Radiographic landmarks for measurement of cranial tibial subluxation in the canine cruciate ligament deficient stifle

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Keywords

Cranial cruciate ligament, radiograph, cranial tibial subluxation, stifle

Summary

Objectives: The primary objective was to develop a repeatable radiographic technique for assessment of cranial tibial subluxation (CTS) and test the intra-observer and inter-observer repeatability of the chosen landmarks. A secondary objective was to determine the effects of digital radiographic magnification on CTS measurement repeatability.
Methods: Twenty-three normal canine pelvic limbs were used to determine the magnitude of CTS before and after transection of the cranial cruciate ligament. Mediolateral radiographs were taken with and without fiduciary markers in place. Three investigators measured the CTS using radiographically visible anatomic landmarks at two different magnifications. The total observed variabilities were assessed by inter-observer and intra-observer differences. Paired t-tests were used to determine the effect of magnification and marker presence on CTS measures.
Results: Measurement of the CTS from the caudal margin of the intercondylar fossa on the femur to the intercondylar eminence was the most repeatable. Poor correlation between the anatomic landmarks and the fiduciary bone markers was observed. We found no effect of magnification or presence or absence of bone markers on measurement of CTS.
Clinical significance: Cranial tibial subluxation can be detected with the most repeatability by measuring between the caudal margin of the intercondylar fossa and the intercondylar eminence. Magnification of the digitized radiographic image had minimal effect on repeatability. This technique can be used for *in vivo* analysis of the canine cruciate ligament deficient stifle joint.

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Introduction

Rupture of the cranial cruciate ligament is one of the most commonly observed pelvic limb abnormalities in dogs (1–3). Osteoarthritis is thought to develop and progress secondary to cranial cruciate ligament rupture in part because of subsequent rotational and translational instability within the stifle joint (4–7). Treatment options include medical and surgical management (8). Current surgical techniques aim to eliminate cranial tibial subluxation (CTS) in an attempt to re-establish joint stability and slow progression of osteoarthritis (4, 9). There are many different surgical techniques used. Most commonly, these include extracapsular repair techniques that mimic the function of the cranial cruciate ligament, and tibial osteotomies that aim to neutralize forces present in the canine cruciate ligament deficient stifle (4, 9). A technique to reliably assess CTS radiographically, both preoperatively and postoperatively, could help to better understand the efficacy of these surgical techniques *in vivo*.

Forces present within the stifle are dynamic and depend on many factors including the degree of stifle flexion and amount of weight loading of the limb. Cranial tibial subluxation in relation to the femur results from an unopposed cranial force in the absence of the cranial cruciate ligament (10). *Ex vivo* experiments have examined the effect of various surgical techniques on CTS and stability of the cranial cruciate ligament deficient stifle joint (4, 11–14). However, *ex vivo* cadaveric studies may not closely mimic forces present within the live dog, and thus there is a need to develop a reliable technique for assessing CTS *in vivo*. In addition, internal rotation, occurring when rupture of the cranial cruciate ligament is present, may affect measurement of CTS.

Clinically, CTS is detected by use of the tibial compression test (7). Measurement of CTS for *in vivo* experimentation has been described by assessing the displacement of the caudal femoral condyles, or long digital extensor fossa, using a plane parallel to the tibial plateau, as well as the location of the origin and insertion of the cranial cruciate ligament (15–18). Precise measurement of CTS in clinical patients may be hampered by the presence of osteophytes in the region of radiographic landmarks. Previous *ex vivo* studies measuring CTS used invasive fiduciary bone markers in the femur and tibia (11, 19, 20). *In vivo,* this method would require surgical implantation of markers. Measurement of the distance between the origin and insertion of the cranial cruciate ligament (cranioproximal margin of the femoral condyles immediately caudal to the intercondylar notch to the cranial margin of the medial tibial condyle) using radiographic imaging may be one way to measure CTS *in vivo* as it has shown promising results *ex vivo* (15).

The overall goal of our research was to develop a repeatable radiographic technique for assessing CTS *in vivo.* To achieve this, the objectives were to determine radiographic landmarks present in dogs with osteoarthritis and then test the repeatability of these different radiographic anatomic landmarks for assessing CTS in a cadaver model. A secondary objective was to assess the effects of radio-opaque markers and digital radiographic magnification on the repeatability of the CTS measurement.

Materials and methods

Overview

To achieve the objectives, radiographs of clinical cases with cranial cruciate ligament ruptures and varying degrees of osteoarthritis were used to determine repeatedly visible landmarks for CTS measurement. Using a custom-made apparatus, CTS was induced and mediolateral radiographs were taken of cadaveric stifles. The stifles were fixed in the apparatus before and after transection of the cranial cruciate ligament, with and without fiduciary markers in place. Using the landmarks selected from the clinical cases with osteoarthritis, three investigators measured the distance between the femoral and tibial landmarks before and after transection of the cranial cruciate ligament. These measurements were performed at two levels of digitized magnification. The difference between the measurements was defined as CTS. Intra- and inter-observer variability was statistically calculated to determine the most repeatable landmarks for measurement of CTS. The effect of magnification on measurement of CTS was also statistically analysed.

Radiographic landmarks

Mediolateral stifle radiographs of ten randomly selected clinical cases, for which a diagnosis of cranial cruciate ligament rupture and varying degrees of osteoarthritis had been made previously, were used to determine anatomic landmarks for measurement of CTS. Radiographs were preoperative tibial plateau levelling osteotomy views, without rotation present. The cases were randomly selected from those that were presented to the Western College of Veterinary Medicine (University of Saskatchewan, Canada) between 2010–2011, and were analysed by two observers (RP, AS). The two femoral landmarks chosen were located at the most distal aspect of the cranial margin of the intercondylar fossa (CIF) at its cranial femoral border, and the most proximal aspect of the caudal margin of the intercondylar fossa (CaIF) at its caudal femoral border. The four tibial landmarks were located at the cranial aspect of the tibial plateau (CTP), the proximal aspect of the groove of the long digital extensor tendon (LDET) on the tibia, the medial caudal tibial plateau (CaTP), and the midpoint intercondylar eminence (IE) (▶Fig. 1). The relationship between each of the two femoral landmarks and the four respective tibial landmarks were used to evaluate CTS (▶Table 1).

Materials

A power study was performed, using previously determined measurements of CTS (16). From this it was determined that a minimum of 12 limbs should be used to avoid a type II error and detect a 2 mm difference in CTS (β = 0.1, α= 0.05). Twenty-three pelvic limbs were collected from 23 different medium to large breed dogs (body weight 22.83 ± 5.34 kg) which were euthanatized for reasons unrelated to this study. The limbs were sealed in plastic bags, frozen and stored at –20° Celsius until the study was performed. Prior to use, the limbs were thawed at room temperature. All soft tissues proximal to the patella were resected from the limbs, leaving the joint capsule intact. During the experiment the limbs were covered in saline soaked gauze sponges or kept moist by spraying tissues with isotonic saline solution.

In vitro biomechanical apparatus

To induce CTS, and mimic normal weight bearing, *ex vivo* limb loading of the stifle joint was performed as previously described (19, 20) (▶Fig. 2). A transverse femoral osteotomy was performed distal to the greater trochanter. The diaphysis of the femur was then fixed into a 10 cm long aluminium tube using five screws[a] (19). A transverse medial to

[a] 6 x 1¼ screws: Precision, Canadian Tire, Saskatoon, Canada

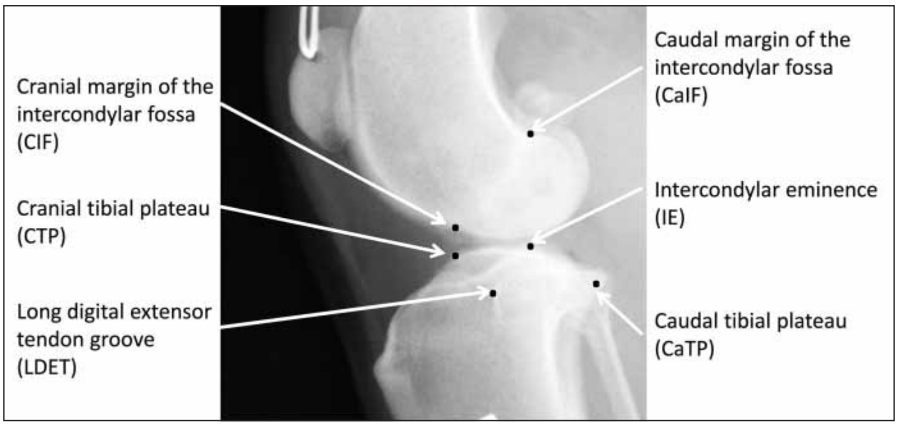

Fig. 1 Radiographic landmarks, on mediolateral projections, used for the measurement of cranial tibial subluxation (CTS). Two landmarks on the femur and four on the tibia were evaluated and used for eight different measurements of CTS.

Table 1 Abbreviations and landmarks for the eight cranial subluxation measurements using anatomic landmarks and fiduciary bone markers.

Cranial subluxation (CTS)	Femoral anatomic landmark	Tibial anatomic landmark
CIF-CTP	Cranial margin of the intercondylar fossa (CIF)	Cranial tibial plateau (CTP)
CIF-LDET	Cranial margin of the intercondylar fossa (CIF)	Groove of the long digital extensor tendon (LDET)
CIF-CaTP	Cranial margin of the intercondylar fossa (CIF)	Caudal tibial plateau (CaTP)
CIF-IE	Cranial margin of the intercondylar fossa (CIF)	Intercondylar eminence (IE)
CaIF-CTP	Caudal margin of the intercondylar fossa (CaIF)	Cranial tibial plateau (CTP)
CaIF-LDET	Caudal margin of the intercondylar fossa (CaIF)	Groove of the long digital extensor tendon (LDET)
CaIF-CaTP	Caudal margin of the intercondylar fossa (CaIF)	Caudal tibial plateau (CaTP)
CaIF-IE	Caudal margin of the intercondylar fossa (CaIF)	Intercondylar eminence (IE)

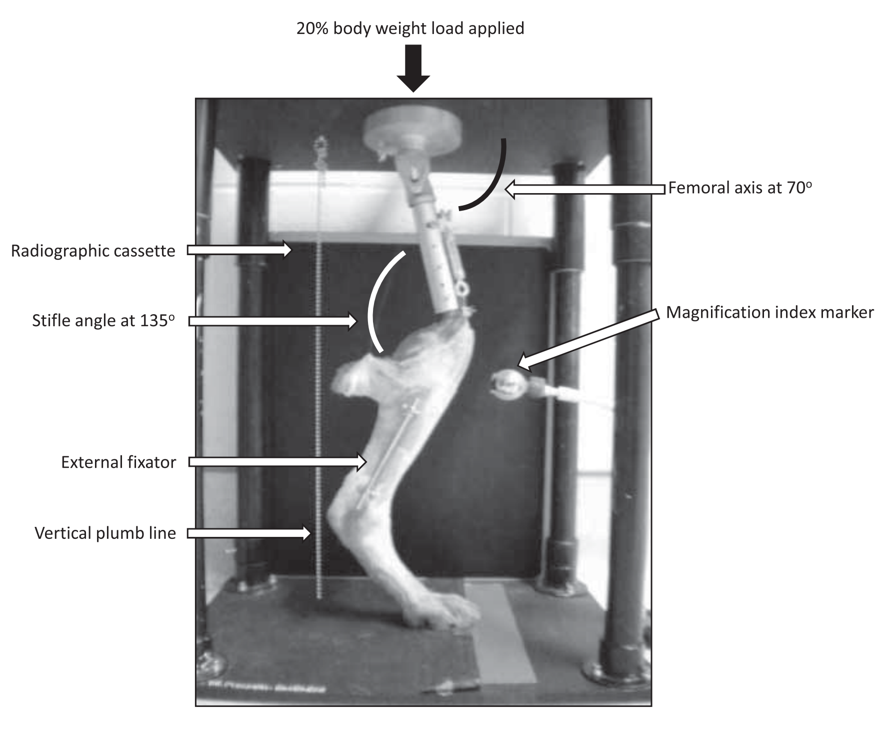

Fig. 2 Photograph of the custom-made limb-press testing apparatus used to apply the 20% body weight load to the canine cadaveric pelvic limb. The femoral longitudinal axis was 20° to the vertical reference plumb line. The quadriceps mechanism was simulated using a cable and turnbuckle extending from the patella to the aluminium tube and adjusted to fix the stifle angle at 135°.

lateral 2.5 mm diameter hole was drilled through the patella at its widest point and steel cable[b] was placed through the hole to form a loop using a compression sleeve[c]. The quadriceps mechanism was simulated using a cable and a turnbuckle extending from the loop of cable through the patella to the aluminium tube (19). A type I external fixator with two pins was applied to the medial aspect of the tibia to aide in measurement of the stifle angle during testing (19). The distal pin was placed approximately 3 cm proximal to the medial malleolus of the tibia and the proximal pin was placed approximately 4 cm distal to the level of the fibular head (19). Beginning distal to the patella, a 2.5 cm long craniomedial mini-arthrotomy was performed to provide exposure to the cranial cruciate ligament. The arthrotomy was performed by one investigator (RP), prior to any data collection, so that its effect on joint stability did not affect the results of the study. Stab incisions were made and holes were then drilled partially through the medial cortex in the distal femur and proximal tibia, just caudal to the origin and insertion of the medial collateral ligament, in preparation for placement of the fiduciary markers[d] during data collection (18). Following collection of data, dissection of this area was completed to ensure accuracy of hole placement.

Each limb was mounted into the custom-made limb-press testing apparatus (▶Fig. 2) with the femur rigidly held in place and the femoral longitudinal axis at 20° to the vertical reference plumb line (19). The turnbuckle was adjusted to fix the stifle angle at 135 ° using a goniometer (19). The stifle angle was measured by using the intersection between the connecting rod of the external fixator and a line that was parallel to the aluminium tube, centering the goniometer over the stifle joint (19).

Radiographs

A mediolateral radiographic view of each stifle was taken using a focal point-to-plate

[b] Braided steel cable: Buildex, Canadian Tire, Saskatoon, Canada
[c] 1/16 inch Aluminium Sleeve: KingChain, Canadian Tire, Saskatoon, Canada
[d] 12 Gauge Shotshell: Sportster, Co-op, Saskatoon, Canada

of 100 cm and exposure parameters (1.6–2.0 mAs, 58–64 kVp) standardized according to the measured width of the limb. All radiographic exposures included a spherical magnification index marker[e]. All exposures taken were collimated to include the entire tibia and tarsal joint as well as the distal aspect of the aluminium tube. The radiographic beam was perpendicular to the vertical plumb line and centered on the stifle joint. For uniformity, all radiographs were obtained by a single investigator (RP) and obliquity minimized by maintaining accurate radiographic superimposition of the femoral condyles. All radiographs were obtained using Agfa CR plates and a CR 30-X digitizer[f]. Radiographic images were viewed and measurements obtained using an open-source DICOM viewer[g] .

Experimental *in vitro* testing

A load equal to 20% of the body weight (BW), representative of the percent of body weight present on the stifle during stance, was applied to the limb and a mediolateral radiograph of the stifle was obtained (19) (▶Fig. 3). Radiopaque markers[d] were then placed using tissue glue into previously drilled holes in the distal femur and the proximal tibia. A second mediolateral radiograph was then taken. The limb was unloaded and the cranial cruciate ligament was transected sharply through the previously made arthrotomy. During unloading the femur was maintained within the aluminium tube and precise location of the paw on the base was maintained. The 20% BW load was reapplied to the limb and another mediolateral radiograph was taken. Without unloading the limb or modifying the joint angle, the radiopaque markers were removed. A final mediolateral radiograph was taken. After data collection, the limbs were dissected to confirm that the cranial cruciate ligament was completely transected. All manipulations were performed by one investigator to minimize variability.

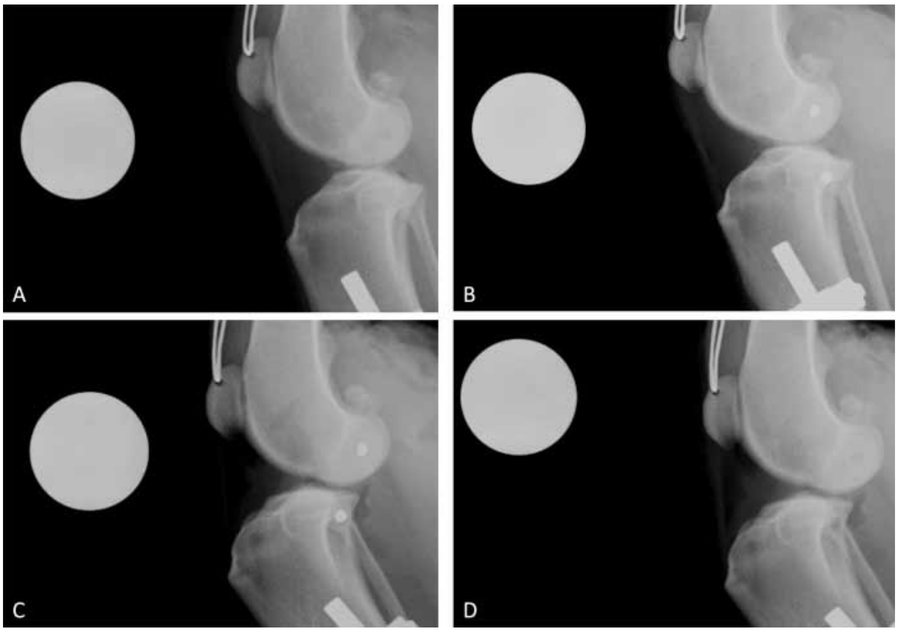

Fig. 3 Representative set of mediolateral radiographs of a canine cadaveric stifle joint before the cranial cruciate ligament (CCL) transection **(A)**, before CCL transection with fiduciary bone markers placed **(B)**, after CCL transection with fiduciary bone markers in place **(C)**, and after CCL transection without the fiduciary bone markers **(D)**.

Radiographic analysis and measurement

Measurement of CTS was performed by measuring the horizontal distance between the chosen anatomic landmarks (▶Table 1, ▶Fig. 1). These measurements were obtained by drawing lines that were made parallel to a vertical plumb line at the cranial aspect of each anatomic landmark or bone marker. The distance between the tibial and femoral anatomic landmarks and bone markers was determined in the intact cadaveric stifle and then subtracted from that obtained in the cranial cruciate ligament transected stifle to determine CTS (in millimetres) present for each cadaver (▶Fig. 4).

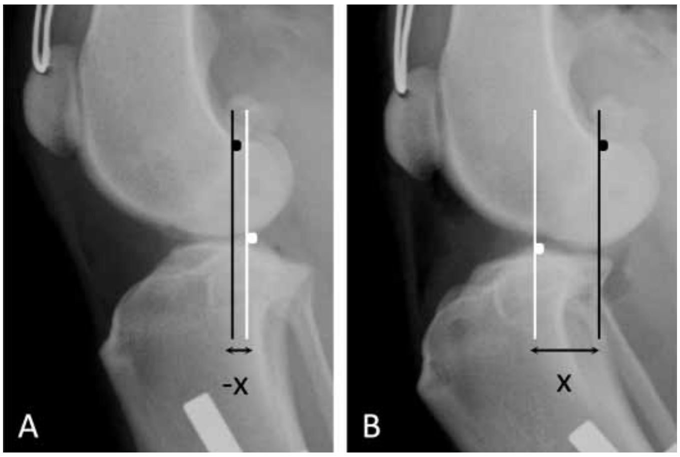

Fig. 4 An example of measurement of the distance between the caudal intercondylar fossa and the cranial tibial plateau (millimetres). Radiographs are of a canine cadaveric stifle joint before cranial cruciate ligament (CCL) transection **(A)**, and after CCL transection **(B)**. The cranial tibial subluxation measurement was obtained by subtracting the measurement in **(A)**, defined by (-x), from the measurement in **(B)**, defined by (x).

[e] Acukal: J2 Medical, Pittsburgh, PA, USA
[f] CR 30-X digitizer: DICOM Solutions, AGFA Healthcare, Etobicoke, Canada
[g] OsiriX Imaging Software, Advanced Open-Source PACS Workstation DICOM Viewer: Pixmeo, Geneva, Switzerland

Table 2 Intra-class correlation coefficients (ICC) and 95% confidence intervals (CI) for intra-observer variability for each set of cranial tibial subluxation (CTS) measurements. Anatomical and bonemarker measurements were performed for each cadaver. In total, eight mediolateral radiographs were read for each set of measurements and used to calculate CTS.

Observer	Statistical category	CIF-CTP	CIF-LDET	CIF-CaTP	CIF-IE	CaIF-CTP	CaIF-LDET	CaIF-CaTP	CaIF-IE	CTS bone-marker
1	ICC	0.825	0.851	0.889	0.863	0.931	0.908	0.924	0.909	0.992
	95% CI	0.715 - 0.936	0.754 - 0.947	0.815 - 0.963	0.774 - 0.953	0.884 - 0.979	0.845 - 0.970	0.872 - 0.976	0.847 - 0.971	0.984 - 0.999
2	ICC	0.781	0.780	0.432	0.736	0.879	0.887	0.851	0.849	0.992
	95% CI	0.648 - 0.915	0.642 - 0.918	0.194 - 0.670	0.581 - 0.890	0.799 - 0.959	0.810 - 0.865	0.754 - 0.948	0.751 - 0.947	0.985 - 0.999
3	ICC	0.888	0.832	0.704	0.844	0.802	0.847	0.914	0.853	0.974
	95% CI	0.814 - 0.963	0.725 - 0.939	0.537 - 0.872	0.744 - 0.945	0.679 - 0.925	0.747 - 0.946	0.855 - 0.973	0.757 - 0.948	0.951 - 0.997

Key: CIF = cranial margin of the intercondylar fossa; CaIF = Caudal margin of the intercondylar fossa; CTP = cranial tibial plateau; LDET = groove of the long digital extensor tendon; IE = intercondylar eminence; CTS = cranial tibial subluxation.

All radiographs were interpreted and measurements were obtained by three different investigators including a board-certified surgeon (PG), a board-certified radiologist (AS) and a small animal surgical resident (RP). Data were recorded using the Vet-Investigate program[h], an online data-entry program developed at Cornell University that allows the user to create custom surveys; multiple data-entry persons may be blinded to different portions of the survey. All data were displayed in a data table that may be exported for statistical analysis using commercially available software.

Images were randomized using unique random identification numbers and investigators were blinded as to the cadaver number and status of the cranial cruciate ligament. Each set of four radiographs (cranial cruciate ligament intact, intact with fiduciary marker, cranial cruciate ligament transected with fiduciary marker, and cranial cruciate ligament transected without fiduciary marker) was measured for the distance between radiographically identifiable landmarks and bone markers on the femur and tibia, at each level of magnification (life size and 2.7 times life size). At the same time, measurements of the magnification index marker[e] were obtained to ensure reliability.

Statistical analysis

A statistical software package[i] was used to perform all statistical analysis. All data were visually inspected for normality using stem and leaf plots, comparison of medians, means, and quartile plots. The Shapiro-Wilk test was used to assess normality.

Intra- and inter-observer variability was analysed between the three observers (RP, AS, PG). Data were pooled for statistical analysis after determining statistically that this had no effect on the outcomes of the analysis. Cranial tibial subluxation measurements for each reader were compared using an intraclass correlation coefficient. Inter-observer agreement of CTS measurements was assessed by calculation of the intraclass correlation coefficients for the three observers, and construction of Bland-Altman plots with 95% limits of agreement (21). The 95% confidence intervals were used to determine differences in all analyses.

The Pearson correlation coefficient and concordance correlation coefficient was used to assess the relationship between each set of CTS measurements and the CTS measured with bone markers. The Pearson correlation coefficient was used to determine the degree to which one set of results varied with a second set but did not directly compare the values obtained (22). The concordance correlation coefficient was used to compare two sets of results, and it reflected the agreements and accuracy between the two sets of results (22).

Since each set of radiographs was taken with and without the bone markers in place, each set of anatomic CTS measurements were compared using a paired t-test to determine if the presence or absence of the fiduciary marker on the radiographs was a bias during measurement. A paired t-test was used to determine the significance of the two different magnifications on measurement of CTS. For all tests, an α level less than five percent ($p < 0.05$) was considered statistically significant.

Results

Measurement of cranial tibial subluxation

Twenty of the 23 cadaveric stifles were used. Two were excluded due to the cable failure during experimentation, and a third due to loosening of an external fixator pin in the tibia. Additionally, while measuring the CTS, one reader could not identify the LDET landmark clearly in one dog so values for this landmark for that specimen were not reported.

[h] Vet Investigate: https://secure.vet.cornell.edu/vi/, Cornell, NY, USA

[i] Stata[tm] 10.0: StatCorp, College Station, USA

Table 3 Intraclass correlation coefficients and 95% confidence intervals for inter-observer variability for each set of cranial tibial subluxation measurements.

	CIF-CTP	CIF-LDET	CIF-CaTP	CIF-IE	CaIF-CTP	CaIF-LDET	CaIF-CaTP	CaIF-IE	CTS bone marker
Interclass correlation	0.780	0.800	0.508	0.804	0.887	0.803	0.872	0.943	0.903
95% Confidence interval	0.636-0.925	0.665-0.935	0.253-0.764	0.672-0.936	0.806-0.968	0.670-0.936	0.782-0.962	0.901-0.985	0.833-0.973

Key: CIF = cranial margin of the intercondylar fossa; CaIF = Caudal margin of the intercondylar fossa; CTP = cranial tibial plateau; LDET = groove of the long digital extensor tendon; IE = intercondylar eminence; CTS = cranial tibial subluxation.

Intra-observer variation

The intraclass correlation coefficients and 95% confidence intervals showed the most intra-observer variability for CIF-CTP, CIF-LDET, CIF-CaTP and CIF-IE (▶Table 2). There was a trend for the least intra-observer variability in CaIF-CTP, CaIF-LDET, CaIF-CaTP and CaIF-IE. The intra-observer variability of the fiduciary markers was low (intraclass correlation between 0.92–0.974).

Inter-observer variation

Intraclass correlation coefficients and 95% confidence intervals were determined for each set of CTS measurements (▶Table 3). The CIF-CaTP showed a trend towards the most inter-observer variability (intraclass correlation 0.508), whereas the CaIF-IE showed a trend towards the least inter-observer variability (intraclass correlation 0.943). The CaIF-CTP and CaIF-CaTP also had minimal inter-observer variability (▶Table 3). As expected, the inter-observer variability of CTS as determined by the fiduciary marker measurement was small. The 95% limits of agreement for each observer were within 1.5 mm for CaIF-IE (▶Fig. 5) and 2.6 mm for CaIF-CTP (▶Fig. 6).

Correlation between cranial tibial subluxation measurements

All anatomic CTS measurements were compared to each other and the CTS bone marker measurement by the Pearson correlation coefficient (▶Table 4). The CaIF-CTP was correlated best with the CTS bonemarker (0.52). The values for CIF-CTP and CaIF-IE correlated second and third best (0.46 and 0.44 respectively). The strongest correlations were between CIF-CTP and CaIF-CTP (0.85), CIF-LDET and CaIF-LDET (0.83), CIF-IE and CaIF-IE (0.83) CaIF-CTP and CaIF-IE (0.81) and CaIF-CaTP and CaIF-IE (0.81). Concordance correlation coefficients were performed for all anatomic CTS measurements in comparison to the CTS bone marker measurement and in comparison to each other (▶Table 5). The strongest concordance correlations were: CIF-CTP and CaIF-CTP (0.82), CaIF-LDET and CaIF-LDET (0.82), and CaIF-IE and CaIF-LDET (0.94).

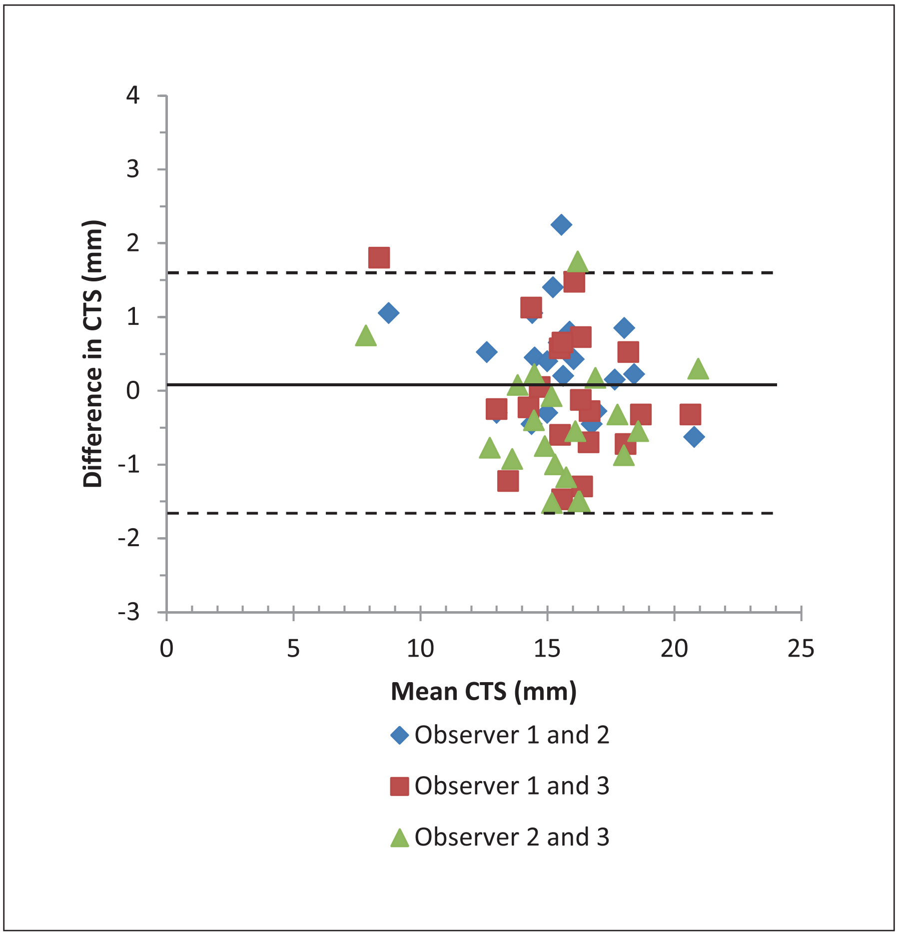

Fig. 5 Bland-Altman plot of differences between the mean CaIF-IE (caudal margin of the intercondylar fossa - intercondylar eminence), as measured by three independent observers. In total, each observer measured 20 stifle joints. Dashed lines represent 95% limits of agreement. CTS = cranial tibial subluxation.

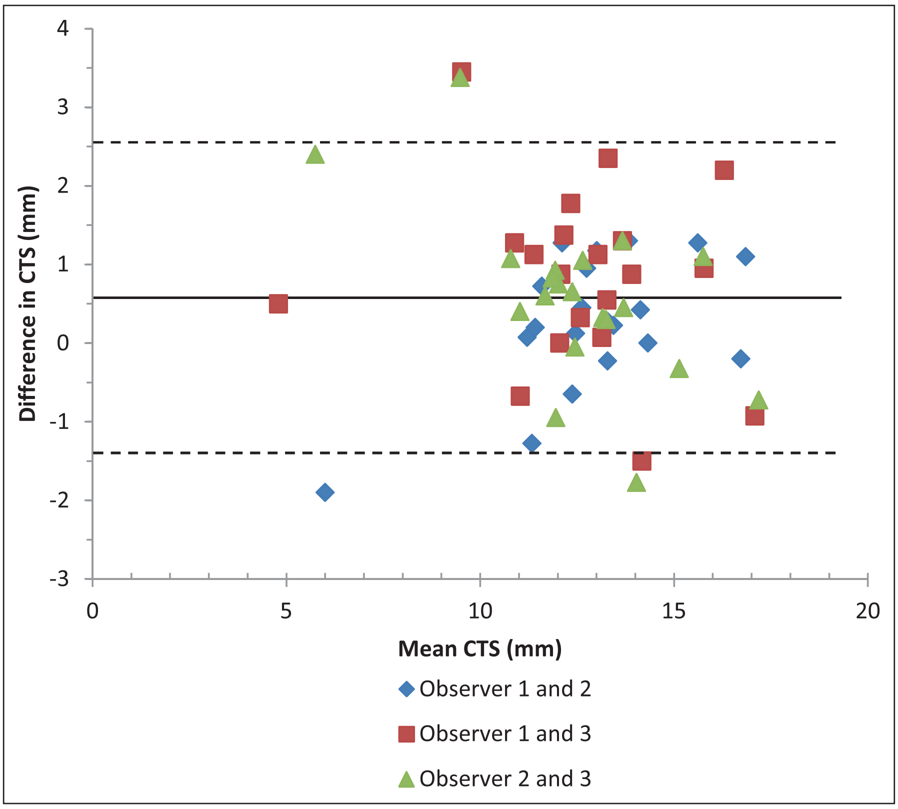

Fig. 6 Bland-Altman plot of differences between the mean CaIF-CTP (caudal margin of the intercondylar fossa - cranial tibial plateau), as measured by three independent observers. In total, each observer measured 20 stifle joints. Dashed lines represent 95% limits of agreement. CTS = cranial tibial subluxation.

Effect of magnification and presence of bone markers on measurements

Each set of measurements at both magnifications was compared before and after calculation of CTS. There was not a significant difference in identification of the landmarks at life size and 2.7 times magnification (p-value between 0.28 and 0.79). There was no significant difference found when comparing the measurements with and without the fiduciary marker (p-value between 0.34 and 0.97).

Discussion

In our study, a total of eight anatomic CTS measurements were examined. Three different observers, with various levels of experience, measured CTS on the radiographic images. The caudal margin of the intercondylar fossa to the intercondylar eminence was the most reliable anatomic measurement of CTS based on intra- and inter-observer variability (inter-observer intraclass correlation of 94.3%). Cranial tibial subluxation measurements using the caudal margin of the intercondylar fossa, to either the cranial tibial plateau or the caudal tibial plateau, were the second most reliable based on intra- and inter-observer variability. This is in agreement with Kim et al. who found an intraclass correlation coefficient of 85.9% for measurement of the cranial margin of the medial tibial condyle to a point immediately caudal to the roof of the intercondylar notch (15). Thus, measurement of CTS using the caudal margin of the intercondylar fossa to the intercondylar eminence was superior to these previously described anatomic landmarks based on this study. However, the effects of stifle flexion on CTS measurement using these landmarks was not evaluated in this study. This high reliability is important for potential use of the anatomic landmarks

Table 4 Pearson correlation coefficients for comparison of anatomical measurements and bone marker cranial tibial subluxation measurements.

	CIF-CTP	CIF-LDET	CIF-CaTP	CIF-IE	CaIF-CTP	CaIF-LDET	CaIF-CaTP	CaIF-IE	CTS bone marker
CIF-CTP	1.00	---	---	---	---	---	---	---	---
CIF-LDET	0.61	1.00	---	---	---	---	---	---	---
CIF-CaTP	0.56	0.48	1.00	---	---	---	---	---	---
CIF-IE	0.68	0.55	0.42	1.00	---	---	---	---	---
CaIF-CTP	0.85	0.51	0.43	0.66	1.00	---	---	---	---
CaIF-LDET	0.66	0.83	0.47	0.60	0.70	1.00	---	---	---
CaIF-CaTP	0.72	0.62	0.60	0.63	0.79	0.77	1.00	---	---
CaIF-IE	0.73	0.62	0.46	0.83	0.81	0.76	0.81	1.00	---
CTS bone marker	0.46	0.10	0.36	0.35	0.52	0.28	0.40	0.44	1.00

Key: CIF = cranial margin of the intercondylar fossa; CaIF = Caudal margin of the intercondylar fossa; CTP = cranial tibial plateau; LDET = groove of the long digital extensor tendon; IE = intercondylar eminence; CTS = cranial tibial subluxation.

Table 5 Concordance correlation coefficients for comparison of anatomic and bone marker cranial tibial subluxation measurements.

	CIF-CTP	CIF-LDET	CIF-CaTP	CIF-IE	CaIF-CTP	CaIF-LDET	CaIF-CaTP	CaIF-IE	CTS bone marker
CIF-CTP	1.00	---	---	---	---	---	---	---	---
CIF-LDET	0.38	1.00	---	---	---	---	---	---	---
CIF-CaTP	0.52	0.39	1.00	---	---	---	---	---	---
CIF-IE	0.36	0.53	0.30	1.00	---	---	---	---	---
CaIF-CTP	0.82	0.34	0.41	0.39	1.00	---	---	---	---
CaIF-LDET	0.45	0.82	0.41	0.94	0.53	1.00	---	---	---
CaIF-CaTP	0.67	0.50	0.60	0.45	0.75	0.67	1.00	---	---
CaIF-IE	0.41	0.60	0.34	0.83	0.50	0.74	0.60	1.00	---
CTS bone marker	0.21	0.03	0.15	0.07	0.24	0.08	0.15	0.10	1.00

Key: CIF = cranial margin of the intercondylar fossa; CaIF = Caudal margin of the intercondylar fossa; CTP = cranial tibial plateau; LDET = groove of the long digital extensor tendon; IE = intercondylar eminence; CTS = cranial tibial subluxation.

for further investigation of CTS in living dogs without the need for invasive surgical placement of fiduciary markers. With this information, further understanding of the canine cranial cruciate ligament deficient stifle and evaluation of the efficacy of various treatment modalities will be possible.

This study showed that measurement of CTS using radiographic anatomical landmarks is not influenced by magnification of the digital images. The ability to easily magnify digital radiographic images is used repeatedly during analysis and measurements on radiographs. Based on the CTS measurements in this study, no difference was observed between the two magnifications. This is important for the radiographic reader who either does not have magnification capabilities, or has performed a portion of the study interpretation at either magnified or life size.

There was poor correlation between the CTS fiduciary markers and CTS anatomic landmark measurements. Fiduciary markers are commonly used for determination of the CTS in cadaveric models by measuring the distance between markers on the tibia and femur and then comparing the measurement to that obtained in the cranial cruciate ligament intact stifle (11). In this study, the bone markers were placed as previously described (19). The poor correlation observed between the fiduciary marker CTS measurements and the anatomic landmark CTS measurement may be due to marker placement, limb rotation, and scanning orientation. First, slight variation was present in the placement of the bone markers based on location of the anatomical collateral ligament location. This may partially explain the poor correlations, but inter- and intra-observer variability of the measurement of the bone marker was minimal. Second, cranial cruciate ligament rupture results in both cranial and proximal translation as well as internal limb rotation due to the anatomy of the tibial plateau slope (caudodistal orientation) and alterations in periarticular soft tissue constraints of the stifle (23). Depending on the axis of craniocaudal rotation of the tibial plateau during CTS (which will change depending on the anatomic location along the femur or tibia), the measurement of CTS could differ between the anatomic landmarks and the fiduciary markers. This may be particularly true for landmarks or fiduciary markers located away from the joint centre, making comparisons of correlations difficult between the various anatomic landmarks and fiduciary markers. Retrospectively, the bone markers could have been placed individually at each of the anatomic landmarks, and the CTS measurements compared individually to determine which of the landmarks was the most repeatable. While theoretically possible, placement of bone markers at these locations would have involved more invasive manipulations and created movement of the joint during experimentation. Despite this, repeatability was determined for the anatomic landmarks, showing that the measurement of CaIF-IE was the most reliable anatomic landmark based on intra- and inter-observer variability. These results provide a reliable set of anatomic landmarks for measurement of CTS, however the accuracy of the measurement of CTS needs to be assessed. Additionally, radiographs (two-dimensional imaging) may not be able to provide precise measurements of CTS (15). It is probable that axial rotation of the tibia can shift the orientation of landmarks. Normally, the cranial cruciate ligament restricts internal rotation of the tibia to 19 degrees, but when the ligament is transected, this can increase to 45 degrees if the stifle is maintained at a 90 degree angle (7, 24). Axial rotation would affect the radiographic measurement of anatomic landmarks or fiduciary markers located away from the joint, potentially resulting in different amounts of CTS depending on location away from the joint centre. Since the anatomic landmarks and fiduciary markers are located variable distances from the centre of axial rotation, CTS measured values will be proportionately different. Third, obliquity of the radiographs may make measurement of landmarks less precise as well as change the amount of CTS observed. Limb positioning has been shown to influence the radiographic appearance of the tibial plateau and have effects on other measurements such as the tibial plateau angle (25). However, in this study, limbs were positioned as accurately as possible and fixed in place by the same investigator to reduce variation and minimize obliquity. Unloading of the limb, which could also be a source of rotation confounding the CTS measurement, was also performed by one investigator thereby minimizing variability.

This study has limitations related to the sample population and method used to assess intra-observer variability. First, cadavers used in this study did not have radiographically visible osteoarthritic changes of the stifle joint. However, landmarks used in the study were determined based on reliably visible anatomic landmarks on the series of ten radiographs of clinical cases with varying degrees of osteoarthritis. It has been suggested that the location and degree of osteoarthritis could possibly obscure anatomic landmarks in some dogs (26, 27). Additionally, osteoarthritis may affect the degree of stifle laxity and amount of CTS present (15). It is also possible that the amount of CTS present is affected by the chronicity of the cranial cruciate ligament rupture and amount of osteoarthritis present. Thus, reliability of the chosen landmarks may change in cases with small measurements of CTS and variable degrees of osteoarthritis. Second, intra-observer variability was determined by comparing the CTS measurements with different imaging scenarios (i.e. CTS measured using a magnified image against CTS measured using a life size image). This approach differs from traditional approaches that use the same images, but were assessed at different time points. It is possible that the magnification effects or the presence of the bone marker may have affected intra-observer variation. However, given that there were no significant differences in identification of the landmarks at life size and 2.7 times magnification, or with and without the fiduciary markers, the authors believe this approach is justified.

The proposed reliable radiographic anatomic landmarks for reproducible measurement of CTS have many clinical uses. Cranial tibial subluxation could be measured to evaluate the efficacy of various surgical repair methods for canine cranial cruciate ligament disease. As well, CTS measurements could be used to evaluate non-surgical cranial cruciate ligament treatment options such as orthotic devices. These landmarks will need to be evaluated in clinical cases with varying degrees of osteoarthritis to determine the visibility and reliability of measurements. Three-dimensional evaluation of CTS measurements may also improve understanding and potential two-dimensional accuracy of CTS in the cranial cruciate ligament deficient stifle.

In conclusion, based on inter- and intra-observer variability, CTS in the normal non-osteoarthritic stifle joint can be quantified with the most reliability by measuring from the caudal aspect of the intercondylar fossa on the femur to the intercondylar eminence on the tibia. Cranial tibial subluxation is secondarily most reliable when measuring from the caudal aspect of the intercondylar fossa to the cranial tibial or caudal tibial plateau respectively. Magnification does not appear to affect reliability of the measurement of CTS obtained.

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Conflict of Interest

None declared.

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