreasing.\(^1\)\(^2\) Measuring TPAs in growing dogs with injuries to the tibia or stifle joint may allow earlier detection of premature physeal closures. As more is learned about the role of the TPA in cruciate ligament injury, early treatment may be possible for growing dogs with cruciate ligament injuries and excessive tibial slope. In regards to change in TPAs over time, we could not reject our hypothesis, as TPAs did not change over time.

2. Ralphs SC, Department of Small Animal Clinical Sciences, College of Veterinary Medicine, University of Minnesota, St Paul, Minn: Personal communication (based on paper in progress), 2002.
6. Orion Pharma, Orion Corp, Espoo, Finland.
7. Butler Pharmaceuticals, Columbus, Ohio.

**References**