Comparison of anatomical tibial plateau angle versus observer measurement from lateral radiographs in dogs

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Summary
This study was conducted to compare the anatomical tibial plateau angle (TPA) with that measured by observers from a lateral radiograph of the limb, the hypothesis being that there would not be any statistically significant differences between the observer measured TPA and the true anatomical TPA. Twelve pelvic limbs from skeletally mature greyhound cadavers, without any clinical or radiographic evidence of stifle pathology, were used in this study. The radiographs were taken of each limb in a lateral position with the primary beam centered over the tibial eminences and collimated to include the stifle and tarsocrural joints. For subsequent radiographs, Kirschner wires were inserted to enable identification of the tibial plateau. The TPA was then measured, by three observers, from the plain radiographs and by one observer from the marked radiographs. The mean observed TPA was 24.4° (range 17°–30°) and the mean anatomical TPA was 23.8° (range 15°–31°). The mean and median discrepancy between the anatomical TPA and the observer TPA was negative and very small (−0.64° and 0°). The magnitude of the discrepancy between individual measurements made by the observers tended to overestimate small angles and underestimate the large ones, and this trend is statistically significant. These results suggest that the measurements made by observers accurately represent the anatomical slope of the tibial plateau. Therefore, observer TPA is suitable for the planning and assessment of TPLO procedures. However, as the anatomical TPA moves away from a median angle (23.25°) the magnitude of error in the measurement increases.

Keywords
Tibial plateau angle, dog, anatomical

Introduction
Rupture of the cranial cruciate ligament (CrCL) represents one of the most common orthopaedic injuries in dogs and is considered to be the major cause of degenerative joint disease of the stifle joint (5). Over the last 40 years, numerous surgical techniques, both intra- and extra-articular, have been developed in an effort to correct the CrCL-deficient stifle and restore joint stability. The majority of these techniques attempt to mimic the function of the previously intact CrCL, which are: prevention of cranial tibial translation, limitation of tibial internal rotation and hyperextension of the stifle joint (1). In 1993, a surgical procedure was developed for the treatment of cranial cruciate ligament deficient stifles in dogs, the tibial plateau levelling osteotomy (TPLO) (7). This procedure does not mimic the action of the CrCL function, but aims to antagonise the caudal thrust of the femur in the CrCL deficient stifle, by changing the slope of the tibial plateau. Determining the slope of the tibial plateau is a requirement for surgical planning of the TPLO procedure. The measurement method that estimates the anatomical tibial plateau angle (TPA) from radiographs, including patient positioning, radiographic view, and radiographic interpretation, has been described and used in a number of previous studies (3, 4, 8, 9).

One study (2) measured the anatomical TPA, but this measurement was not consistent with the anatomical reference points described for measurement of TPA (3, 4, 8, 9). Anatomical measurements in the study (2) were made from digital photographs of the dissected bones, defining the tibial plateau angle as a line tangential to the cranial linear portion of the medial tibial condyle at the femorotibial contact point. The authors concluded that using conventional measurement techniques there was an underestimation of TPA. An alternative method of TPA measurement was described based upon identifying the femorotibial contact point; this was shown to be more accurate in measuring the anatomical TPA (2). However, because the reference points are not consistent, some dogs with rupture of the CrCL have stifle subluxation, and in these circumstances this ‘new method’ may not provide an accurate assessment of TPA.

Another study (6) measured anatomical TPA and compared this to observer TPA and did not find any significant difference between the measurements. However, the sample size in this study was very small and therefore statistical analysis of observer measurement was limited.

Determination of the TPA requires the observer to subjectively select anatomical landmarks from a lateral radiographic projection of the hock and stifle. This process can introduce variability. One study demonstrated intra-observer variability of ±3.4° and inter-observer variability of ±4.8° (3). However, in that study there was no anatomical value with which to compare the measured values, hence the discrepancy from true anatomical value was not possible to determine.

The study presented herein was conducted to compare the anatomical TPA with that measured by observers from a lateral radiograph of the limb using the same anatomical reference points for both calculations. It was hypothesized that there would not be any statistically significant differ-
ence between the observer measured TPA, from the plain lateral radiographs, and the true anatomical TPA. A secondary objective was to assess inter-observer variability for the measurement of TPA from plain lateral radiographs.

Methods

Animals

Twelve pelvic limbs were taken from 16 skeletally mature greyhounds euthanized for reasons unrelated to this study. A sample size of 12 was considered appropriate for a projected means of 20° and 25° and standard deviation of 4° (2), to achieve a power of 80% with a probability of type 1 error (α) = 0.05.

Only pelvic limbs without any clinical or radiographic evidence of stifle pathology were used in this study. The presence and amount of cranial drawer movement, crepitus, joint effusion, periarticular fibrosis, or patellar luxation were recorded. The limbs were then dissected, leaving just the passive restraints of the stifle joint (collateral, cranial cruciate and caudal cruciate ligaments) and the menisci, as well as the soft tissues of the hock and distal limb.

Radiographic methods

Each leg was positioned with the femur and tibia parallel to the table and the stifle and tarsal joints at 90° angles. The cadaver legs were held by two clamp stands, one clamp stand securing the mid-diaphysis of the femur and another secured around the metatarsals. This arrangement positioned each limb approximately 5 cm above the radiographic cassette. Lateral radiographs were taken of each limb with an exposure of 65 kVp and 0.8 mAs; due to the similarity in size the same settings were used for all limbs. The primary beam was centered over the tibial eminences and collimated to include the stifle and tarsal joints. The radiographs were repeated if the femoral condyles were separated caudally, distally, or cranially by ≥2 mm. Limb position was adjusted by rotating, raising or lowering the clamp.

For subsequent radiographs, 1 mm Kirschner wires (K-wires) were inserted with a drill to enable identification of the tibial plateau, as described in other papers (8). The K-wires were inserted in the cranial intercondylar area (immediately medial and cranial to the insertion of the cranial cruciate ligament) and in the most caudal aspect of the medial tibial condyle (immediately medial to the insertion of the caudal cruciate ligament (CaCL)). The wires were inserted while the limb was secured by the clamp stands on the radiography table to minimize movement of the leg. Following this, repeat lateral radiographs were taken with the radiographic markers in place (Fig. 1). Three observers read the plain radiographs to determine the observer TPA. The observers were ‘blinded’ to dog number and anatomical measurements. Two observers were orthopaedic surgeons with >10 years of experience and were Slocum-licensed to perform the TPLO procedure (Observers A and B). One observer (C) was a Resident in Surgery with three years of clinical experience.

Observer TPA measurement

The tibial plateau slope was determined from each lateral radiograph without the K-wire markers (3). The tibial long-axis line was drawn through a point, proximally (dividing the medial and lateral intercondylar tubercles) and distally (through the centre 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 (the origin of the cranial cruciate ligament) and caudally by the point of insertion of the caudal cruciate ligament. The TPA was measured between the tibial plateau line and a line was drawn perpendicular to the functional axis of the tibia. Transparent acetate overlay films and wet erase pens were used so that no marks were made on the radiographs, which could have influenced the subsequent observers. A protractor was used to measure the angles and values were read to the nearest half a degree.

Anatomical TPA measurements

The radiographs with the K-wire markers were used to determine the anatomical tibial plateau angle. A line was drawn between the centre of the two tibial intercondylar eminences and the centre of the talus; this line represented the functional axis of the tibia. The tibial plateau slope was identified as the line joining the K-wires (at the wire bone interface), implanted at the medial insertion of the CrCL and the medial insertion of the CaCL. The TPA was measured between the tibial plateau line and a line drawn perpendicular to the functional axis of the tibia, using a protractor, as previously described. All anatomical angles were measured by one observer (JG), in random order, on three separate occasions.

Statistical analyses

Summary statistics were obtained for the individual observers’ TPA measurements, for the true anatomical TPA and for the difference between mean observed TPA and anatomical TPA. In order to assess inter-observer reproducibility, the mean absolute deviation from the mean and mean inter-observer variance were calculated. The reliability of using single, or averaged measures, was
assessed by intra-class correlation coefficients obtained using a two-way random effects model.

In order to assess whether the differences between observed and anatomical TPA were related to the true anatomical TPA, the difference was plotted between the anatomical TPA and mean observed TPA against the anatomical TPA and the Pearson correlation coefficient was calculated.

The hypothesis that mean observed TPA significantly differed from the true anatomical TPA was assessed by means of a Wilcoxon signed ranks test. Associations were deemed significant if $P<0.05$.

All of the analyses were carried out with version 12.0 of SPSS for windows (SPSS Inc. Chicago, IL).

**Results**

The mean, range and standard deviation of TPA for each of the three observers are presented in Table 1. For all 12 limbs, the mean observed TPA was $24.4^\circ$ (Range $17–30^\circ$) and the mean anatomical TPA was $23.8^\circ$ (Range $15–31^\circ$).

The mean absolute deviation from the mean and mean inter-observer variance were $2.88^\circ$ and $11.69$, respectively.

The intra-class correlation coefficients obtained showed that the reliability for any single observer measurement was low (ICC=0.24; 95% CI:-0.037 to 0.612) and the reliability of the average measurement was moderate (ICC=0.49; 95% CI:-0.171 to 0.829).

There was a relationship between the observed TPA and anatomical TPA (Fig. 2). For small anatomical TPAs, there appeared to be an overestimation by the observers, while for large anatomical TPAs the observers tended to underestimate the actual value. The correlation between the discrepancy (anatomical – observed) and the true anatomical value was statistically significant (Pearson correlation coefficient $r$=0.80; $P=0.02$).

The differences between the mean anatomical TPA and the observed TPA ranged from $-7.2$ to $4.7$, with a mean of $-0.64^\circ$ and a median of $0^\circ$. The absolute mean and median differences were both $3^\circ$. The Wilcoxon signed ranks test for equality of the median anatomical and median (average) observed TPA gave $P=0.593$. However, upon inspection of Fig. 2, it was obvious that anatomical and observed TPAs do not relate in the same way across the range of TPAs and it was decided to divide the legs into two groups using the median anatomical TPA ($23.25^\circ$) as a threshold and to repeat the analysis. When this was done, the difference between anatomical and observed TPA was significant (Median difference $= -3.64^\circ$; $P=0.04$) for those legs with anatomical TPA $< $ the median and not significant for those with anatomical TPA $> $ median (Median difference $= +3^\circ$; $P=0.24$).

**Discussion**

The main objective of the study was to compare the anatomical TPA with that measured by observers from a lateral radiograph of the limb, using the same anatomical reference points for both calculations. Before conducting a formal statistical test the discrepancy between the two measurement procedures was described graphically and numerically and found that:

- The mean and median discrepancy between the anatomical TPA and the observer TPA was negative and very small ($-0.64^\circ$ and $0^\circ$).
- The magnitude of the discrepancy between individual measurements of the observers tended to overestimate small angles and underestimate the large ones, as indicated by the Pearson correlation coefficient and this trend is statistically significant.

One previous study (2) reported on the mean absolute deviation from the mean and mean inter-observer variance as a measure of inter-observer variability. This is the only study that assessed observer measurements

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Summary statistics of TPA measured by three observers.</th>
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<tr>
<td>Observer</td>
<td>Number of legs</td>
</tr>
<tr>
<td>A</td>
<td>12</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
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<tr>
<td>C</td>
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![Fig. 2 Scatter diagram of the differences between anatomical TPA and observer measured TPA plotted against anatomical TPA (all figures in degrees).](image-url)
of TPA. The same parameters were calculated from our data and obtained very similar results (mean absolute deviation 2.88° and 2.7°; mean inter-observer variance 11.69 and 16.5 in our study and in the previous study (2), respectively), suggesting that inter-observer variability was similar in both studies.

A more common measure of inter-observer variability is the intra-class correlation coefficient (ICC), which assesses the observers’ reliability by comparing the variability of measurements by different observers on the same leg to the total variation across all observations and legs. In other words, in this study it is the proportion of total variability not accounted for by the variability among the legs. Our estimates were low, especially for single measurements, suggesting a low reliability. However, caution should be taken when interpreting these results because this study population (16 skeletally mature greyhounds) is not a true random representation of the general population in which the TPLO procedure is routinely performed. On the contrary, our population is considerably more homogeneous than the normal population for the procedure, resulting in low TPA variability among legs and consequently low ICCs and an underestimation of the likely reliability of observers in a normal population of dogs. Furthermore, our estimates of ICC have a low precision as indicated by the wide confidence intervals, which reflect the small sample size.

It is evident that such an overall comparison across the range of measured values fails to show a biologically relevant trend. After splitting the observations into two groups, and repeating the test separately for the two groups, anatomical and observed TPAs were significantly different for those legs with anatomical TPAs below the median (median difference = −3.8°; P = 0.04). The differences for the legs with TPAs above the median were not significant (median difference = +3°; P = 0.24), however, these comparisons have a very low power, involving only six legs per group. Prior to the study a power analysis was performed suggesting an appropriate sample size of 12, the subsequent division of the results into two groups reduced the reliability of the statistical analysis. Additionally, further canine cadaver studies with increased numbers of limbs from a variety of different breeds could aim to estimate observers’ errors more accurately.

The existence of a marked correlation between discrepancy and actual value has major implications in the assessment of observer TPA compared to anatomical TPA: first, the average or median difference (-0.64° and 0°) gives an unrealistically low estimate of the discrepancy, since deviations in one direction are compensated by deviations in the opposite direction. The mean and median absolute difference of 3° would be in this situation, a more appropriate summary of the magnitude of the discrepancy. Second, an overall test of significance will very likely fail to reject the null hypothesis of equality of the means or medians since, overall, the difference between the two groups of measurements is very small.

The standard method tends towards underestimation of higher angles and overestimation of the lower angles. Whilst marking points on radiographs, observers may subconsciously place marks in a position that avoids giving extreme values. The observers’ error was slightly higher at smaller anatomical angles than larger anatomical angles (median errors -3.8° and +3°, respectively). Across the range of measured angles, the median absolute discrepancy between the anatomical and observer TPA of 3° will result in a considerable variation in the rotation of the proximal tibia following osteotomy. This degree of variation could result in differences of ±1.25 mm rotation using the 24 mm blade and approximately ±1.5 mm rotation using the 30 mm blade.

Clinical significance
The observer TPA from lateral radiographs can be used as a guide to the degree of tibial plateau rotation required. However, measurement variability should be taken into consideration during preoperative planning of the TPLO procedure, because both over and under rotation of the tibial plateau can lead to complications and potentially poor clinical outcome (8).

One previous study (6) looked at the effect of limb positioning on TPA. Limb positioning can alter the TPA by as much as 3.6° when measured using conventional measurement techniques. It showed that the potential effects of this were minimized by ensuring that on the lateral radiographs the femoral condyles were not separated by more than 2.0 mm and the primary x-ray beam was centered on the stifle joint and collimated to include the hock joint. Hence, in our study special attention was paid to radiographic positioning. Further areas for study include the specific effects of stifle joint osteoarthritis on the measurement of the TPA from lateral radiographs.

These results suggest that in the normal stifle joint, measurements made by use of the conventional TPA method can accurately represent the slope of the tibial plateau. This would suggest that the conventional method for measuring TPA is suitable for the planning and assessment of TPLO procedures. However, it must be remembered that as the anatomical TPA moved away from a median angle (23.25°), in this population of greyhounds, the magnitude of error in the measurement increases. These measurements would not be influenced by subluxation of the stifle joint occurring with cranial cruciate ligament rupture, unlike that described in another study (2) which reported measurements based on identifying the femorotibial contact point.

References

Protocol for the positioning of animals for radiographs.

1. Radiographs

Lateral views of any part should be orientated with the cranial or rostral part to the viewer’s left. Ventrodorsal or dorsoventral images should be viewed with the left side on the reader’s right. Images of extremities should have the proximal portion of the limb at the top of the image. There is not a convention as to whether the lateral or medial aspect of the limb should be to the right or the left, but the orientation should be consistent within the manuscript.

2. Ultrasound

For abdominal imaging with the patient in dorsal recumbency sagittal images should be orientated with the ventral surface at the top of the image and the cranial aspect to the left. In the transverse plane the patient’s right side should be on the left of the image. If the transducer has been placed on the right side of the abdomen in a transverse plane ventral should be on the right of the image and dorsal on the left. For images obtained from the left side of the abdomen ventral should be on the left side of the image and dorsal on the right.

3. Echocardiographic images

These should be obtained in the recognised standard imaging planes and displayed in the same orientation (3)

4. Cross-sectional imaging

CT and MR images should be oriented in the following manner:
Head and spine:
Sagittal plane: cranial (rostral) at the top, dorsal at the top
Transverse plane: dorsal at top, left to the reader’s right
Dorsal plane: cranial (rostral) at the top, left to the reader’s right
Thorax and abdomen: images should be displayed as they were acquired.

References