

Intra- and Interobserver Measurement Variability of Tibial Plateau Slope From Lateral Radiographs in Dogs

Measurement of the tibial plateau slope from lateral hind-limb radiographs is a preoperative requirement when performing tibial plateau leveling osteotomy (TPLO) for repair of the cruciate-deficient stifle in dogs. Two measurements of the tibial plateau slope in 312 stifles of 156 dogs were taken from lateral radiographs by each of three observers with varying degrees of experience in the measurement method. Intraobserver variability was $\pm 3.4^\circ$, and interobserver variability was $\pm 4.8^\circ$. No significant differences were identified for the intraobserver measurements; however, in evaluating interobserver variability, a significant difference was found between the inexperienced observer and the two experienced observers. *J Am Anim Hosp Assoc* 2001;37:263–268.

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Introduction

Cranial cruciate ligament (CrCL) rupture is a common cause of hind-limb lameness in dogs. If left uncorrected, the loss of this important supporting structure ultimately results in degeneration of the stifle joint with chronic, irreversible changes in the articular and periarticular tissues. The pathogenesis of CrCL rupture has been reviewed and summarized elsewhere in the literature.^{1,2}

Numerous surgical techniques have been developed to correct the CrCL-deficient canine stifle.^{3–10} All of the techniques and their modifications share the objective of stabilizing the stifle and preventing or limiting the cranial drawer sign.¹¹ Recently, a procedure has been developed in which the angle of the tibial plateau is decreased by performing a cylindrical proximal tibial osteotomy and rotating the proximal tibial component, thereby leveling the articular surface of the tibia.¹² The success of the tibial plateau leveling osteotomy (TPLO) procedure relies, in part, upon neutralizing the detrimental effects of cranial tibial thrust, which is the cranial translation of the proximal tibia during weight bearing.^{12,13} This active force is created by a combination of muscular pull across the stifle joint and compression between the femur and tibia from weight bearing. The magnitude of cranial tibial thrust is a function of both the degree of compression and the slope of the tibial plateau.¹³ By altering the slope of the tibial plateau, Slocum and Devine showed that cranial tibial thrust can be controlled.¹⁴

Determining the slope of the tibial plateau is a prerequisite to the TPLO procedure. An accurate measurement is necessary to plan for precise rotation of the proximal tibial component following the osteotomy. Because determination of the tibial plateau slope requires the observer to subjectively select anatomic landmarks from a lateral radiographic projection of the hock and stifle, variability may be introduced. This investigation assesses the intra- and interobserver variability when measuring the tibial plateau slope from a lateral radiographic view in dogs.

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Materials and Methods

One hundred eighty-seven client-owned dogs with body weights >18 kg were radiographed between January 1999 and July 1999. Exclusion on the basis of body weight was made because, at the time this study was conducted, the specialized instrumentation required to perform the TPLO procedure limited dogs as surgical candidates to approximately 18 kg body weight or larger, loosely related to the size of the tibia. The dogs were randomly selected from clinical cases examined during this time. Dogs with any clinical hind-limb lameness were excluded. Permission was obtained from owners to take a lateral radiographic view of each hind limb from the hock to the stifle. The dogs were anesthetized, sedated, or awake and manually restrained, depending upon individual clinical circumstances. Radiographs were initially evaluated for positioning, technique, open proximal tibial physis, and the presence of osteoarthritic signs in the stifle joint. Thirty-one dogs were excluded because of poor positioning or technique, open proximal tibial physis, or osteoarthrosis. Therefore, 156 dogs (312 stifles) were ultimately included in this study.

Body weights ranged from 18.1 kg to 65.3 kg (median, 32.2 kg; mean, 32.4 kg). The dogs ranged in age from 11 months to 15 years (median, 5.0 years; mean, 5.5 years). There were 76 (48.7%) male dogs (44 castrated, 32 sexually intact) and 80 (51.3%) female dogs (58 spayed, 22 sexually intact). The Table shows the various breeds represented in this study.

Tibial plateau slope was determined from each lateral radiograph [Figure 1]. The tibial long-axis line was drawn through a point, proximally (dividing the medial and lateral intercondylar tubercles) and distally (through the center of the talus). The tibial plateau line was drawn along the medial articular surface. The margins of the articular surface were defined cranially by a small step and caudally by the location of attachment of the caudal cruciate ligament [Figure 2]. The tibial plateau slope was measured as the angle between the tibial plateau line and a line drawn perpendicular to the tibial long-axis line.^a

Three observers with varying degrees of experience at performing measurements of the tibial plateau slope evaluated the radiographs. One observer (Caylor) was Slocum-licensed to perform the TPLO procedure and had 3 years of experience; the second observer (Zumpano) had 6 months of experience performing measurements; and the third observer (Evans) was trained in the measurement technique the day the study began. Each examiner evaluated each radiograph on two separate occasions. A minimum interval of 21 days was allowed between evaluations of any given radiograph. Transparent acetate overlay film^b and wet erase pens^c were used so that no marks were made on the radiographs. All examiners used identical protractors.^d Angles were read to the nearest whole number and rounded up in any instance of a measurement resulting in a half-degree reading.

Intra- and interobserver variability were determined using the method of residuals previously described by Bland and Altman.¹⁵ The differences between measurements are plot-

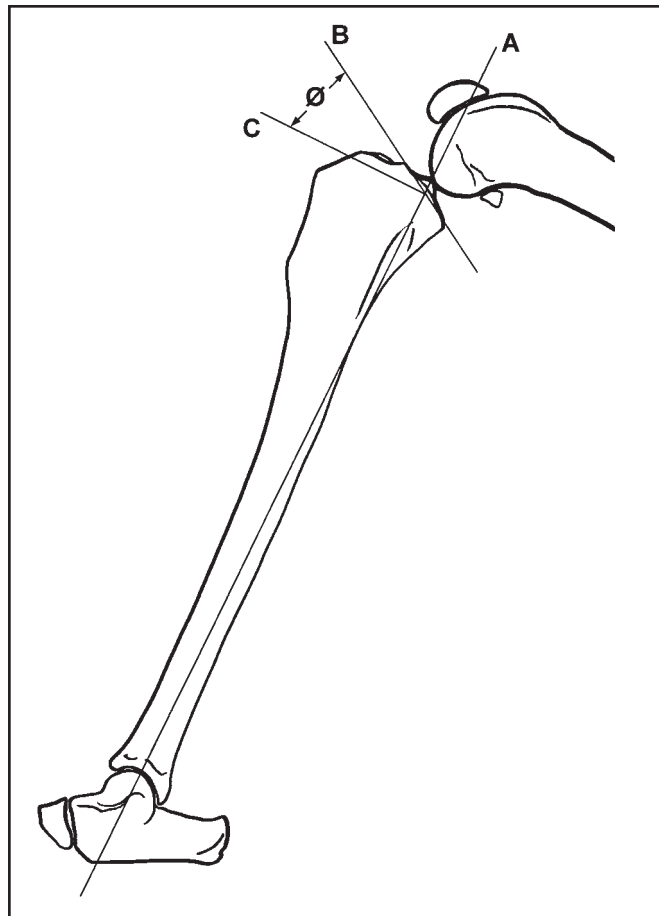


Figure 1—The angle of the tibial plateau slope ($\emptyset$) as found from a line (A) drawn along the tibial long-axis, passing through a point proximally (dividing the medial and lateral intercondylar tubercles) and distally (through the center of the talus). The tibial plateau line (B) was drawn along the medial articular surface. The margins of the articular surface were defined cranially by a small step and caudally by the location of attachment of the caudal cruciate ligament. The tibial plateau slope was measured as the angle ($\emptyset$) between the tibial plateau line (B) and a line (C) drawn perpendicular to the tibial long-axis line.

ted against their mean. The statistical analysis discussed by Bland and Altman¹⁵ does not advocate the use of correlation coefficients, which may increase by virtue of an increase in the measurement range. Furthermore, correlation coefficients are a measurement of the strength of association and not a measurement of agreement. An intraobserver variability estimate based on 95% confidence is the minimal difference required in two successive measurements by the same observer to be 95% certain a real difference is present. An estimate of interobserver variability based on 95% confidence is the minimal difference required in two successive measurements by two different observers to be 95% certain a real difference is present.

The mean differences in measurements between the first and second observation were established for each observer. The mean differences were compared using a multivariate

Table

**Breed Distribution and the Mean Measurements in Degrees of the Tibial Plateau Slope
From Lateral Radiographic Views of the Left and Right Stifles in 156 Dogs**

Breed	No. of Dogs (<i>n</i>=156; Stifles Evaluated=2<i>n</i>)	Mean Slope (<i>Range</i>) in Degrees	
		Left	Right
Mixed-breed dog	37	24 (20-29)	24 (17-30)
Labrador retriever	19	23 (20-29)	23 (18-30)
Golden retriever	18	22 (18-30)	22 (19-30)
German shepherd dog	12	25 (20-28)	25 (20-28)
Boxer	8	28 (25-31)	27 (24-30)
Pit bull terrier	8	22 (20-25)	23 (21-27)
Rottweiler	7	22 (18-26)	22 (19-28)
Standard poodle	7	24 (22-25)	23 (21-26)
Doberman pinscher	5	24 (22-26)	24 (22-26)
Australian shepherd	4	23 (20-25)	23 (20-25)
Dalmatian	3	22 (21-23)	23 (22-24)
English springer spaniel	3	23 (21-24)	24 (19-27)
Wheaten terrier	3	21 (20-23)	22 (18-24)
Akita	2	22 (22-22)	23 (23-24)
Rhodesian ridgeback	2	24 (22-25)	21 (20-22)
Afghan hound	1	26	27
Alaskan malamute	1	30	29
American bulldog	1	24	23
Belgian Malinois	1	24	23
Bernese mountain dog	1	17	20
Bull terrier	1	17	17
Chow chow	1	19	19
Collie	1	26	26
Irish setter	1	25	24
Kuvasz	1	25	23
Newfoundland	1	26	26
Nova Scotia duck tolling retriever	1	17	21
Old English sheepdog	1	21	23
Samoyed	1	21	21
Siberian husky	1	23	22
Vizsla	1	25	24
Walker hound	1	21	20
Weimaraner	1	27	26
Total mean (left and right stifles)		23.5	

analysis of variance (ANOVA) to evaluate whether the magnitude of intraobserver variability differed by observer. Computer software was used for all data organization and statistical analyses.^{e,f}

Results

The 95% confidence interval (CI) for intraobserver variability of all measurements was $\pm 3.4^\circ$ [Figure 3]. The mean differences between the first and second measurement for each observer were 1.0° for the longest-trained observer, 1.0° for the intermediate-trained observer, and 1.1° for the novice-

trained observer. Statistical analysis showed there was no significant difference in the mean intraobserver differences between the two measurements for each of the three observers (experienced observer, $P=0.944$; intermediate-experienced observer, $P=0.545$; novice observer, $P=0.845$).

The 95% CI for interobserver variability was $\pm 4.8^\circ$. Statistical analysis identified a significant difference between the novice-trained observer and the two observers with experience ($P<0.05$). There was no statistical difference between the measurements of the two experienced observers ($P>0.05$).

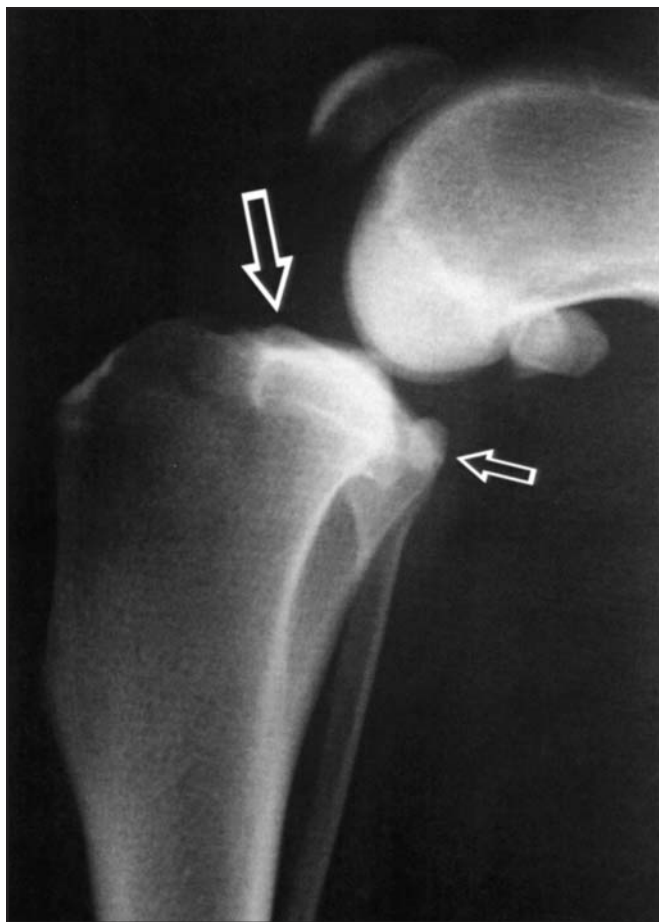


Figure 2—Radiographic landmarks for identifying the medial articular surface of the proximal tibia are the small step (large arrow) cranially and the location of attachment of the caudal cruciate ligament (small arrow) from a lateral projection of the stifle. Note the superimposed femoral condyles, indicating ideal positioning.

Mean tibial plateau slopes and ranges were determined for the various breed groups represented in this study [see Table].

Discussion

Determining tibial plateau slope is an integral component of the TPLO procedure, but variability in the measurement of the angle between observers or within an individual observer's repeated measurements have not been previously documented. To the authors' knowledge, this is the first study to assess the intraobserver and interobserver variability in the measurement of tibial plateau slopes from lateral radiographs. Three observers with different levels of experience were used to evaluate intraobserver variability. The ability to reproduce measurements was high for all three observers. This would indicate an ability to consistently recognize subjectively determined landmarks on the radiographs, even with limited previous experience.

Not surprisingly, interobserver variability was greater than intraobserver variability. Additionally, the angles measured by the inexperienced observer differed significantly

from those measured by the two experienced observers. Three sources of nonobserver variability could include the use of wet erase markers instead of thin-marking pencils, error introduced with variations in positioning of the hind limb, and subtleties in individual anatomic variation. The wet erase markers used in this study were fine-pointed, but the line produced was approximately a millimeter in width. While the contribution of marker width to measurement error could not be quantified, greater accuracy potentially could be obtained with the use of pencils on copied radiographs. Using copied radiographs would also eliminate the need for plastic overlay film, although no practical problems arose with its use during this study.

Secondly, the measurements in this study were conducted on what was subjectively thought to be the highest quality radiographs of the test subjects. However, perfect positioning was difficult to obtain in some cases, either because of patient compliance, operator error, or potential natural rotational limb defects. Studies in humans have addressed the changes in axial alignment of the knee on radiographic projections as a function of rotation of the limb or flexion of the knee, finding that positioning does alter alignment indices.¹⁶⁻¹⁸ Analogous studies in the dog are lacking to the authors' knowledge, although in the initial study by Slocum and Devine (which investigated cranial tibial thrust as it relates to tibial plateau slope), there is reference to mathematically correcting angle measurements because of internal rotation of disarticulated limbs during radiography.¹³ Subtle flexion, rotation, or sagittal variations in positioning of the stifle may alter the radiographic appearance of the landmarks required for placement of the tibial long-axis and tibial plateau lines, potentially creating sources of measurement error.

Finally, even with what was considered perfect positioning, distinct landmarks for the tibial plateau line were at times somewhat anomalous [Figure 4]. Most commonly, the caudal aspect of the tibial articular surface had a curvilinear appearance, making determination and reproducibility of the specific site of caudal cruciate attachment difficult. Occasionally the well-defined step at the cranial margin of the tibial articular surface was blunted or sloping, making the articular margin difficult to identify as a distinct, reproducible point through which to pass the tibial plateau line.

The high degree of reproducibility in the intraobserver measurements suggests that all observers could consistently reproduce measurements from any given radiograph. However, the loss of statistical significance between the inexperienced observer and the two experienced observers may indicate that the subjective selection of specific landmarks varied somewhat according to experience. The difference discovered between the inexperienced observer and the two experienced observers would indicate a short learning curve, since the intermediate-trained observer had only 6 months of experience in this study. It can be concluded that correct and repeatable landmark recognition is attained within a short period of time. However, while the intermediate-trained observer may have developed proficiency quickly following initial instruction, that skill was attained with interactive

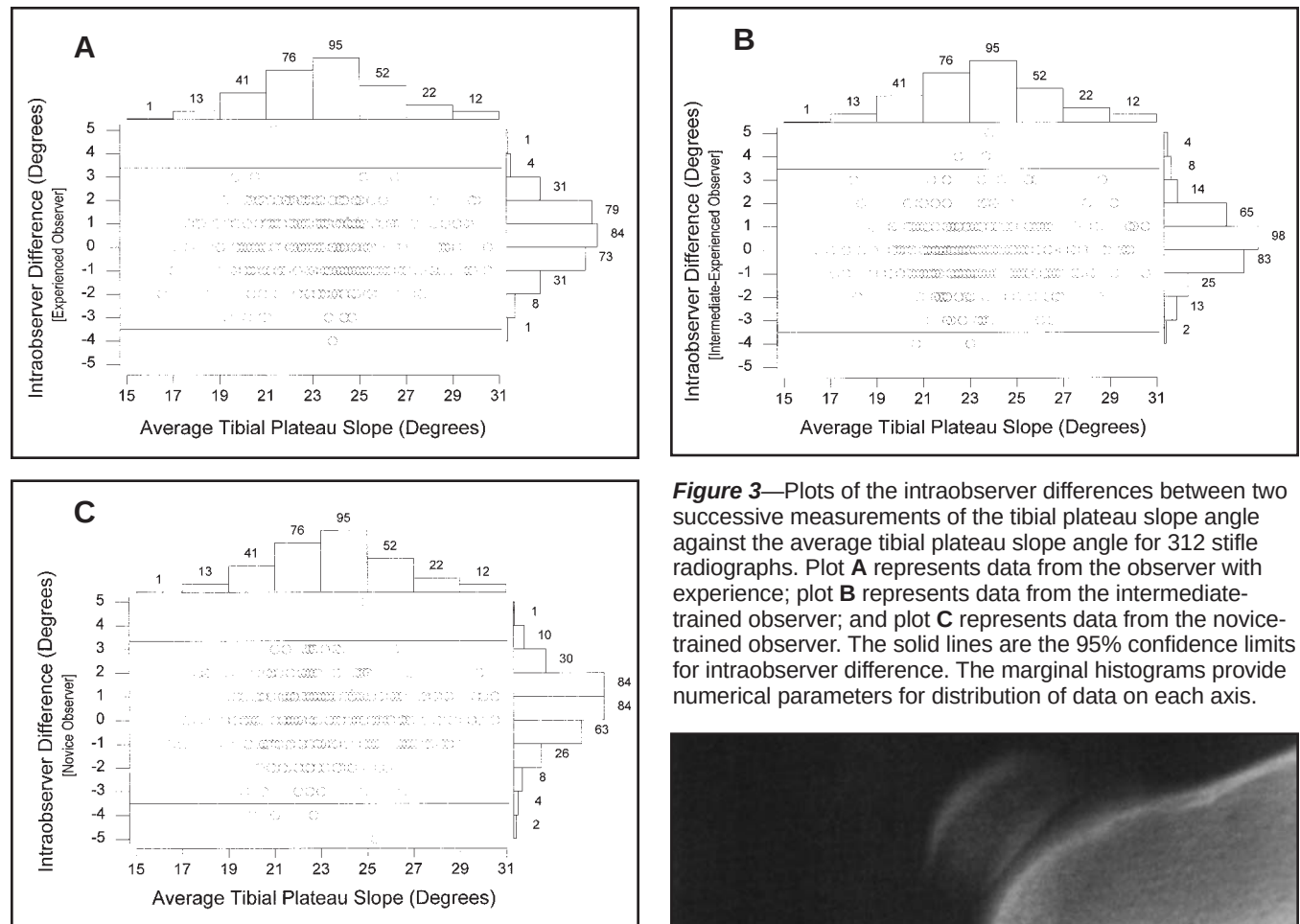


Figure 3—Plots of the intraobserver differences between two successive measurements of the tibial plateau slope angle against the average tibial plateau slope angle for 312 stifle radiographs. Plot **A** represents data from the observer with experience; plot **B** represents data from the intermediate-trained observer; and plot **C** represents data from the novice-trained observer. The solid lines are the 95% confidence limits for intraobserver difference. The marginal histograms provide numerical parameters for distribution of data on each axis.

guidance during the frequent evaluation of clinical cases; whereas, the novice observer was provided only initial instruction.

An “average,” or typical, tibial plateau angle common to the population of dogs evaluated was not identified. In fact, there was considerable range in the angles measured within the group of dogs examined [see Table]. Subjectively it appeared there might be breed-related variation, but in-depth analysis of this interesting concept was beyond the scope of the authors’ study. The mean tibial plateau slope of the population of dogs in this study was 23.5°. This compares favorably to the 22.6° mean angle of inclination of the tibial plateau previously reported in 16 dogs.¹³

The clinical significance of the $\pm 3.4^\circ$ intraobserver variability and $\pm 4.8^\circ$ interobserver variability in measuring the tibial plateau slope identified in this study is unknown. This error reflects only measurement error and does not consider the effects that changes in positioning of the stifle may have on subsequent radiographs of the same dog. Understanding positioning error is imperative if preoperative and postoperative radiographic comparisons are to be meaningful. While a smaller, more uniformly controlled population of dogs may yield less variability, it was the intention of this study to simulate the spectrum of anatomic variation and clinical radiography seen in general practice.

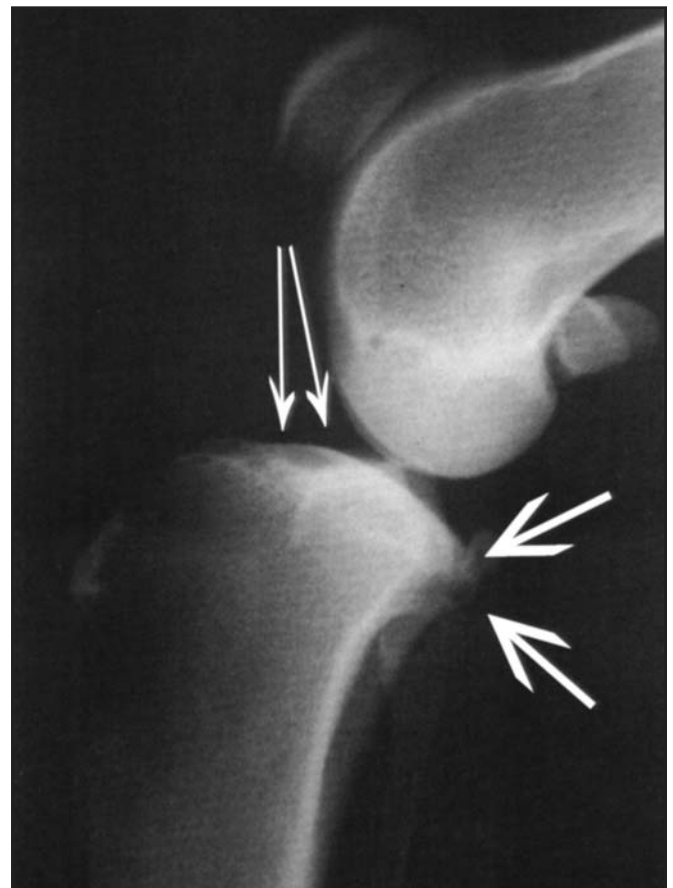


Figure 4—A well-positioned lateral radiograph of a stifle, illustrating sloping of the cranial (small arrows) and caudal (large arrows) boundaries of the medial articular surface of the proximal tibia in a dog. The poor delineation of these landmarks is one possible source of error in the reproducibility of the measurement of tibial plateau angles.

Measurement variability does have at least one potential operative impact. Over-rotation of the proximal tibial component during the TPLO procedure increases the biomechanical stress applied to the caudal cruciate ligament.^{14,19} It has been reported that under-rotating the proximal tibial component to approximately 6° of level may be important in protecting the caudal cruciate ligament from stress.¹⁹ Obviously, under-rotation of the proximal tibial component may fail to control cranial tibial thrust, thus resulting in a poor clinical outcome. Measurement variability should be taken into consideration during preoperative planning for the TPLO procedure.

Future areas of study include the specific effects limb positioning and anatomical variations have on the measurement of the tibial plateau slope from lateral radiographs in dogs. Additionally, a canine cadaver study is needed to verify that the tibial plateau slope measurements from lateral radiographs are consistent with the true anatomic slope of the proximal tibial articular surface. Clinical studies are necessary to explore how the magnitude of rotation of the proximal tibial component during a TPLO procedure influences clinical outcome. The latter investigations will help put the measurement variability identified in this study into clinical perspective.

- a Slocum B. Personal communication, 1996. Tibial plateau measurement. Slocum Enterprises, Inc., Eugene, OR
 b Clear-Lay Plastic Film (0.003); Grafix Plastics, Cleveland, OH
 c Vis-à-Vis Fine Point Wet Erase; Sanford, Bellwood, IL
 d Protractor-6 inch; Helix, Medford, NY
 e Excel; Microsoft, Redmond, WA
 f Minitab Statistical Software; Minitab Inc., State College, PA

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