

# Use of Blumensaat's line for assessment of cranial tibial subluxation in dogs with cranial cruciate ligament deficiency

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## Abstract

**Background:** This study aimed to determine whether Blumensaat's line, a consistently present radiographic feature delineating the peak of the femoral intercondylar fossa, could be used to assess for cranial tibial subluxation in canine stifles with cranial cruciate ligament disease.

**Methods:** Thirty sequential, neutrally positioned, standing-angle stifle radiographs were taken from dogs presenting to a specialist referral centre for treatment of cruciate ligament disease. Thirty similarly positioned radiographs of healthy canine stifles were used as a control group. The radiographs were anonymised and submitted to blinded observers for measurement of the tibial plateau angle, patella tendon angle, Blumensaat's line length and the length of Blumensaat's line cranial to the tibial mechanical axis.

**Results:** Finding that the tibial mechanical axis intersects Blumensaat's line cranial to its midpoint, as a marker of cranial tibial subluxation, had a positive predictive value of 76% for subsequent surgical identification of cruciate ligament disease.

**Conclusions:** Tibial cranial subluxation is detectable and quantifiable radiographically using the intersection of the tibial mechanical axis and Blumensaat's line. Once quantified, this measurement could be used both as a radiographic marker of cruciate ligament disease and to adjust tibial osteotomy procedures to minimise the risk of under advancement of the tibial tuberosity resulting in a persistently unstable stifle.

## INTRODUCTION

Canine cruciate ligament (CCL) disease is a common cause of pelvic limb lameness in dogs, and is significant both economically and with respect to canine welfare.<sup>1,2</sup> Following failure of the cranial cruciate ligament, degenerative joint disease develops rapidly and progresses, at least in some part, due to the instability of the stifle joint to rotational and translational forces.<sup>3,4</sup> Surgical treatment is commonly recommended in canine patients with CCL rupture, and has been shown to provide a better chance of a successful outcome compared to conservative management in most patient groups, particularly larger dogs.<sup>5</sup> A variety of surgical treatment options exist for treating

these patients including both intra- and extracapsular stabilisation and tibial osteotomy techniques. Tibial tuberosity advancement (TTA) and triple tibial osteotomy (TTO) are examples of osteotomy techniques that aim to alter the angle between the patella tendon and the tibial plateau to 90° to neutralise the femorotibial cranial shear force that exists in the absence of a functional CCL.<sup>6–8</sup>

Both these procedures rely on accurate preoperative assessment of the patella tendon angle (PTA) relative to the tibial plateau. However, the degree of correction suggested by these assessments can be affected by a number of factors including the method of assessment used and the radiographic positioning of the stifle.<sup>9</sup> Herein lies the clinical conundrum, as

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cranial cruciate ligament insufficiency is both the reason for surgical intervention, and, where cranial tibial subluxation is present, this will undoubtedly lead to an alteration of the assessed PTA and hence failure of accurate planning for that surgical intervention. If the PTA calculated is underestimated, then the associated correction is also likely to be underestimated. Under advancement of the tibial tuberosity is common, potentially resulting in suboptimal clinical outcome due to ongoing instability generated by femorotibial cranial shear force, highlighting the need for a mathematical correction for surgical planning inaccuracies.<sup>10,11</sup>

Damage to the medial meniscus is a common sequelae to cruciate ligament failure in the canine stifle, with up to 70% of cruciate deficient stifles reported to have a medial meniscal tear.<sup>12</sup> Meniscal tears can also occur, and/or be identified, subsequent to CCL surgery as a late meniscal injury.<sup>13,14</sup> These tears may have been present at the time of surgery as latent or hidden meniscal injuries or they may have occurred at some time after the surgery, due to residual instability, and be postliminary tears.<sup>15</sup> Late meniscal tears are the most common cause for surgical revision.<sup>16,17</sup> Correct assessment of the PTA leading to an appropriate advancement and subsequent neutralisation of cranial femorotibial shear force is therefore of critical importance in planning these procedures, as under advancement of the tibial tuberosity has been associated with persistent tibial thrust and postoperative meniscal tears.<sup>17,18</sup>

Blumensaat's line is a consistently visible radiographic feature, used for morphological assessment in human cruciate ligament surgery, and delineates the peak of the femoral intercondylar fossa on a mediolateral radiograph of the stifle.<sup>19</sup> A previous study has shown that the PTA measured from a stifle radiograph is significantly affected by the degree of flexion of the stifle from the positioning of the patient.<sup>9</sup> Following from this observation, a precursor to this study showed that Blumensaat's line was also a consistent feature in normal canine stifles and could be used to indirectly assess femoral alignment and hence aid measurement of stifle flexion angle, which can then be used to correct calculated PTAs and improve the presurgical planning for TTA and TTO procedures.<sup>20</sup> During this study, in which healthy canine stifle joints were radiographed, the authors proposed that the line corresponding to the tibial mechanical axis perfectly bisected Blumensaat's line.

The main aim of the current study was to assess whether the tibial mechanical axis intersecting Blumensaat's line at a point cranial to its midpoint is a consistent finding in cruciate deficient stifles. Secondly, if cranial tibial subluxation can be quantified, then a mathematical correction for the degree of subluxation could be proposed for surgical planning for TTA and TTO procedures.

Our hypothesis was that the tibial mechanical axis intersecting Blumensaat's line at a point cranial to its midpoint would correlate with findings of partial or complete cranial cruciate ligament failure at surgery.

## METHODS

Power calculations were performed, based on a  $p$ -value of 0.05 with projected incidence of radiographically detectable cranial tibial subluxations of 40%–80% and a  $\beta$  value of 0.1. These gave required sample sizes of between 8 and 28 stifles (Microsoft Excel, Redmond, WA, USA). A previous cadaveric study looking at cranial tibial subluxation in cruciate deficient stifles performed power calculations that produced a required sample size of 12.<sup>21</sup>

Neutrally positioned mediolateral stifle radiographs were taken for 30 sequentially presenting dogs undergoing surgical treatment planning for cranial cruciate ligament disease at a single referral hospital. Radiographs were positioned and taken by an experienced radiographer using a previously documented, repeatable technique, which has been advocated for TTO surgical planning.<sup>20</sup> Radiographs were rejected if there was more than a 2 mm imperfect superimposition of the femoral condyles. Patients were excluded if they were subsequently found at surgery not to have partial or complete cruciate ligament failure. In addition to signalment, data collected and recorded at surgery from these cases included whether the CCL appeared torn grossly, what proportion of the CCL appeared torn (0%–24%, 25%–49%, 50%–74%, 75%–99% or 100%) and whether a meniscal tear was present. Data from a previous study population in which the authors radiographed healthy dogs' stifles were used as a control group.<sup>20</sup>

Thirty cases were randomly selected from the historic, healthy stifle control group by assigning case numbers and using a random list generator ([www.random.org/lists](http://www.random.org/lists)). All radiographs were then randomised and anonymised of all signalment information and submitted to blinded observers in a DICOM format for digital assessments. Radiographic measurements were made using commercial software (Horos, Annapolis, MD, USA/Osiris, Geneva, Switzerland). The observers, who were blinded from the final purpose of the study, consisted of an intern in small animal orthopaedics (Lida Pappa), a European College of Veterinary Surgeons (ECVS) final-year resident (Pablo Pérez López) and an ECVS specialist in small animal surgery (Robert Quinn). Observers were asked to measure TPA, PTA, Blumensaat's line length and the length of Blumensaat's line cranial to the tibial mechanical axis.

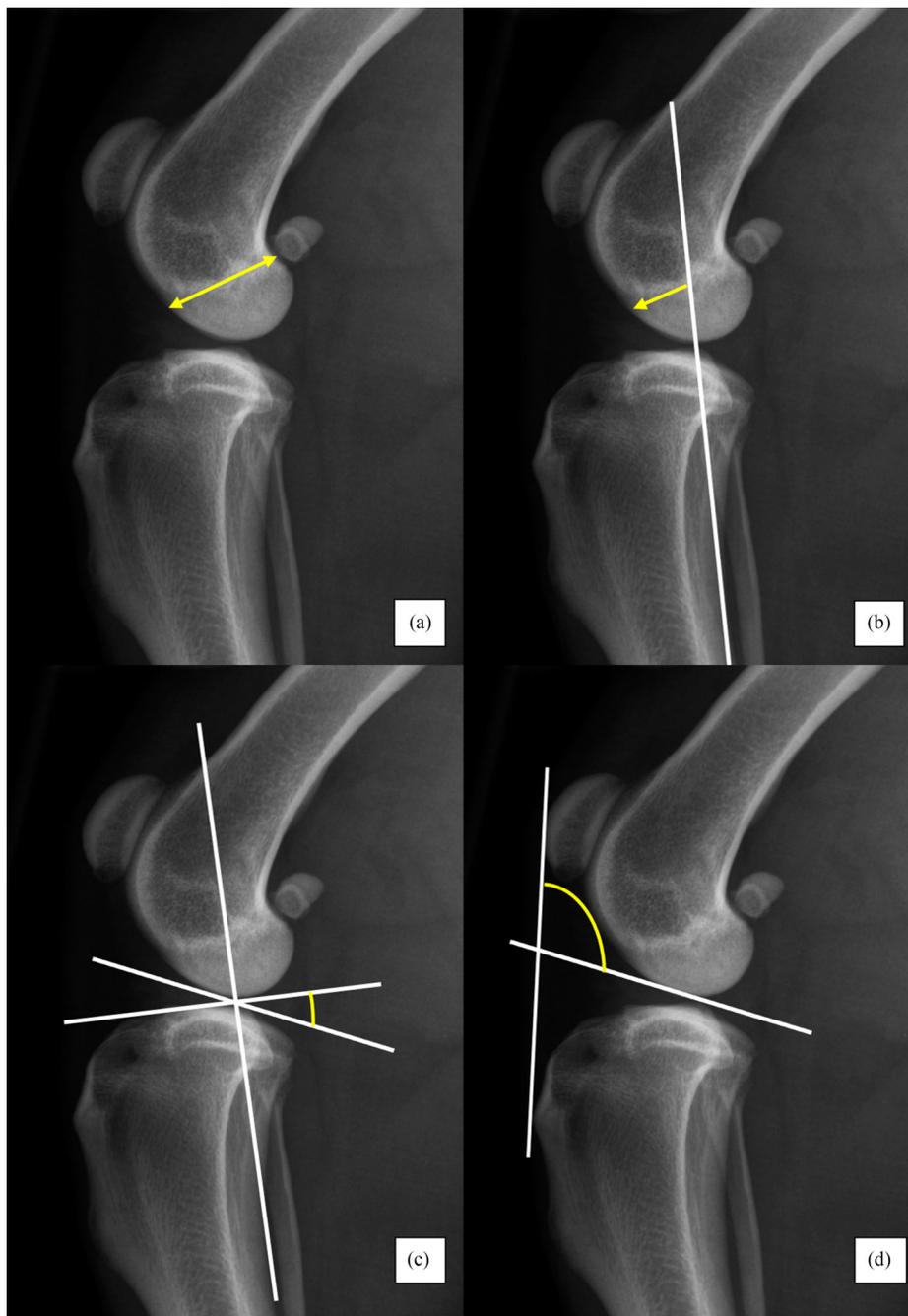
The following definitions and images (Figure 1) were supplied to the blinded observers:

*Blumensaat's line* (Figure 1a) is the line which can be seen across the femoral condyle, illustrating the peak of the intercondylar fossa.

*Mechanical axis of the tibia* (Figure 1b) is a line through the centre of the intercondylar eminence on the tibial plateau and the centre of the tibiotarsal joint.

*Tibial plateau angle* (Figure 1c) is the angle between a line perpendicular to the tibial mechanical axis and the medial tibial plateau.

*Patella tendon angle* (tibial plateau method) (Figure 1d) is the angle between the medial tibial



**FIGURE 1** Images demonstrating measurements requested (yellow) from the blinded observers. (a) Blumensaat's line—a consistently visible radiographic feature, extending from the cranial most to the caudal most margin of the femoral condyles, delineating, at the region of maximal opacity, the peak of the femoral intercondylar fossa. (b) Distance of Blumensaat's line cranial to a line continuous with the tibial mechanical axis. (c) Tibial plateau angle. (d) Patella tendon angle, tibial plateau method. The angle between the medial tibial plateau line; a line intersecting the cranial and caudal borders of the medial tibial plateau, and a line along patella ligament from the tibial crest to the most cranial distal extent of the patella

plateau line and a line along patella tendon from the tibial crest to the most cranial distal extent of the patella.

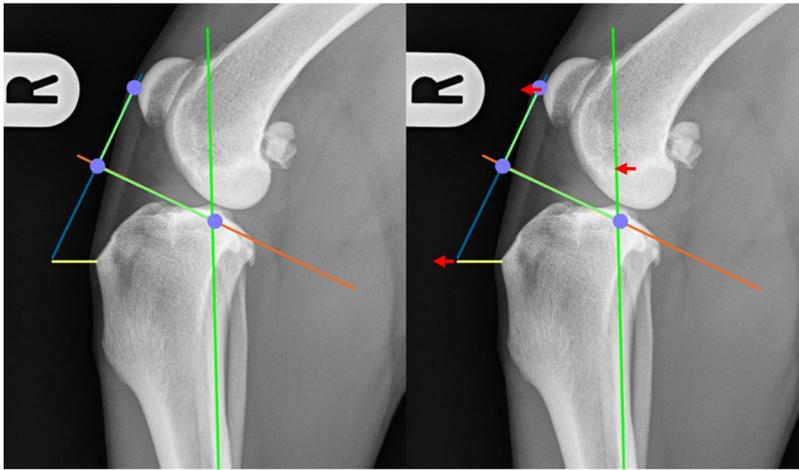
Two of the blinded observers, the ECVS specialist and the final-year ECVS resident, additionally measured the angle between Blumensaat's line and the mechanical axis of the tibia. These measurements were used to compare mean estimated stifle angles between the groups according to a previously published method (Table 1).<sup>20</sup>

Following initial analysis by the blinded observers, radiographs of stifles found at surgery to have par-

**TABLE 1** Estimated stifle angles in the healthy stifles and cruciate deficient stifles groups

	Estimated stifle angle
Healthy stifles	124.5 ± 15.8
Cruciate deficient stifles	119.8 ± 14.1

tial or complete failure of the cranial cruciate ligament were assessed by one of the authors (Sebastian Prior) and planned for TTA surgery as described previously.<sup>16</sup> TTA surgery was planned for each stifle before and



**FIGURE 2** A proposed tibial tuberosity advancement procedure in a canine cruciate ligament deficient stifle with (right) and without (left) adjustment based on the tibial cranial subluxation demonstrated by assessment of the bisection of Blumensaat's line by the tibial mechanical axis. The proposed advancement is increased by the distance between the midpoint of Blumensaat's line and the point at which a line continuous with the tibial mechanical axis bisects Blumensaat's line (red arrow)

**TABLE 2** Four-cell matrix used to calculate sensitivity, specificity, positive and negative predictive values

	CCL failure	Healthy stifle	
Blumensaat's line cranial to the tibial mechanical axis	True positive ( <i>A</i> )	False positive ( <i>B</i> )	Positive predictive value = $A/(A + B) \times 100$
Blumensaat's line not cranial to the tibial mechanical axis	False negative ( <i>C</i> )	True negative ( <i>D</i> )	Negative predictive value = $D/(C + D) \times 100$
	Sensitivity = $A/(A + C) \times 100$	Specificity = $D/(B + D) \times 100$	

Abbreviation: CCL, canine cruciate ligament.

after adjustment for tibial cranial subluxation based on the cranial intersection of Blumensaat's line by the tibial mechanical axis (Figure 2). The adjustment was made by extending the advancement by the distance from the midpoint of Blumensaat's line to the intersection of Blumensaat's line and the tibial mechanical axis.

Data were recorded and returned using commercial spreadsheet software (Microsoft Excel) and subsequently analysed using both spreadsheet and statistical analysis software (Microsoft Excel) (IBM Corp. IBM SPSS Statistics, Version 27.0, Armonk, NY, USA).

## Statistical analysis

The data for weight, age, TPA, PTA and Blumensaat's line length (all observers) were assessed for normality with a Shapiro–Wilk test for both the affected stifles and healthy stifles groups. The age and weight data from both groups were compared using the independent samples Kruskal–Wallis test. The mean estimated stifle angles in the healthy stifles and cruciate deficient stifles groups were compared using a two-tailed *t*-test. The percentage of Blumensaat's line found to be cranial to an extension of the tibial mechanical axis in the healthy stifles and cruciate deficient stifles groups were compared using an unpaired two-tailed *t*-test. The interobserver reliability was assessed using limits of agreement of mean difference in measurement, standard error mean and linear regression. The positive predictive value of using cranial intersection of Blumensaat's line by the tibial mechanical axis was calculated as previously described using a four-cell matrix (Table 2).<sup>22</sup>

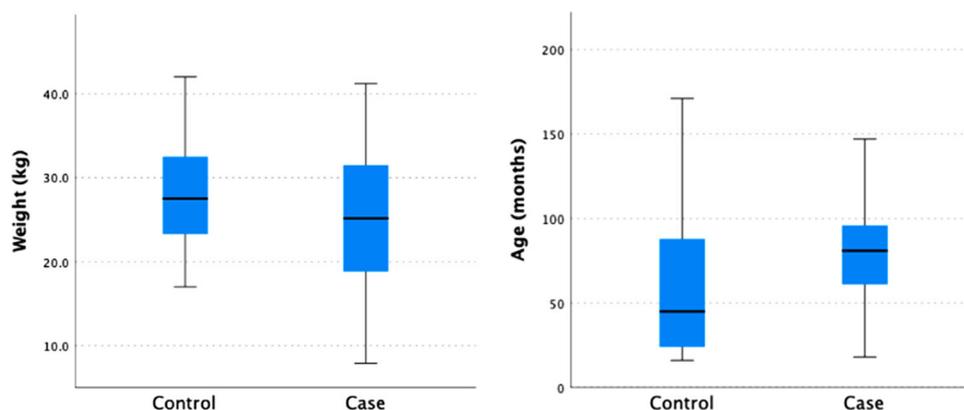
## RESULTS

The cruciate deficient stifles group ( $n = 30$ ) contained the following breeds: labrador (six), golden retriever (four), crossbreed (four), beagle (two), cocker spaniel (two), bearded collie (one), boxer (one), cavalier King Charles spaniel (one), border collie (one), English springer spaniel (one), Jack Russell terrier (one), Lancashire heeler (one), rottweiler (one), Siberian husky (one), Staffordshire bull terrier (one), Victorian bulldog (one) and west highland white terrier (one). There were 14 neutered males, 13 neutered females, two entire males and one entire female dog in the cruciate deficient group. The mean age of the cruciate deficient group was 82.4 months with the median 81 months. The mean weight of the cruciate deficient group was 24.25 kg with the median weight 25.15 kg.

The control group ( $n = 30$ ) contained the following breeds: labrador (10), English springer spaniel (three), Staffordshire bull terrier (three), crossbreed (two), dogue de Bordeaux (two), German shepherd dog (two), Chinese shar pei (two), cocker spaniel (one), dobermann (one), border collie (one), dalmatian (one), Musterlander (one) and old tyme bulldog (one). The mean age of the healthy stifles group was 61.1 months with the median 45 months. The mean weight of the healthy stifles group was 27.8 kg with the median weight 27.5 kg.

In the cruciate deficient stifles group, the data for PTA were found to be distributed normally. The data for age, weight, TPA and Blumensaat's line length were all found not to be distributed normally.

In the healthy stifles group, the data for PTA were found to be distributed normally. The data for age, weight, TPA and Blumensaat's line length were all found not to be distributed normally.



**FIGURE 3** Box-whisker distribution plots assessing healthy stifles (control) and cruciate deficient stifles (case) groups

**TABLE 3** Mean values measured by blinded observers for case and control groups for tibial plateau angle (TPA) and patella tendon angle (PTA)

	Mean case TPA	Mean control TPA	Mean case PTA	Mean control PTA
Observer 1: orthopaedic intern	26.2°	25.7°	102.9°	107.9°
Observer 2: ECVS resident	25.2°	23.3°	101.4°	104.9°
Observer 3: ECVS specialist	29.2°	28.3°	105.4°	110.0°
All observers	26.9°	25.7°	103.2°	107.6°

Abbreviation: ECVS, European College of Veterinary Surgeons.

The weight distribution was found not to be significantly different between the groups ( $p = 0.06$ ) (healthy stifles; median 27.5 kg, minimum 17 kg, maximum 42 kg, 95% confidence intervals 26.3–29.3 kg) (cruciate deficient stifles; median 25.2 kg, minimum 7.9 kg, maximum 41.2 kg, 95% confidence intervals 22.4–26.2 kg). The age distribution was found to be different, with the healthy stifles group having a younger age profile ( $p < 0.001$ ) (healthy stifles; median 45 months, minimum 16 months, maximum 171 months, 95% confidence intervals 51.8–70.3 months) (cruciate deficient stifles; median 81 months, minimum 18 months, maximum 147 months, 95% confidence intervals 75.8–89.1 months) (Figure 3).

The estimated stifle angles were found not to be statistically different between the two groups ( $p = 0.62$ ) (Table 1).

The mean TPA and PTA of the two groups as measured by the observers are shown in Table 3.

All three observers found a significant difference between the groups in the proportion of Blumensaat's line which was cranial to an extension of the tibial mechanical axis (Table 4 and Figure 4).

Interobserver reliability was assessed using limits of agreement of mean difference in measurement (Table 5 and Appendix 1), standard error mean and linear regression.

Of our 30 cases, there were 15 complete and 15 partial cruciate tears (Table 6). The length of Blumensaat's line found to be cranial to the tibial mechanical axis was found to be similar in complete and partial tears (mean 8.9 and 9.4 mm).

The mean difference in proposed TTA across all cases was 2.4 mm (range 0–9 mm) (Table 7). In only cases where cranial tibial subluxation was identified radiographically, the mean difference was 3.4 mm.

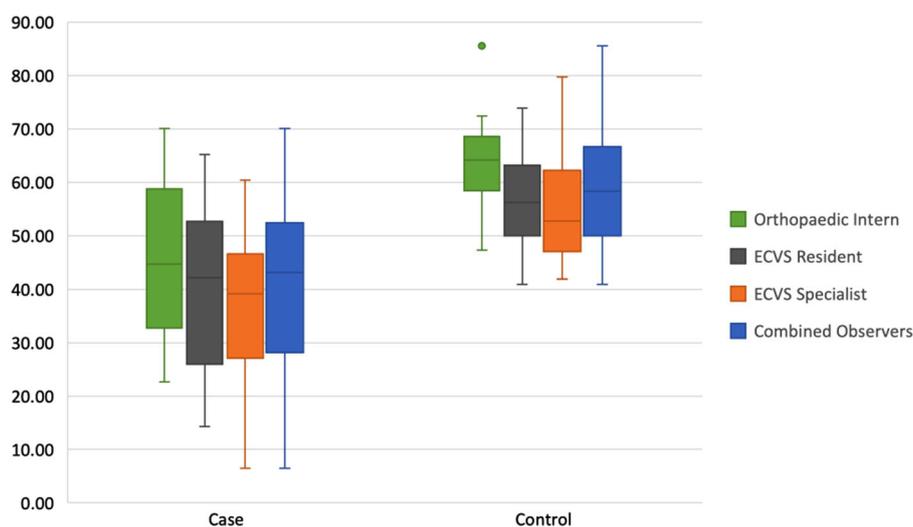
## DISCUSSION

Radiographically measurable cranial tibial subluxation provides two clinical benefits. Firstly, detection of tibial cranial subluxation can aid the reaching of a diagnosis of CCL insufficiency and secondly it could be used, as demonstrated, to adjust measurements used for planning of proposed tibial osteotomy procedures reliant on PTA assessment. Previous studies have highlighted a variable degree of effacement of the infrapatellar fat pad opacity in radiographs of cruciate deficient stifles.<sup>23,24</sup> This feature is however not specific to cruciate failure, rather implying stifle joint effusion or increased intra-articular soft tissue.<sup>23–25</sup> There are radiographic markers of degenerative joint disease such as osteophytosis, enthesiophytosis and subchondral sclerosis which have also been suggested as useful in the diagnosis of cruciate disease, but these signs are similarly not specific to the cruciate deficient stifle.<sup>23–25</sup> Cadaveric studies have shown that following transection of the CCL, significant cranial tibial subluxation can be present.<sup>11,26</sup> Radiographically detectable signs of cranial tibial translation are useful in the diagnosis of CCL failure because the manual assessments through cranial drawer and tibial compression tests have limitations, especially when these are performed in the conscious patient.<sup>27</sup> Cra-

**TABLE 4** Blinded observers' measurements of the percentage of Blumensaat's line found cranial to an extension of the tibial mechanical axis

Observer	Case median	Case maximum	Case minimum	Case confidence intervals	Control median	Control maximum	Control minimum	Control confidence intervals
Orthopaedic intern	44.6%	70.1%	22.6%	39.4%–50.3%	64.8%	85.6%	47.3%	60.9%–67%
ECVS resident	42.2%	65.2%	14.3%	33.8%–45%	56.5%	73.9%	40.9%	54.7%–60.9%
ECVS specialist	39.2%	60.4%	6.5%	32.1%–42.3%	52.7%	79.7%	41.9%	51.3%–59.4%
Combined observers	43.1%	70.1%	6.5%	37.4%–43.5%	58.3%	85.6%	40.9%	56.5%–60.5%

Abbreviation: ECVS, European College of Veterinary Surgeons.

**FIGURE 4** A box-whisker plot of the percentage of Blumensaat's line cranial to an extension of the tibial mechanical axis as measured by the orthopaedic intern ( $p < 0.001$ ), the European College of Veterinary Surgeons (ECVS) resident ( $p < 0.001$ ), the ECVS specialist ( $p < 0.001$ ) and all observers combined ( $p < 0.001$ )**TABLE 5** Interobserver reliability assessed with mean difference in measurement, standard error mean and linear regression

Interobserver variability		Mean difference	Standard deviation	Standard error mean	<i>p</i> -Value	95% confidence interval of the difference
Orthopaedic intern versus ECVS resident	Blumensaat's line cranial to the tibial mechanical axis	-0.2	1.39	0.18	0.03	-0.056 to 0.16
	TPA	1.73	4.07	0.52	0.001	0.68–2.78
	PTA	2.2	3.97	0.51	0.176	1.17–3.23
Orthopaedic intern versus ECVS specialist	Blumensaat's line cranial to the tibial mechanical axis	1.44	1.44	0.18	0.279	1.06–1.81
	TPA	-2.74	4.61	0.59	0.00004	-3.93 to -1.55
	PTA	-2.31	4.44	0.57	0.008	-3.46 to -1.16
ECVS resident versus ECVS specialist	Blumensaat's line cranial to the tibial mechanical axis	1.63	1.42	0.18	0.00003	1.23–2.01
	TPA	-4.47	3.81	0.49	0.205	-5.45 to -3.49
	PTA	-4.5	3.4	0.44	0.079	-5.39 to -3.63

Abbreviations: ECVS, European College of Veterinary Surgeons; PTA, patella tendon angle; TPA, tibial plateau angle.

nial translation of the tibia has been demonstrated radiographically previously by showing the tibial eminences and the caudal margin of the fibula displaced cranially relative to the normal neutral position.<sup>28</sup> It has also been shown that the degree of cranial

translation that can be demonstrated radiographically is greater in cruciate deficient stifles compared to those with partially deficient cruciate ligaments and intact cruciate ligaments.<sup>29</sup> In human patients, passive anterior tibial subluxation of over 3.5 mm, detected via

**TABLE 6** Subjective visual assessment of the degree of canine cruciate ligament (CCL) damage and meniscal injury

Percentage of CCL damaged	Number of cases with this damage	Number of these cases found to have meniscal injury
0%–24%	3	0
25%–49%	2	0
50%–74%	4	0
75%–99%	6	1
100%	15	5

**TABLE 7** Tibial tuberosity advancement (TTA) planned with and without adjustment for tibial cranial subluxation based on Blumensaat’s line

Case No.	Proposed advancement without adjustment (mm)	Proposed advancement with adjustment (mm)	Difference in advancement (mm)
1	17	17	0
3	13	13	0
6	14	14	0
7	13	13	0
8	6	10	4
9	5	10	5
10	12	14	2
11	18	18	0
15	12	15	3
18	12	12	0
19	8	11	3
21	3	7	4
22	11	11	0
23	8	11	3
26	7	9	2
28	5	8	3
31	12	12	0
38	5	14	9
39	18	20	2
40	4	8	4
44	4	9	5
45	11	17	6
47	7	9	2
49	11	12	1
50	9	12	3
52	19	21	2
53	5	8	3
58	14	18	4
59	8	10	2
60	8	8	0
Mean	9.97	12.37	2.4

**TABLE 8** Positive predictive value (PPV), negative predictive value (NPV), sensitivity and specificity of <50% Blumensaat’s line cranial to an extension of the tibial mechanical axis for canine cruciate ligament (CCL) deficiency

Observer	PPV	NPV	Sensitivity	Specificity
Orthopaedic intern	86%	71%	63%	90%
ECVS resident	81%	74%	70%	83%
ECVS specialist	66%	75%	80%	60%
Overall	76%	72%	71%	77%

Abbreviation: ECVS, European College of Veterinary Surgeons.

**TABLE 9** Positive predictive value (PPV), negative predictive value (NPV), sensitivity and specificity of <40% Blumensaat’s line cranial to an extension of the tibial mechanical axis for canine cruciate ligament deficiency

Observer	PPV	NPV	Sensitivity	Specificity
Orthopaedic intern	100%	64%	37%	100%
ECVS resident	100%	64%	50%	100%
ECVS specialist	100%	64%	50%	100%
Overall	100%	62%	47%	100%

Abbreviation: ECVS, European College of Veterinary Surgeons.

MRI, has been used as a highly specific and sensitive diagnostic marker for complete anterior cruciate ligament tears.<sup>30,31</sup>

In our study, all the blinded observers found a statistically significant difference in the percentage of Blumensaat’s line that was cranial to an extension of the tibial mechanical axis in the cruciate deficient stifles group compared to healthy stifles (Figure 4 and Table 4). Therefore, we accept our hypothesis, that the tibial mechanical axis intersecting Blumensaat’s line at a point cranial to its midpoint correlates with surgical findings of cranial cruciate ligament disease. We propose that this displacement is associated with stretching or tearing of the diseased ligament.

In our data, the tibial mechanical axis intersecting Blumensaat’s line at a point cranial to its midpoint had a positive predictive value of 76%, a sensitivity of 71% and a specificity of 77% for CCL disease (Table 8). If the intersection of Blumensaat’s line by the tibial mechanical axis was in the cranial two-fifths, that is <40% was cranial to the intersection, the positive predictive value and specificity reached 100% in our data, although sensitivity at this intersection point was poor at 47% (Table 9).

A previous study which assessed diagnostic tests for cruciate ligament failure in dogs found that another radiographic marker, effacement of the infrapatellar fat pad, assessed by a specialist and final-year resident, had a perfect positive predictive value and specificity in their sample population.<sup>27</sup> However, effacement of the fat pad is not specific to cruciate failure and can be present with stifle joint effusion or increased intra-articular soft tissue.<sup>23–25</sup> Our results suggest that a quick and simple assessment of where the tibial mechanical axis intersects Blumensaat’s line could add to other radiographic and clinical evidence when making a diagnosis of CCL disease. This radiographic

**TABLE 10** False positives from 30 control radiographs using Blumensaat's line cranial to an extension of the tibial mechanical axis for canine cruciate ligament (CCL) deficiency

Observer	False positives at 50% cranial	False positives at 40% cranial
Orthopaedic intern (/30)	3	0
ECVS resident (/30)	5	0
ECVS specialist (/30)	12	0
Overall (/90)	20	0

Abbreviation: ECVS, European College of Veterinary Surgeons.

feature should not be considered definitive, with false positives, particularly at 50% of Blumensaat's line cranial (Table 10), making this inappropriate. As such, we do not propose its use alone as justification for more invasive stifle procedures.

Our data were produced from a group of radiographs in which half were from cruciate deficient stifles, that is a population in which the true disease prevalence was 50%. The positive and negative predictive values, sensitivity and specificity of a diagnostic test depend on the prevalence of the target condition.<sup>22</sup> The prevalence in our data is not representative of the general canine population, and as such the performance of this radiographic marker may be found to be different if radiographs were representative of a more general population. However, the prevalence of cruciate failure in stifles undergoing radiography is likely to be higher than that seen in the general population. How representative the 50% prevalence used in our data is of this population is unclear.

A more recent study used a handmade, custom-designed radiographic positioning device to apply a force across the stifle to demonstrate cranial tibial translation radiographically.<sup>32</sup> Cranial tibial subluxation has also been assessed by placing radiographic markers at the sites of origin and insertion of the cruciate ligament in cadaveric limbs.<sup>33</sup> A study looking at radiographic assessment of cranial tibial translation concluded that it was reliably detected by measuring the distance between the caudal margin of the intercondylar fossa and the intercondylar eminence of the tibia.<sup>21</sup>

Our data demonstrate a simple method by which cranial tibial subluxation can be quantified on a standard or cropped radiograph in clinical cases. The ability to use a cropped radiograph is beneficial because it can be difficult, or impossible, to include the entire pelvic limb in larger dogs. With this proposed method, tibial cranial subluxation can be quantified so long as the tibial mechanical axis can be defined and its intersection with Blumensaat's line identified. The directional quantification of subluxation we propose has the secondary benefit in mimicking the distance which the patella effectively sags and the distorts the assessment of PTA—hence its use may allow correction for this displacement in surgical planning.

TTA and TTO procedures aim to neutralise the femorotibial cranial shear force acting on the CCL deficient stifle, thus creating a dynamically stable sti-

ple joint with a PTA of 90°. <sup>16,34</sup> Correct calculations and measurement of the PTA in TTO and TTA procedures are crucial in order to neutralise this force. If the PTA remains greater than 90°, studies have suggested a cranial tibial shear force may continue to be present. <sup>10,11,35</sup> When cranial tibial subluxation is present in the radiograph used to plan the corrective osteotomy, the patella and femoral condyles are displaced more caudally than in the anatomically correct position. As the patella likely maintains contact with the femoral condyle in all but the most disrupted of stifles, this condylar displacement equates to the caudal patella sag. As such there is a risk that the proposed osteotomy results in an under advancement of the tibial tuberosity. This was confirmed in a previous study of cadaveric stifles, which demonstrated that cranial tibial subluxation, present after transection of the CCL changes the measurements for TTA. <sup>36</sup> The radiographs taken of cruciate deficient stifles in our study were assessed and TTA procedures planned by one of the authors (Sebastian Prior). Of the 30 cruciate deficient stifles in this group, 21 had tibial cranial subluxation detected using assessment of the tibial mechanical axis and Blumensaat's line. Using Blumensaat's line to adjust for this would have produced a mean additional advancement of 2.4 mm (range 0–9 mm) across all 30 CCL deficient stifles (Table 7) and of 3.4 mm in the 21 where cranial tibial subluxation was detected based on the intersection of Blumensaat's line by the tibial mechanical axis. These distances are significant enough to alter the implants that would be selected should this osteotomy procedure be performed.

To our knowledge, the proportion of cruciate deficient stifles that have radiographically detectable cranial tibial subluxation has not been reported, so how representative our study population was in this regard remains unclear. While the mean values reported in this study are illustrative, additional advancement to this degree in all cases would not be appropriate given the wide variability in the additional advancement proposed (range 0–9 mm).

Further studies would be required to demonstrate the clinical effect of this proposed correction, however, based on our data from clinically affected patients, we suggest that case by case adjustment for cranial tibial subluxation using Blumensaat's line and the methodology described warrants further consideration.

During the study, the surgeon or resident involved in the CCL surgical cases was asked to make a subjective assessment of what proportion of the CCL was torn (Table 6).

Of the 30 cases, only six patients had suffered meniscal injury identified at the time of surgery, making the sample size too small to assess whether Blumensaat's line was a useful marker to predict this without risking a type II statistical error. All cases of meniscal injury were found in stifles where the proportion of the CCL damaged was subjectively assessed by the surgeon as 75% or greater.

Interobserver variability showed some evidence of proportional bias in one set of observer comparisons in each of the measures assessed in our data.

Table 5 shows linear regression for the mean difference in measures, and for the proportion of Blumensaat's line cranial to the tibial mechanical axis, the orthopaedic intern and ECVS specialist pairing *p*-value suggest some proportional bias. In the TPA measures, there was a similar finding between the ECVS resident and specialist while in the PTA measures, this was found between the orthopaedic intern and ECVS resident. Despite this, limits of agreement scatter plots for the proportion of Blumensaat's line cranial to the tibial mechanical axis show that 95% of the difference in measures fall within two standard deviations of the mean in each of the observer comparisons, suggesting an acceptable level of agreement (Appendix 1).<sup>37</sup>

There was significant variation in the measured TPA across the three observers (Table 3). A study of nearly 4000 dogs with CCL disease found that the average TPA was 29°. <sup>38</sup> In our study, the ECVS specialist observer found the mean TPA of cruciate deficient dogs to be very close to this value at 29.2° with the ECVS resident finding a mean TPA of 25.2° and the orthopaedic intern 26.2°. Specialist orthopaedic surgeons measure TPA with significant frequency for planning tibial osteotomy procedures. While residents and interns are involved in this at times, the increased familiarity and frequency with which a specialist surgeon performs these measurements may go some way to explaining the differences observed here.

The observers in this study were blinded from the aims of the study and hence may not have fully appreciated the significance of the accuracy of the assessments which were asked of them, however we felt that blinding was an important aspect of this prospective investigation. This interobserver variability being present did not however detract from the consistent finding of the more cranial intersection of tibial functional axis and Blumensaat's line, irrespective of observer in patients with cranial cruciate ligament insufficiency.

While the proposition from the previous study that Blumensaat's line was perfectly bisected by the tibial functional axis, was not corroborated in our data (Figure 4), cranial tibial subluxation was a consistent feature in the stifles with demonstrated cruciate disease. Quantification of the degree of subluxation along Blumensaat's line might be proposed to be measured from the midpoint of that line if only one stifle radiograph is available for assessment from the affected patient, or in the presence of bilateral disease. As an alternative, radiography of the contralateral, clinically unaffected stifle, where possible to compare this finding, might allow for more accurate quantitative assessment of the degree of cranial tibial subluxation for an individual surgical case.

## LIMITATIONS

This study has a number of limitations. The number of blinded observers was small and contained only one observer of each type (ECVS specialist, ECVS resident,

orthopaedic intern). Having more observers might have reduced the impact of individual variations in measurement techniques.

Our case sample series contained the lower end of reported incidence of CCL deficient stifles that had suffered meniscal damage. As cranial tibial shear force is associated with meniscal damage, it is possible that our CCL deficient stifles did not suffer as much cranial tibial subluxation as a more representative sample group, although if this were the case, then the findings of this study may have been even more evident in a group with more cases of meniscal injury.

The stifle angles were not directly measured in the case radiographs and this may have introduced a source of error in degree of cranial tibial subluxation and indeed in PTA assessments, however the methodology for radiographic positioning was consistent with a previously recommended technique, used for both the case and control population in this study and the estimated stifle angles were not found to be statistically different between groups (Table 1).<sup>20</sup>

While observers were blinded from the reason for the measurements in this study, they could not be blinded from the presence of other radiographic features of cruciate disease, that is stifle effusion and degenerative joint disease.

## CONCLUSIONS

Tibial cranial subluxation is detectable and quantifiable radiographically using assessment of the position of the intersection of the tibial mechanical axis and Blumensaat's line. The clinical significance of this is that, in addition to contributing to the diagnosis of CCL disease, once quantified this feature may be used to adjust tibial osteotomy procedures to minimise the risk of under advancement of the tibial tuberosity.

## CONFLICT OF INTEREST

There are no conflicts of interests applicable to the authors.

## FUNDING INFORMATION

The authors received no specific funding for this work.

## AUTHOR CONTRIBUTIONS

The study was designed by Sebastian Prior, Francisco Silveira and Darren Barnes. Sebastian Prior and Francisco Silveira drafted the manuscript with supervision and editing by Darren Barnes. Lida Pappa, Pablo Pérez López and Robert Quinn were blinded observers and provided feedback and editing on the initial draft.

## ETHICS STATEMENT

The study design was approved by the clinical ethical review panel of Nottingham University's school of veterinary medicine and science (ref. 1623 151124).

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## REFERENCES

- Johnson JA, Austin C, Breur GJ. Incidence of canine appendicular musculoskeletal disorders in 16 veterinary teaching hospitals from 1980 through 1989. *Vet Comp Orthopa Traumatol.* 1994;7(2):56–69.
- Wilke VL, Robinson DA, Evans RB, Rothschild MF, Conzemius MG. Estimate of the annual economic impact of treatment of cranial cruciate ligament injury in dogs in the United States. *J Am Vet Med Assoc.* 2005;227(10):1604–7.
- Elkins AD, Pechman K, Herron M. A retrospective study evaluating the degree of degenerative joint disease in the stifle joint of dogs following surgical repair of anterior cruciate ligament rupture. *J Am Anim Hosp Assoc.* 1991;27(5):533–40.
- Slocum B, Devine T. Cranial tibial thrust: a primary force in the canine stifle. *J Am Vet Med Assoc.* 1983;183(4):456–9.
- Wucherer KL, Conzemius MG, Evans R, Wilke VL. Short-term and long-term outcomes for overweight dogs with cranial cruciate ligament rupture treated surgically or nonsurgically. *J Am Vet Med Assoc.* 2013;242(10):1364–72.
- Bruce WJ, Rose A, Tuke J, Robins GM. Evaluation of the triple tibial osteotomy. A new technique for the management of the canine cruciate-deficient stifle. *Vet Comp Orthop Traumatol.* 2007;20(3):159–68.
- Hoffmann DE, Miller JM, Ober CP, Lanz OI, Martin RA, Shires PK. Tibial tuberosity advancement in 65 canine stifles. *Vet Comp Orthop Traumatol.* 2006;19(4):219–27.
- Kim SE, Pozzi A, Kowaleski MP, Lewis DD. Tibial osteotomies for cranial cruciate ligament insufficiency in dogs. *Vet Surg.* 2008;37(2):111–25.
- Bush MA, Bowlt K, Gines JA, Owen MR. Effect of use of different landmark methods on determining stifle angle and on calculated tibial tuberosity advancement. *Vet Comp Orthop Traumatol.* 2011;24(3):205–10.
- Kapler MW, Marcellin-Little DJ, Roe SC. Planned wedge size compared to achieved advancement in dogs undergoing the modified Maquet procedure. *Vet Comp Orthopa Traumatol.* 2015;28(6):379–84.
- Apelt D, Kowaleski MP, Boudrieau RJ. Effect of tibial tuberosity advancement on cranial tibial subluxation in canine cranial cruciate-deficient stifle joints: an in vitro experimental study. *Vet Surg.* 2007;36(2):170–7.
- Ralphs SC, Whitney WO. Arthroscopic evaluation of menisci in dogs with cranial cruciate ligament injuries: 100 cases (1999–2000). *J Am Vet Med Assoc.* 2002;221(11):1601–4.
- Metelman LA, Schwarz PD, Salman M, Alvis MR. An evaluation of three different cranial cruciate ligament surgical stabilization procedures as they relate to postoperative meniscal injuries: a retrospective study of 665 stifles. *Vet Comp Orthop Traumatol.* 1995;8(2):118–23.
- Thieman KM, Tomlinson JL, Fox DB, Cook C, Cook JL. Effect of meniscal release on rate of subsequent meniscal tears and owner-assessed outcome in dogs with cruciate disease treated with tibial plateau leveling osteotomy. *Vet Surg.* 2006;35(8):705–10.
- Case JB, Hulse D, Kerwin SC, Peycke LE. Meniscal injury following initial cranial cruciate ligament stabilization surgery in 26 dogs (29 stifles). *Vet Comp Orthop Traumatol.* 2008;21(4):365–7.
- Lafaver S, Miller NA, Stubbs WP, Taylor RA, Boudrieau RJ. Tibial tuberosity advancement for stabilization of the canine cranial cruciate ligament-deficient stifle joint: surgical technique, early results, and complications in 101 dogs. *Vet Surg.* 2007;36(6):573–86.
- Steinberg EJ, Prata RG, Palazzini K, Brown DC. Tibial tuberosity advancement for treatment of CrCL injury: complications and owner satisfaction. *J Am Anim Hosp Assoc.* 2011;47(4):250–7.
- Wolf RE, Scavelli TD, Hoelzler MG, Fulcher RP, Bastian RP. Surgical and postoperative complications associated with tibial tuberosity advancement for cranial cruciate ligament rupture in dogs: 458 cases (2007–2009). *J Am Vet Med Assoc.* 2012;240(12):1481–7.
- Blumensaat C. Die lageabweichungen und verrenkungen der kniescheibe. Berlin, Heidelberg: Springer; 2011. p. 149.
- Barnes DC, Owen MR. Indirect assessment of stifle angle for improved accuracy of preoperative planning of tibial osteotomy procedures in dogs. *Vet Rec.* 2015;177(4):99.
- Plesman R, Sharma A, Gilbert P, Campbell J, Johnston JD, Shmon C, et al. Radiographic landmarks for measurement of cranial tibial subluxation in the canine cruciate ligament deficient stifle. *Vet Comp Orthop Traumatol.* 2012;25(6):478–87.
- Trevethan R. Sensitivity, specificity, and predictive values: foundations, pliabilities, and pitfalls in research and practice. *Front Public Health.* 2017;5:307.
- Fuller MC, Hayashi K, Bruecker KA, Holsworth IG, Sutton JS, Kass PH, et al. Evaluation of the radiographic infrapatellar fat pad sign of the contralateral stifle joint as a risk factor for subsequent contralateral cranial cruciate ligament rupture in dogs with unilateral rupture: 96 cases (2006–2007). *J Am Vet Med Assoc.* 2014;244(3):328–38.
- Widmer WR, Buckwalter KA, Braunstein EM, Hill MA, O'Connor BL, Visco MD. Radiographic and magnetic resonance imaging of the stifle joint in experimental osteoarthritis of dogs. *Vet Radiol Ultrasound.* 1994;35(5):371–83.
- DeCamp CE. Brinker, Piermattei and Flo's handbook of small animal orthopedics and fracture repair. 5th ed. Elsevier (ScienceDirect Freedom Collection); 2016.
- Miller JM, Shires PK, Lanz OI, Martin RA, Grant JW. Effect of 9 mm tibial tuberosity advancement on cranial tibial translation in the canine cranial cruciate ligament-deficient stifle. *Vet Surg.* 2007;36(4):335–40.
- Carobbi B, Ness MG. Preliminary study evaluating tests used to diagnose canine cranial cruciate ligament failure. *J Small Anim Pract.* 2009;50(5):224–6.
- Ashour AE, Hoffman CL, Muir P. Correlation between orthopaedic and radiographic examination findings and arthroscopic ligament fibre damage in dogs with cruciate ligament rupture. *Aust Vet J.* 2019;97(12):490–8.
- Lopez MJ, Hagquist W, Jeffrey SL, Gilbertson S, Markel MD. Instrumented measurement of in vivo anterior-posterior translation in the canine knee to assess anterior cruciate integrity. *J Orthop Res.* 2004;22(5):949–54.
- Chan WP, Peterfy C, Fritz RC, Genant HK. MR diagnosis of complete tears of the anterior cruciate ligament of the knee: importance of anterior subluxation of the tibia. *Am J Roentgenol.* 1994;162(2):355–60.
- Hardy A, Klouche S, Szarzynski P, Charpentier E, Beranger JS, Bauer T, et al. A threshold value of 3.5 mm of passive anterior tibial subluxation on MRI is highly specific for complete ACL tears. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(3):885–92.
- Tambella AM, Omini L, Attili AR, Vullo C, Martin S. Evaluation of cranial tibial translation in dogs: diagnostic accuracy of radiographic method using a simple device. *PLoS One.* 2020;15(2):e0228621.
- Kim SE, Lewis DD, Pozzi A, Seibert RL, Winter MD. Radiographic quantitative assessment of cranial tibial subluxation before and after tibial plateau leveling osteotomy in dogs. *Vet Comp Orthop Traumatol.* 2009;22(6):473–8.
- Moles AD, Hill TP, Glyde M. Triple tibial osteotomy for treatment of the canine cranial cruciate ligament-deficient stifle joint: Surgical findings and postoperative complications in 97 stifles. *Vet Comp Orthopa Traumatol.* 2009;22(6):473–8.

35. Kipfer NM, Tepic S, Damur DM, Guerrero T, Hassing M, Montavon PM. Effect of tibial tuberosity advancement on femorotibial shear in cranial cruciate-deficient stifles. An in vitro study. *Vet Comp Orthopa Traumatol*. 2008;21(5): 385–90.
36. Bielecki MJ, Schwandt CS, Scharvogel S. Effect of tibial subluxation on the measurements for tibial tuberosity advancement in dogs with cranial cruciate ligament deficiency. *Vet Comp Orthop Traumatol*. 2014;27(6):470–7.
37. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;1(8476):307–10.
38. Fox EA, Dycus DL, Leasure CS, Fox HA. Average tibial plateau angle of 3,922 stifles undergoing surgical stabilization for cranial cruciate ligament rupture. *Vet Comp Orthopa Traumatol*. 2020;33(3):167–73.

## SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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