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Ideal Anchor Points for Patellar Anti-rotational Sutures for Management of Medial Patellar Luxation in Dogs: A Radiographic Survey

Parisa Mazdarani[1] James Edward Miles[2]

[1] College of Veterinary Medicine, University of Florida, Gainesville, Florida, United States
[2] Department of Veterinary Clinical Sciences, University of Copenhagen, Frederiksberg C, Denmark

Address for correspondence James Edward Miles, BSc, BVetMed, PhD, Department of Veterinary Clinical Sciences, University of Copenhagen, Dyrlægevej 16, 1870 Frederiksberg C, Denmark (e-mail: jami@sund.ku.dk).

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Abstract

Objective The aim of this study was to identify the ideal anchor point for patellar anti-rotational sutures for adjunctive stabilization of medial patellar luxation in both small and large breed dogs.

Study Design Retrospective radiographic survey was performed on 110 stifles from 101 dogs. Radiographs were grouped based on patient weight (≤15 kg; >15 kg) and diagnosis (medial patellar luxation, cranial cruciate ligament rupture, and normal joints). Radiographic measurements included: the proximal, middle, and distal points of the trochlear ridge, the caudal aspect of Blumensaat's line (roof of the intercondylar notch), the centre of the lateral fabella, as well as the "best-fit" centre of a circle overlying the trochlea. These landmark coordinates were used to calculate radii for comparison, and for scaling between joints.

Results Use of the fabellar centre resulted in larger radii (corrected $p < 0.001$) than those from the best-fit circle centre for all but one combination of patient group and trochlear end point locations. Using the best-fit circle centre, radius variation was less marked than with the fabellar centre. Significant differences in location for centres of the best-fit circle and fabella were seen across all patient categories (Pillai's trace $p < 0.001$).

Conclusion The fabella is unlikely to be the best choice for anchoring a patellar anti-rotational suture. Use of the best-fit circle centre to place a suture anchor should be preferred to maximise suture isometry during joint flexion and extension in large and small breed dogs.

Keywords
- dogs
- stifle joint
- patellar luxation
- patellar anti-rotational suture
- radiography

Introduction

Patellar luxation is one of the most common orthopaedic problems in dogs.[1–4] Medial patellar luxation is more common than lateral luxation in all breeds.[2,5,6] The incidence of medial patellar luxation in small breed dogs is 12 times higher than in large breed dogs, however, the incidence of medial patellar luxation in large breeds appears to be growing.[6,7] It is primarily a developmental disorder, likely the result of hindlimb anatomical abnormalities that may be present at birth.[8,9] While the precise causes of patellar luxation remain unclear, associated abnormalities include malalignment of quadriceps mechanism, coxofemoral joint conformation (abnormal angles of inclination and anteversion, decreased acetabular coverage, and hip dysplasia), distal femoral torsion and angulation, medial deviation of the tibial crest, tightness/atrophy of the quadriceps muscles, shallow femoral trochlear groove, and hypoplasia of the

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medial femoral condyle.[5,9–11] Occasionally, the cause is traumatic with femoropatellar instability occurring due to tearing or stretching of the parapatellar joint capsule and/or fascia.[5,9,12]

Stabilization of patellar luxation can be divided into two groups: soft tissue reconstruction and bone reconstruction. Soft tissue procedures can be used as a supplementary technique for bone reconstruction in mature animals or as the first stage of two-stage repair in immature animals in order to correct the abnormal forces on the growing bones until skeletal maturity is reached and the second stage of repair can be performed.[5,8,9] Soft-tissue techniques for medial patellar luxation include medial desmotomy, lateral imbrication, release of medial musculature, and patellar or tibial anti-rotational sutures. Patellar anti-rotational sutures, in a similar manner to extracapsular sutures for repair of cranial cruciate ligament, create a synthetic lateral femoropatellar ligament by anchoring the lateral fabella to the patella with a nonabsorbable suture.[5,8] These sutures might be a useful adjunct to other procedures, since up to half of all dogs that undergo surgical correction of patellar luxation experience subsequent reluxation.[13–15] The incidence of reluxation in Pomeranians increased with higher severity of luxation before the surgery, although another study found no significant association between patellar luxation grade and reluxation.[14,16]

While the fabella has been assumed to be the centre of the arc of rotation of patella such that a fabellopatellar suture would remain taut at all stifle angles,[5] we hypothesized that the fabella might not be co-located with the patella's centre of rotation. As a result, these supplementary anti-rotational sutures might not maintain uniform traction at all angles. Furthermore, we hypothesized that there might be an alternative position on the distal femur which could be used as a location for rotationally centred suture anchor, and that the trochlear ridge could be used as a reasonable proxy for the arc of the patellar centre.

Materials and Methods

Local ethical committee (Department of Veterinary Clinical Sciences, University of Copenhagen) consent and owner consent for the use of radiographic and cadaver materials for this study were obtained.

Preliminary assessment of the viability of the use of trochlear ridge as a substitute for patellar centre for identification of optimal anchor position was performed using fluoroscopic recordings of nine large breed stifle joints moving from flexion to extension under load, obtained from another study.[17] Multiple still images from each recording were analysed sequentially by a single experienced observer using ImageJ2 software.[18] The coordinates of the centre of a circle best approximating the curve of trochlear ridge were found, along with 9 to 10 points along the trochlear ridge. Using the position of a tunnel drilled transversely mid-patella as a proxy for the patellar centre, this location was tracked across multiple images to identify the movement of patella. Coefficients of variation for the trochlear ridge and patellar tunnel coordinates were calculated and compared.

Radiographic records from 2018 to 2021 were screened for mediolateral stifle joint radiographs. Inclusion criteria comprised adequate exposure, distal femur completely visible, and condyles overlapping within 2 mm. Exclusion criteria were presence of fabellar dysplasia or aplasia. Associated patient records were retrieved and patients were assigned by weight ($\leq$15 kg; $>$15 kg) and diagnosis (medial patellar luxation, cranial cruciate ligament rupture, normal stifle) by careful reading of the records prior to, at the time of and following the radiographs. Patients which developed cranial cruciate ligament rupture after a history of medial patellar luxation or in which patellar instability appeared following cranial cruciate ligament rupture were excluded from the study. Stifles in the normal group had to have no prior suspicion of either condition, normal findings on both the contemporaneous radiographic report and subsequent radiographic review, and no subsequent history consistent with either medial patellar luxation or cranial cruciate ligament rupture in either stifle joint.

Radiographs were evaluated by a single experienced observer using freely available ImageJ2 software.[18] The proximal and distal extents of the trochlear ridge were marked, along with the visually-assessed midpoint along the trochlea, the caudal aspect of Blumensaat's line (the roof of the intercondylar notch),[19] and the centre of the lateral fabella. Using a series of concentric circles (printed on transparent film) overlaid on the trochlear ridge, the "best-fit" centre of the circle for which the trochlea formed an arc was found (►**Fig. 1**). Coordinates for these landmarks were transferred to spreadsheet software.

The distance d_B from the distal aspect of the trochlea to the caudal aspect of Blumensaat's line was calculated for each stifle and individually defined as 100% to scale all subsequent measurements between stifles. Radii from both the centre of the best-fit circle and the lateral fabella to the proximal, mid and distal trochlea were calculated, and scaled by d_B. The angular orientation of the line from distal trochlea to caudal aspect of Blumensaat's line was found, and the coordinates of this line along with those for the fabella centre and the centre of the best-fit circle were rotated and scaled, so that the line lay horizontally and had a length of 100 units.

Statistical Analysis

Proprietary statistical software was used (SPSS 28.0, IBM). Data were assessed for normality using quartile:quartile plots. Radii were compared between origins (fabella vs. best-fit centre), end points (proximal, mid, or distal trochlea), and patient category (small vs. large with normal, cranial cruciate ligament rupture, or medial patellar luxation) using a linear mixed model with an unstructured covariance structure and using repeated factors of origin and end point, with a fixed factor of group, and their factorial interactions. Post hoc pairwise comparisons were made using Bonferroni's correction. Location data were evaluated graphically and patient groups and methods were compared

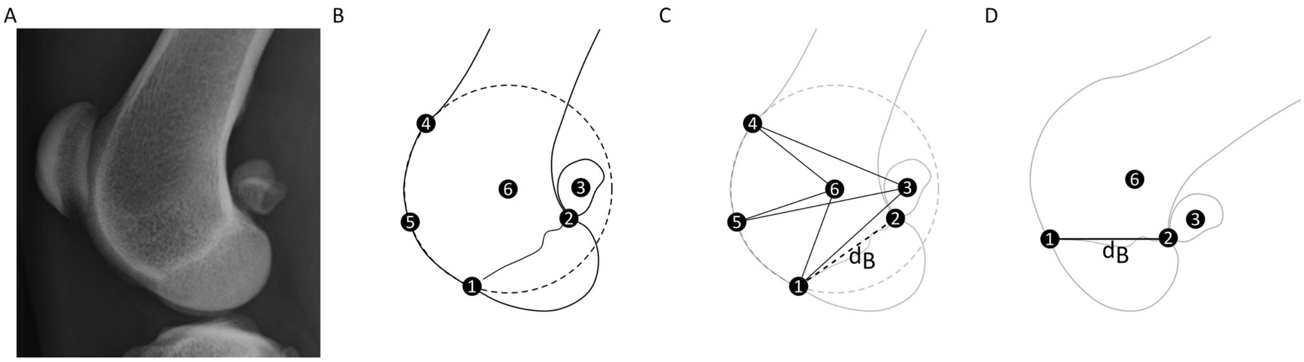

Fig. 1 Measurement locations and transformations. **(A)** Typical mediolateral radiograph from a normal large dog. **(B)** Six landmarks were identified on each radiograph, 1–distal end of trochlea adjacent to cranial aspect of Blumensaat's line, 2–caudal aspect of Blumensaat's line, 3–centre of the lateral fabella, 4–proximal aspect of trochlear ridge, 5–visually-assessed midpoint along trochlear ridge between points 1 and 4, 6–centre of best-fit circle (dashed) over trochlear ridge. **(C)** Radii were constructed from points 3 and 6 to points 1, 4, and 5, and normalised to the length of a line (*dashed*) between points 1 and 2 (line d_B). **(D)** Coordinate locations of the centres of the best-fit circle and fabella were normalised by rotation of line d_B to the horizontal and setting its length to 100%.

using MANOVA, with post hoc multivariate pairwise comparisons.[a]

Statistical significance was set at the 5% level.

Results

The mean coefficients of variation for the trochlear ridge coordinates (1.2%) and patellar tunnel coordinates (1.5%) did not differ significantly ($p = 0.5$), indicating that they had similar centres of rotation.

Satisfactory radiographs and records were retrieved for 110 stifle joints and 101 dogs (►**Table 1**, ►**Supplementary Table S1** [available in online version only]). Use of the fabellar centre resulted in larger radii (corrected $p < 0.001$) than those from the best-fit circle centre for all patient categories and all end point locations, except for the proximal location in small dogs with cranial cruciate ligament rupture (corrected $p = 0.8$) (►**Fig. 2**). With differences expressed as a percentage of d_B, fabellar centre radii ranged from 17.1 to 34.5% greater for the distal end point, 23.4 to 32.3% for the middle end point, and 13.2 to 17.2% for the proximal end point, with the exception of small dogs with cranial cruciate ligament rupture, where the difference was 0.5% (►**Supplementary Table S2** [available in online version only]).

Using the fabellar centre, radii differed within groups ($p \leq 0.001$) for all end point comparisons except between distal and middle end points in normal small dogs ($p = 0.5$) and small dogs with medial patellar luxation ($p = 1$). Significant differences ranged from 5.9 to 28.2% of d_B (►**Supplementary Table S3** [available in online version only]). Radii for the proximal and distal end points did not differ significantly between groups. For the middle end point, significant differences were seen between normal large dogs and large dogs with cranial cruciate ligament rupture ($p = 0.045$), normal small dogs ($p = 0.03$), small dogs with cranial cruciate ligament rupture ($p = 0.002$), and small dogs with medial patellar luxation ($p = 0.02$), with differences of 14.3 to 18.8% of d_B (►**Supplementary Table S4** [available in online version only]).

Using the best-fit circle centre, radius variation was less marked than with the fabellar centre. Proximal end point radii were smaller than distal end point radii ($p < 0.001$) for large dogs (normal and cranial cruciate ligament rupture), by 3.8 and 5.2% of d_B, respectively. In normal large dogs, radii for the distal and middle end points also differed significantly ($p = 0.02$, 3.8%). Finally, in normal small dogs, the middle end point gave significantly ($p < 0.001$) larger radii than the proximal (7.3%) and distal (6.8%) end points (►**Supplementary Table S3** [available in online version only]). Radii for the small dogs with cranial cruciate ligament rupture differed significantly from large dogs with cranial cruciate ligament rupture ($p \leq 0.009$) and normal large dogs ($p \leq 0.047$) at all end points, and normal small dogs proximal and distal end points ($p = 0.01$), with differences of 13.7 to 17.4% of d_B (►**Supplementary Table S4** [available in online version only]).

Multivariate analysis showed significant differences in location for centres of the best-fit circle and fabella across all patient categories (Pillai's trace $p < 0.001$). For the best-fit circle centre, pairwise comparison showed that the location relative to line d_B differed between both large dog categories and all three small dog categories, but not between the large dog categories (►**Fig. 3**; ►**Table 2**). Normal small dogs differed from small dogs with cranial cruciate ligament rupture, and small dogs with cranial cruciate ligament rupture differed from small dogs with medial patellar luxation. For the fabellar centre, pairwise comparison showed that this location did not differ between large dog categories, but did differ between normal large dogs and small dogs with medial patellar luxation, and between large dogs with cranial cruciate ligament rupture and both normal small dogs and small dogs with medial patellar luxation (►**Fig. 4**; ►**Table 2**). Normal small dogs differed from small dogs with cranial cruciate ligament rupture and small dogs with cranial

[a] Multivariate pairwise comparisons after multivariate ANOVA, https://www.ibm.com/support/pages/multivariate-pairwise-comparisons-after-multivariate-anova, accessed 25.1.2022

Table 1 Demographic data for this study

	Small (≤15 kg)			Large (>15 kg)	
	Normal	CCLR	MPL	Normal	CCLR
Mean body mass (kg)	7.7 (SD 3.7)	8.2 (SD 3.3)	7.6 (SD 3.4)	32.8 (SD 8.4)	30.9 (SD 6.5)
Body mass range (kg)	1.8–14.8	2.8–15.0	3.4–14.4	15.8–51.7	20.2–45.4
Age at radiography	4 y 9 mo (SD 3 y 7 mo)	7 y 1 mo (SD 3 y 3 mo)	4 y 9 mo (SD 3 y 5 mo)	6 y 8 mo (SD 3 y 7 mo)	6 y 5 mo (SD 2 y 10 mo)
Number of stifles	20	24	22	22	22
Number of dogs	18	19	21	22	21
Female (entire/neutered)	5/2	8/2	9/5	7/1	10/6
Male (entire/neutered)	8/3	8/1	6/1	9/5	2/3

Abbreviation: SD, standard deviation.
Note: Dogs were grouped by weight and primary diagnosis as either unaffected by stifle disease (normal), cranial cruciate ligament rupture (CCLR), or medial patellar luxation (MPL).

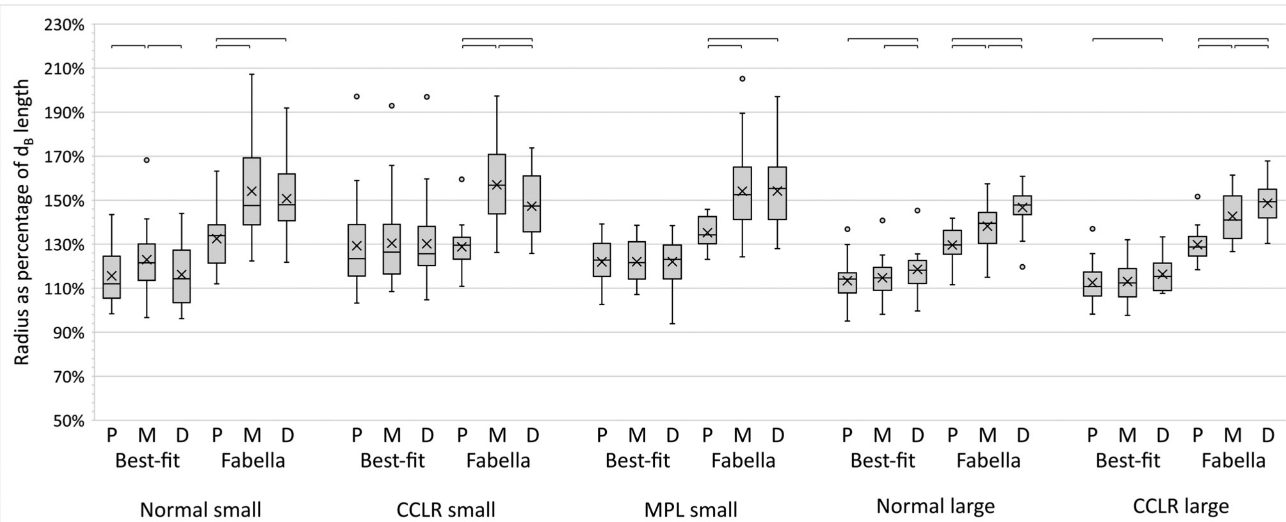

Fig. 2 Normalised radii for the best-fit circle and fabellar centres. Radii were normalised to the length of Blumensaat's line (roof of the intercondylar notch) for each stifle. Radii are grouped by dog size (small vs. large, with cut-off at 15 kg), category (normal, cranial cruciate ligament rupture – CCLR, or medial patellar luxation – MPL), start point (best-fit circle vs. fabellar centre), and end point location along trochlea (proximal – P, middle – M, or distal – D). Bars above the box and whisker plots indicate significant ($p < 0.05$) pairwise comparisons.

cruciate ligament rupture differed from small dogs with medial patellar luxation.

Discussion

We demonstrated that the trochlear ridge was a reasonable proxy for the patellar centre, and that patellar suture radii would be inconsistent when the fabella was used as the centre of rotation of patella. In comparison, suture isometry was improved by using the centre of best-fit circle, but this point may not always lie within the femoral metaphysis.

A proximally positioned patella (patella alta) is associated with medial patellar instability, since the patella exits the femoral trochlea proximally and loses support from the trochlear ridges, increasing the risk of luxation as the patella moves distally with flexion.[11,20,22,23] Use of a fabellopatellar suture for medial patellar luxation and patella alta should therefore focus on attaining sufficient tension with the stifle joint in extension and the patella in its most exposed position. Our results indicate that this will lead to excessive suture tension at flexed stifle angles. Possible consequences could include unwanted lateral luxation, suture breakage or stretching, restricted joint flexion, and fabellar avulsion. The latter has been described as a complication of fabellotibial suture placement.[24] Our results demonstrate that consistent suture tension throughout all patellar positions might be comparatively more achievable by use of the best-fit circle centre, and placement of a suture anchor at this location for the patellar anti-rotational suture. Considering that an anti-rotational suture for medial patellar luxation should mimic the lateral femoropatellar ligament which attaches at the fabella, the lack of isometry for this landmark is surprising, but may reflect ligament elasticity, fabellar mobility, or the insubstantial nature of this structure in many dogs.[25]

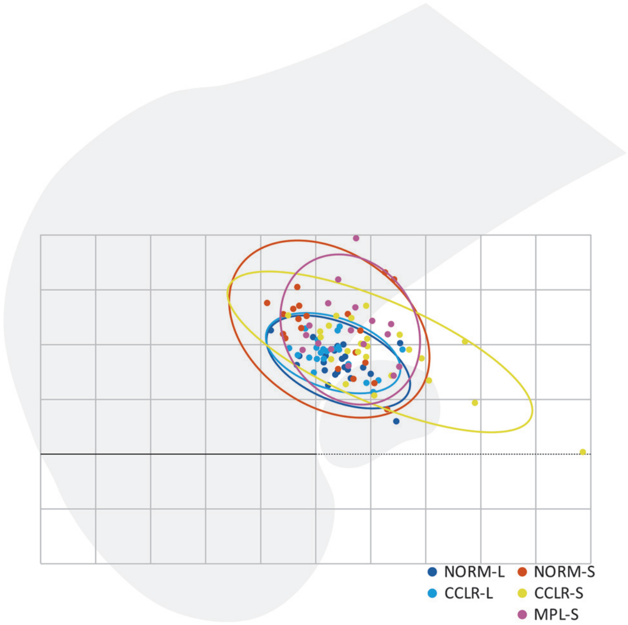

Fig. 3 95% confidence ellipses for best-fit circle centres. Circle centres were found for each dog size (small, ≤15 kg – S; large, >15 kg – L) and category (normal – NORM, cranial cruciate ligament rupture – CCLR, medial patellar luxation – MPL) and normalised to the length of Blumensaat's line. Error ellipses were calculated by derivation of eigenvalues and major axis regression. The solid horizontal line represents Blumensaat's line. Square sides are 20% of this length. Femoral outline is not necessarily representative for all femora studied.

The location of the fabellar centre relative to Blumensaat's line appeared similar in all assessed radiographs, despite the significant pairwise differences between groups. While the location of the best-fit centre generally lay cranial to the fabella, due to size-related anatomical differences, the distance between the fabella and the centre of the best-fit circle was inconsistent; therefore, use of the fabella as a guiding landmark to get the best-fit circle centre might not be accurate. Nevertheless, defining a landmark location will probably be more straightforward in larger breeds because of their more similar anatomical features in the distal femur. Standardizing the procedure will be more challenging in smaller breeds, and pre- and intraoperative measurement of anchor site position, or another templating method, is recommended for accurate surgery.

The variation seen here in best-fit circle centres reflects the varying anatomy of the distal femur both between larger and smaller dogs and between the smaller breeds themselves. Limited data are available on femoral condylar morphology, despite morphological studies in medium to large breed dogs, and in small breeds.[23,26–29] A trend to a more "vertically" oriented trochlea was noted in small breeds with medial patellar luxation.[23] Visually, many of our small breed dogs had "hockey-stick"-shaped distal femora and a relatively large radius to the trochlear arc, resulting in placement of the best-fit centre caudal to the metaphysis. In such cases, placement of a bone anchor relatively distally to ensure appropriate suture tension with the stifle in extension while avoiding excessive tension at other angles might be a solution: if both distal and proximal stabilization is required, a double anchor/suture system may be required, or an alternative means of stabilizing the patella should be employed. Further evaluation in clinical cases is warranted.

Patient groups were selected based on the availability of radiographs and records and potential application of patellofemoral sutures. The authors were interested in highlighting potential differences or similarities between dogs without a medial patellar luxation or cranial cruciate ligament rupture diagnosis and those with either diagnosis. Both medial patellar luxation and cranial cruciate ligament rupture

Table 2 Pairwise multivariate comparisons for fabellar and best-fit circle centres

		CCLR_L	Normal_S	CCLR_S	MPL_S
Best-fit circle	Normal_L	0.59	<0.001	<0.001	<0.001
	CCLR_L		0.02	<0.001	<0.001
	Normal_S			<0.001	0.19
	CCLR_S				0.01
Fabella	Normal_L	0.5	0.33	0.18	0.02
	CCLR_L		0.03	0.73	<0.001
	Normal_S			0.005	0.28
	CCLR_S				<0.001

Note: Pairwise comparisons for coordinate locations between normal, cranial cruciate ligament rupture (CCLR), and medial patellar luxation (MPL) groups for large (L, >15 kg) and small (S, ≤15 kg) dogs.

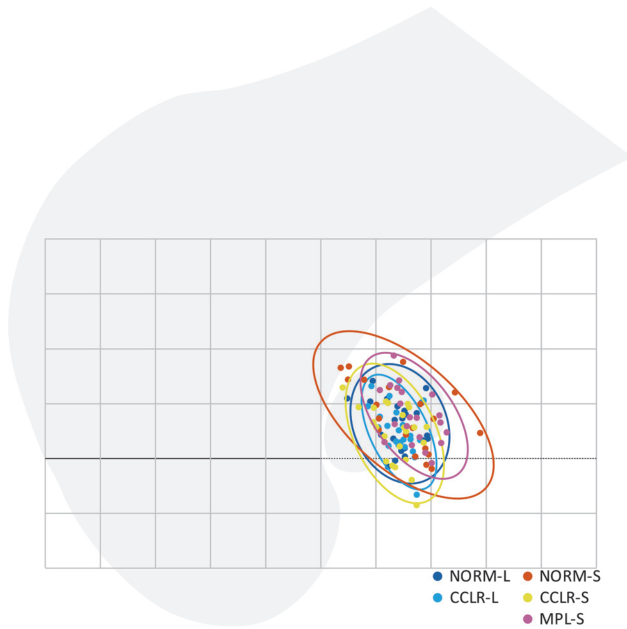

Fig. 4 Ninety-five percent confidence ellipses for fabellar centre locations. Fabellar centres were found for each dog size (small, ≤15 kg – S; large, >15 kg – L) and category (normal – NORM, cranial cruciate ligament rupture – CCLR, medial patellar luxation – MPL) and normalised to the length of Blumensaat's line. Error ellipses were calculated by derivation of eigenvalues and major axis regression. The solid horizontal line represents Blumensaat's line. Square sides are 20% of this length. Femoral outline is not necessarily representative for all femora studied.

can contribute to each other's clinical presentation.[5,6,13,30,31] In one report of concomitant cranial cruciate ligament rupture in small breed dogs with medial patellar luxation, 67 of 162 dogs developed cranial cruciate ligament rupture, and this was associated with higher medial patellar luxation grades.[30] Likewise, medial patellar luxation can occur as an uncommon complication of cranial cruciate ligament rupture surgery in larger dogs, possibly due to unconstrained internal rotation or persistent cranial tibial subluxation.[31] There were insufficient medial patellar luxation cases in dogs over 15 kg at our institution for inclusion in our study in the period examined.

This study has some limitations. First, only a two-dimensional analysis was performed, whereas the femoral condyles have a three-dimensional structure which may affect the distance assumptions. Another limitation was that since the study was retrospective, normal cases, without medial patellar luxation or cranial cruciate ligament rupture, were selected based on a recorded history that did not indicate orthopaedic problems. This means that it was impossible to perform clinical examinations to rule out the absence of patellar luxation or other stifle conditions, and that subsequent development of patellar luxation or cranial cruciate ligament rupture might have occurred in some dogs in the normal groups. The cut-off for small and large dogs was arbitrarily set at 15 kg, although similar limits have been employed in the literature.[32,33] We used the trochlear ridge as a proxy for the location of the patellar centre during stifle joint extension and flexion. Due to the retrospective nature of this study, multiple radiographic positions were not available. However, based on our preliminary analysis using large breed dog stifle joints, it does not seem unreasonable to use the trochlear ridge as a patellar proxy, since the coefficients of variation of radii for the trochlear ridge and patella were not significantly different. If these two structures had different best-fit centres, we would have expected significant differences in their coefficients of variation relative to the single point used. Whether this holds true for all sizes of dog and femoral conformations is unknown, but similar anatomical relationships could be expected to exist across breeds.

The presence of osteoarthritis may have affected some measurements in the cranial cruciate ligament rupture patient groups, due to the presence of marginal osteophytes around the fabella and the proximal and distal trochlear ridge. While the outline of the trochlear ridge for definition of the best-fit circle was unaffected by osteophytosis, identification of the proximal landmark may have been slightly affected by severe osteophytosis. Fabellar osteophytes did not noticeably obscure identification of the fabellar centre. Therefore, any effect of osteophytosis on the results presented here was likely to be small. Finally, following trochleoplasty for medial patellar luxation, the rotational centre of the patella may be altered, especially if the depth of trochlea is not increased uniformly along its length. It was not possible to model this effect here. However, our observations in medial patellar luxation patients are that the lateral trochlear ridge is generally unaffected by hypoplasia, and since the lateral parapatellar fibrocartilage should ride along this ridge, use of the lateral trochlear ridge to determine the best-fit centre is likely still valid. Further evaluation in prospective studies examining patients pre- and postoperatively is recommended to confirm or refute this assumption.

In conclusion, the fabella is unlikely to be the best choice for anchoring a patellar anti-rotational suture. Use of the best-fit circle centre to place a suture anchor should be preferred to maximise suture isometry during joint flexion and extension in large and small breed dogs, provided this point lies within the femoral metaphysis.

Data Availability

Data related to this study are available at: https://doi.org/10.6084/m9.figshare.20080523.v1

Authors' Contributions

J.E.M. conceptualized the study, P.M. designed the study, P.M. acquired the data, J.E.M. and P.M. analysed and interpreted the data, drafted the manuscript and are accountable for the relevant content.

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Conflict of Interest

None declared.

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