

## Diagnostic value of patellofemoral parameters in small breed dogs with medial patellar luxation: a tangential X-ray study

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**ABSTRACT.** Knowing the diagnostic value of radiological patellofemoral parameters is important for evaluating the status of small-breed dogs with medial patellar luxation (MPL). This retrospective survey was conducted in four small dog breeds (Mini Pinscher, Pomeranian, Chihuahua, and Yorkshire terrier) on 46 healthy stifle joints and 72 joints with grade II and III MPL. The following morphometric parameters were measured on tangential radiographs: trochlear sulcus angle, lateral and medial trochlear inclination angles, trochlear depth, horizontal and vertical patellar diameters, length of the lateral and medial patellar facets, lateral and medial facet angles, Wiberg angle, congruence angle, and axial linear patellar displacement. Receiver operating characteristic (ROC) analysis was performed to evaluate the cut-off values, sensitivity, and specificity of the parameters associated with MPL. The trochlear sulcus angle and trochlear depth were capable of consistently identifying the MPL-affected joints (AUCs > 0.9). The parameters describing the position of the patella within the trochlear groove (congruence angle and axial linear patellar displacement) were found to be the most accurate, with an AUC of over 0.990 and a sensitivity/specificity of over 94%. The patellar morphology parameters had no diagnostic value in distinguishing between healthy and MPL stifles.

**Keywords:** patella; luxation; radiology; ROC analysis; trochlea; morphology; congruence.

## INTRODUCTION

Medial patellar luxation (MPL) is a common orthopaedic condition in dogs (Di Dona *et al.*, 2018). However, its pathogenesis is still not completely understood. Most cases are considered developmental, with anatomical deformities leading to pelvic limb malalignment and stifle extensor mechanism deficiency, such as coxa vara/valga, smaller anteversion angle, distal external femoral torsion, internal proximal tibial torsion, patella alta, and shallow trochlear groove (Perry & Dejardin, 2021; Sasaki *et al.*, 2022). The breed is the most significant risk factor for the development of MPL (Kalff *et al.*, 2014). Dogs from small breeds are about 12 times more susceptible than large breeds, particularly Pomeranians, Yorkshire Terriers, Chihuahuas, Poodles, Bichons and Pinschers (Bound *et al.*, 2009; O'Neill *et al.*, 2016).

Medial patellar luxation in dogs can develop without clinical signs. Assessment of the possibility of its progression to clinical disease is valuable for dog owners with regard to informed decision making regarding pet health (Farrell, 2022). The diagnosis is routinely based on clinical signs and imaging findings (Linney *et al.*, 2011). The results of the orthopedic examination, however, depend strongly on the experience of veterinarians in diagnosing MPL, especially in grade II cases when the patella may only be temporarily located within the sulcus.

Apart from identification of the patellar position within the trochlear groove, radiography of the stifle joints with

MPL may confirm or reject the presence of secondary osteoarthritis and cranial cruciate ligament damage. Accurate and sensitive radiological parameters are, therefore, important for assessing the condition of bone structures and making adequate decisions regarding the necessary surgical intervention (Marino & Loughlin, 2010).

Receiver operating characteristic (ROC) analysis is an approved method for evaluating and comparing the diagnostic value of radiological examinations (van Erkel & Pattynama, 1998). Over the past decade, it has been increasingly used not only in radiology but also in clinical biochemistry (Glazkov *et al.*, 2020; Nahm, 2022). ROC analysis was designed to assess the overall diagnostic performance of a test, to determine an object from the study sample as either positive or negative based on a specific classifier, and to calculate the optimal cut-off value showing the best diagnostic performance. ROC curves were also used to compare the performance of two or more diagnostic tests.

In human medicine, there are numerous studies on patellofemoral diagnostic imaging parameters, and the use of ROC analysis to outline those that seem most relevant in the diagnosis of patellar instability (Ridley *et al.*, 2016; Prakash *et al.*, 2016; Geraghty *et al.*, 2022; Kim & Parikh, 2022). To date, in dogs, ROC analysis data on sensitivity, specificity, and cut-off values have been reported only for trochlear groove morphometric parameters in small and large breeds (Longo *et al.*, 2023) and proximodistal patellar position indices (Murakami *et al.*, 2023); however, there

are no data on parameters of patellar morphology and patellofemoral alignment. This information seems valuable, as lameness affecting the opposite limb might have been missed in cases of bilateral MPL. In addition, half of the asymptomatic dogs with grade II MPL have been reported to develop chronic lameness or require surgery later in life (Hamilton *et al.*, 2020).

The aim of this retrospective tangential radiological study was to identify parameters of trochlear anatomy, patellar anatomy, and patellofemoral congruence that differ significantly between healthy small-breed dogs and dogs with medial patellar luxation grades II and III, their cut-off values, and to assess their clinical diagnostic usefulness.

## MATERIAL AND METHODS

### Study cohort

The present single-observer retrospective survey was performed using tangential radiographs of 46 healthy stifle joints and 72 joints with grade II and III medial patellar luxation. All animals were of four small breeds: Mini Pinscher, Pomeranian, Chihuahua, and Yorkshire terrier.

The control group included 23 dogs (10 female and 13 male) who were referred to the clinic for prophylactic orthopedic examination or for minor interventions requiring anesthesia, mostly dental procedures. The median age of the dogs at the first presentation was 12 months (range, 8–28 months), and the median body weight was 2.6 kg (from 0.9–4.0 kg). The breed distribution was 12 Mini Pinschers, four (4) Pomeranians, three (3) Chihuahuas, and four (4) Yorkshire terriers. Both limbs of the animals were radiographed and measured, and 24 healthy stifles were examined from Mini Pinschers, eight (8) from Pomeranians, six (6) from Chihuahuas, and eight (8) from Yorkshire terriers. The inclusion criteria for the healthy joint group were a negative patellar displacement test (for detection of patellar subluxation or ligament laxity) and dancing patella test (for detection of joint effusion), as described by Verez-Fraguela *et al.* (2017), symmetrical femoral and gluteal muscles of both limbs, and lack of signs of long-term proprioceptive dysfunction.

The medial patellar luxation group included 43 dogs (17 Mini Pinschers, 12 Pomeranians, 10 Chihuahuas, and 4 Yorkshire terriers) diagnosed by physical examination and radiography. The MPL grade was determined according to Putnam's routine clinical classification – 41 of joints as grade II MPL and the other 31 as grade III MPL. In dogs with bilateral luxation, both stifles were included, whereas only the affected joint was included in dogs with unilateral luxation. Dogs were of similar age (median; range – 14 months; 9–72 months) and body weight (median; range – 2.7 kg; 1–5.7 kg) as controls. The male-to-female ratio was 18/25. Of the 72 stifle joints from the MPL group, 44 were from female dogs and 28 were from male dogs. The breed distribution was 30 joints from Mini Pinschers, 19 joints from Pomeranians, 18 joints from Chihuahuas, and

five (5) joints from Yorkshire terriers. Informed consent was obtained from the owners of all patients involved in the study.

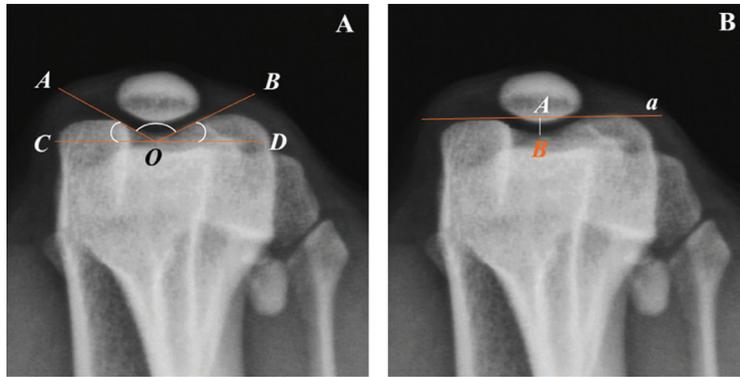
### Measurements

After sedation, radiographs were obtained in a tangential (skyline) view using Bucky Diagnost CS4 stationary X-ray equipment (Philips, Bucky Diagnost CS4, Holland) with an iQ-CR ACE acquisition station and iQ-VIEW/PRO version 2.7. software. The exposure data was uniform at 50 kV and 10 mA. Patients were positioned according to the vertical position of the X-ray tube; in ventral recumbency, the examined stifle was flexed as much as possible. After palpation of the distal femur and patella, the X-ray beam was centered at the distal femur level between the condyles. All measurements were performed by a single observer using the image analysis system of the X-ray equipment software.

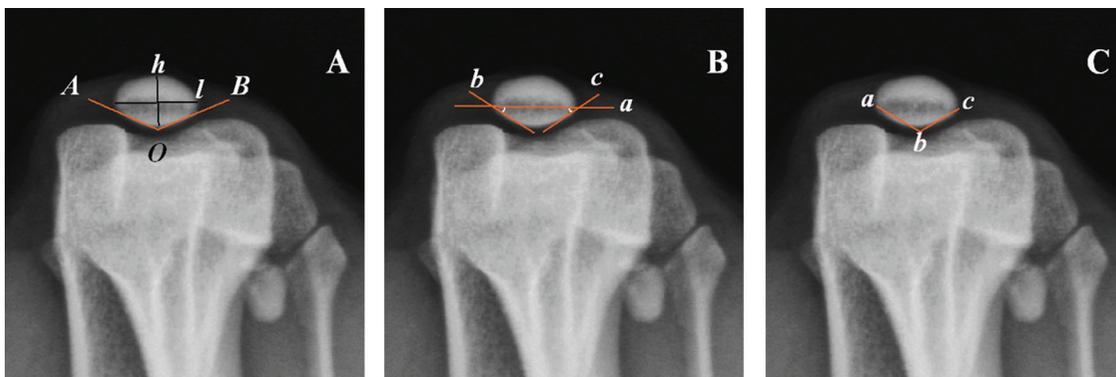
The morphometric parameters selected for the evaluation of trochlear morphology were trochlear sulcus angle (Brattstroem, 1964), lateral and medial trochlear inclination angles (Laurin *et al.*, 1978), and trochlear depth (Pfirrmann *et al.*, 2000) (Figure 1). Patellar morphology was assessed using the horizontal and vertical patellar diameters (Staubli *et al.*, 1999), length of the lateral and medial patellar facets (Wiberg, 1941), lateral and medial facet angles (Jimenez *et al.*, 2021), and Wiberg angle (Wiberg, 1941) (Figure 2). Two parameters, congruence angle (Merchant *et al.*, 1974) and axial linear patellar displacement (Urch *et al.*, 2009), were used to describe patellofemoral alignment in the axial plane (Figure 3).

### Statistical analysis

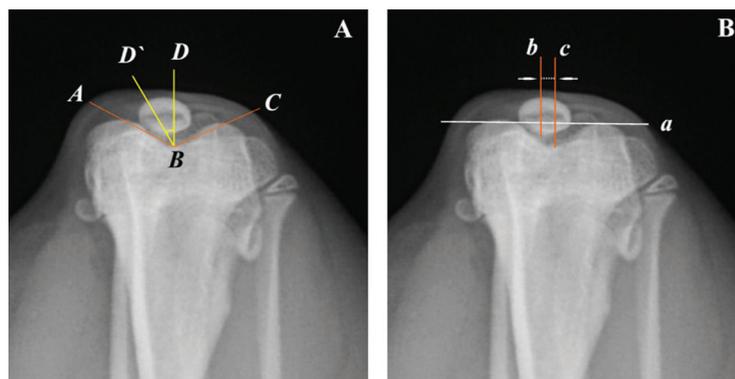
The measurements are reported as median values and the minimum-maximum range. The Shapiro-Wilk test was used to evaluate the normality of data distribution. The Mann-Whitney U-test was used to compare the differences in numerical parameters between healthy joints and joints with medial patellar luxation at a level of  $P < 0.05$ . The Chi-square test was used to assess the association between MPL and categorical variables (sex and breed). A non-parametric receiver operating characteristic (ROC) curve analysis was performed using the recommended algorithm of DeLong *et al.* (1988) to calculate optimal cut-off values of parameters distinguishing healthy and medial patellar luxation joints on the basis of the Youden J statistic, the areas under the ROC curves (AUCs) as measures of diagnostic parameter accuracy, and the sensitivity and specificity of classifiers. The interpretation of the AUC as a measure of diagnostic accuracy was as follows: 0.90–1: excellent diagnostic test; 0.80–0.90: good diagnostic test; 0.70–0.80: fair diagnostic test; 0.60–0.70: poor diagnostic test; and 0.50–0.60: fail (Nahm, 2022). All statistical analyses were performed using MedCalc 15.8 (Belgium).



**Figure 1.** Tangential view of normal Pomeranian stifle. A) The sulcus angle ( $\angle AOB$ ) is formed by lines connecting the lateral and medial femoral condyles with the trochlear bottom. The lateral ( $\angle BOD$ ) and medial ( $\angle AOC$ ) trochlear inclination angles are formed by the lines tangential to the posterior condyle ( $CD$ ) and the line passing from the sulcus center to the lateral ( $BO$ ) and medial ( $AO$ ) condyles; B) trochlear depth ( $AB$ ) is the segment between the point of interception of the line passing through both trochlear facets ( $a$ ) and the perpendicular line drawn from the trochlear bottom.



**Figure 2.** Tangential view of a normal Pomeranian stifle. A) The Wiberg angle ( $\angle AOB$ ) is formed by the medial and the lateral patellar facet tangents. The length between the most medial and the most lateral patellar edges corresponds to the horizontal patellar diameter ( $l$ ), and the length between the farthest anterior and posterior patellar poles corresponds to the vertical patellar diameter or height ( $h$ ); B) the lateral patellar facet angle is formed between the patellar horizontal diameter (line  $a$ ) and the lateral patellar facet tangent ( $c$ ); the medial patellar facet angle is formed between line  $a$  and the medial patellar facet tangent ( $b$ ); C) lateral ( $ab$ ) and medial ( $bc$ ) patellar facets were measured from the patellar apex to the most lateral and medial edges of the patella, respectively.



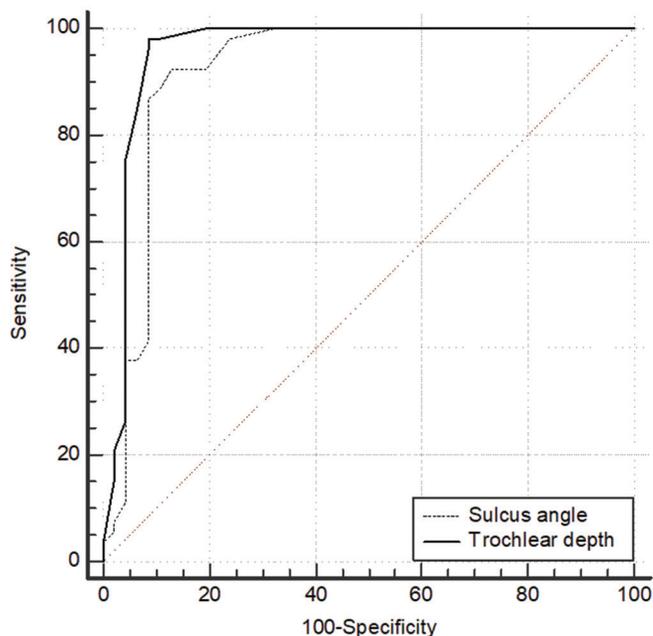
**Figure 3.** Tangential view of a Chihuahua stifle with grade II luxation. A) The congruence angle ( $\angle DBD'$ ) is formed between the sulcus angle bisector ( $BD$ ) and the line passing through the trochlear bottom and the most posterior patellar edge ( $BD'$ ); B) linear axial patellar displacement is the distance between two perpendiculars to the line connecting the femoral condyles ( $a$ ): one from the trochlear groove bottom ( $c$ ) and another from the most posterior patellar edge ( $b$ ).

## RESULTS

Analysis of the association between signalment data and the presence/absence of MPL showed no statistically significant effects of breed ( $P = 0.42$ ), age ( $P = 0.09$ ), or sex ( $P = 0.38$ ).

The patellofemoral parameters measured in both joint groups are presented in Table 1. All the studied parameters of trochlear anatomy and patellofemoral alignment were significantly different between the groups. Among the patellar morphological parameters, the horizontal patellar diameter, lateral patellar facet length, and lateral patellar facet angle did not demonstrate significant between-group differences (Table 1).

The results of the ROC analysis (Table 2) showed that the sulcus angle and trochlear depth had excellent diagnostic value, as seen from the areas under the ROC curve



**Figure 4.** ROC curves of sulcus angle (AUC = 0.920;  $P < 0.001$ ) and trochlear depth (AUC = 0.956;  $P < 0.001$ ) as trochlear morphology parameters distinguishing healthy from MPL-affected joints.

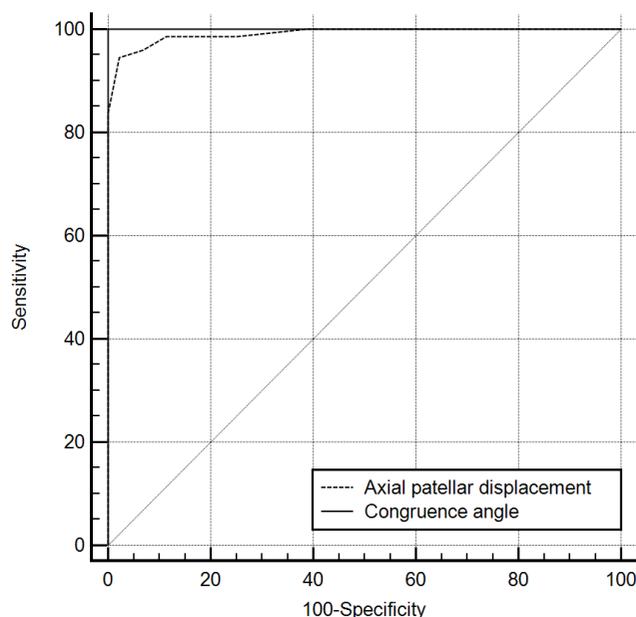
## DISCUSSION

In dogs from small breeds, patellar luxation occurs as a consequence of complex morphological musculoskeletal abnormalities affecting the entire pelvic limb, but the pathogenetic role of the shallow trochlear groove (Longo *et al.*, 2023) and medial femoral condyle hypoplasia (Garnoeva, 2021) is thought to be the leading cause. Therefore, tangential radiographs of canine stifles are preferred for satisfactory evaluation of trochlear groove depth and shape.

(AUCs) (Figure 4). The cut-offs of these parameters had a sensitivity of over 90% (92.45% for sulcus angle and 98.1% for trochlear depth); therefore, they were deemed capable of reliably distinguishing medial patellar luxation joints. The lateral and medial inclination angles were defined as poor diagnostic classifiers.

The parameters of patellar morphology did not have high diagnostic value, as their AUC values corresponded to the definition of a poor diagnostic test, except for the Wiberg angle, which was interpreted as a fair diagnostic test.

According to the results, the two indices of patellofemoral alignment in the axial plane (congruence angle and axial linear patellar displacement) corresponded to the definition of excellent diagnostic tests. The congruence angle exhibited maximum sensitivity and specificity of 100% (Table 2, Figure 5).



**Figure 5.** ROC curves of the congruence angle (AUC = 1.000;  $P < 0.001$ ), axial linear patellar displacement (AUC = 0.990;  $P < 0.001$ ), medial facet length (AUC = 0.991;  $P < 0.001$ ), and medial facet angle (AUC = 0.956;  $P < 0.001$ ) as patellofemoral alignment parameters distinguishing healthy joints from MPL-affected joints.

In diagnostic practice, the aim of ROC analysis is to choose objective parameters that will yield maximum true positives and true negatives and minimize false positive and false negative results. The sensitivity of a parameter is a measure of its ability to correctly identify pathological states (in our case, the presence of medial patellar luxation) and its specificity to correctly identify the lack of pathology. In a clinical setting, it is especially important not to “miss” positive cases and to reduce false-negative results as much as possible.

**Table 1.** Trochlear, patellar, and patellofemoral alignment parameters in both joint groups. Values are presented as medians (ranges).

	"Healthy joints (n = 46)"	"MPL joints (n = 72)"	P
<i>Trochlear parameters</i>			
Lateral trochlear inclination angle (°)	29.5 (12.0-39.0)	25.0 (11.0-35.0)	< 0.0001
Medial trochlear inclination angle (°)	28.0 (14.0-35.0)	23.0 (9.0-32.0)	0.0002
Sulcus angle (°)	122.0 (112.0-153.0)	136.0 (126.0-160.0)	< 0.0001
Trochlear depth (mm)	2.2 (0.7-3.1)	1.1 (0.5-1.9)	< 0.0001
<i>Patellar parameters</i>			
Horizontal patellar diameter (mm)	5.1 (2.7-7.6)	5.3 (2.5-6.6)	0.6493
Lateral patellar facet angle (°)	37.0 (26.0-52.0)	36.0 (28.0-69.0)	0.8809
Lateral patellar facet length (mm)	2.6 (1.7-4.4)	2.8 (1.3-4.3)	0.4741
Medial patellar facet angle (°)	34.0 (18.0-51.0)	38.0 (28.0-58.0)	0.0285
Medial patellar facet length (mm)	2.6 (1.6-4.8)	3.0 (1.0-4.1)	0.0099
Patellar thickness (mm)	3.1 (1.8-5.0)	2.8 (1.3-4.1)	0.0012
Wiberg angle (°)	123.0 (112.0-136.0)	131.0 (110.0-178.0)	< 0.0001
<i>Patellofemoral alignment parameters</i>			
Axial linear patellar displacement (mm)	0.2 (0.1-0.8)	1.2 (0.3-11.5)	< 0.0001
Congruence angle (°)	-3.0 (-10.0 to -1.00)	-30.5 (-123.0 to -14.0)	< 0.0001

**Table 2.** Areas under the ROC curves (AUC), cut-off values, sensitivity, and specificity of the studied patellofemoral parameters.

	AUC	Cut-off value	Cut-off sensitivity	Cut-off specificity
<i>Trochlear parameters</i>				
Sulcus angle (°)	0.920***	> 129	92.45	86.96
Lateral trochlear inclination angle (°)	0.763***	≤ 25	58.49	86.96
Medial trochlear inclination angle (°)	0.723**	≤ 23	54.72	84.78
Trochlear depth (mm)	0.956***	< 1.6	98.1	91.3
<i>Patellar parameters</i>				
Patellar thickness (mm)	0.678***	≤ 3.7	97.14	32.61
Medial patellar facet angle (°)	0.620*	> 37	54.29	65.22
Medial patellar facet length (mm)	0.642*	< 2.7	68.57	65.22
Wiberg angle (°)	0.738***	< 129	58.57	76.09
<i>Patellofemoral alignment parameters</i>				
Congruence angle (°)	1.000***	≤ -14	100	100
Axial patellar displacement (mm)	0.991***	> 0.7	94.59	97.73

\* P < 0.05; \*\* P < 0.01; \*\*\* P < 0.001.

AUC is widely used to measure the accuracy of diagnostic tests. The ROC curves closer to the upper-left corner of the graph denote the tests with higher accuracy. The ideal ROC curve had an AUC of 1.0. Curves closer to the 45° diagonal were considered to have low accuracy and were meaningless diagnostic tools. Therefore, in general, acceptable classifiers must have AUCs greater than 0.8 (Nahm, 2022).

In human medicine, many studies have performed ROC analysis on patellofemoral parameters associated with patellar luxation to report their cut-off values, sensitivity, and specificity (Hedgecock *et al.*, 2022; Geraghty *et al.*, 2022; Kim & Parikh, 2022). In canine orthopaedics, ROC analysis has been used to evaluate parameters related to developmental diseases, such as hip dysplasia (Gaspar *et al.*, 2016) and medial elbow coronoid disease (Hersh-Boyle *et al.*, 2021). In dogs with patellar luxation, only the cut-off values of femoral trochlear morphological parameters (Longo *et al.*, 2023) and indices of proximodistal patellar position (Murakami *et al.*, 2023) have been reported.

In the CT study by Longo *et al.* (2023), the cut-off value for sulcus angle in small-breed dogs was  $> 134^\circ$ , with a sensitivity and specificity of 80% and 100%, respectively. These values were comparable to those in the present tangential X-ray study: the cutoff value for the sulcus angle was  $> 129^\circ$ , the sensitivity was 92.45%, and the specificity was 86.96%. The differences in cutoff values may be explained by the different imaging techniques used. A similar difference was reported in a comparative study of human sulcus angles evaluated by radiography ( $145^\circ$ ) and magnetic resonance imaging ( $158^\circ$ ), which concluded that, although sometimes underestimated, radiography was also reliable for the diagnosis of trochlear dysplasia (Donaldson *et al.*, 2012).

In a human study, Geraghty *et al.* (2022) provided information on the sensitivity and specificity of parameters measured on radiographs between 2010 and 2022 to evaluate patellar instability. The results confirmed that trochlear depth, sulcus angle, and lateral and medial inclination angles were highly sensitive and specific parameters of trochlear dysplasia predisposing patients to patellar luxation.

The present study is the first to evaluate the diagnostic value and cutoffs of parameters of patellar morphology and patellofemoral alignment in small-breed dogs with medial patellar luxation. The results demonstrated that the best diagnostic parameters were those describing the translation of the patella in the sulcus: congruence angle and linear axial patellar displacement, both with AUCs over 0.99 and sensitivity over 94%. The congruence angle showed the maximum possible sensitivity and specificity (100% each).

In men, only a few radiological parameters were found to be accurate for diagnosing patellar luxation. In a study of 1392 stifle joints with patellar luxation and a control group of 1525 healthy joints, statistically significant differences ( $P < 0.0001$ ) were observed in the patellar height, lateral patellar facet angle, and trochlear sulcus angle (Smith

*et al.*, 2011). The congruence angle showed only a slight difference between the healthy and diseased joints. The trochlear groove depth was outlined as one of the most accurate parameters for patellar instability in an overview by Ridley *et al.* (2016). The high variability between the healthy and instability groups as a cause of the low specificity is discussed.

In a radiological study to determine the reference values of patellofemoral parameters in Koreans (Prakash *et al.*, 2016), ROC analysis showed that the most important indices of patellar instability were trochlear depth (AUC = 0.852), increased congruence angle (AUC = 0.985) and patellar tilt (AUC = 0.974). These results are consistent with data from the present study.

The limitations of the present study were mainly related to the small number of dogs in the study cohort. A larger number of dogs, both healthy and with patellar luxation, would increase the reliability of the results and yield more precise deviation thresholds. With data from a larger population, breed- and sex-specific thresholds may be calculated. Despite efforts to reduce external influences (use of standardized procedures and protocols, uniform exposure data, and regular technical maintenance of radiography equipment), the effects of systemic and random observational errors were not investigated in this study. The participation of more observers can reduce subjective measurement errors owing to the identification of osseous landmarks on radiographs.

## CONCLUSION

In dog stifles with medial patellar luxation, the calculation of indices "sensitivity" and "specificity" allowed defining optimum cut-offs of diagnostic imaging parameters of trochlear morphology and patellofemoral alignment with regard to the optimization of therapeutic strategies.

Of all the analyzed tangential radiological patellofemoral parameters, congruence angle, axial linear patellar displacement, sulcus angle, and trochlear depth had the highest sensitivity and specificity. Based on the areas under the ROC curves, they were determined to be excellent diagnostic tests with AUCs  $> 0.9$ . The most sensitive parameters were those describing the position of the patella within the trochlear groove: the congruence angle and linear axial patellar displacement, both with AUCs  $> 0.99$ , and sensitivity  $> 94\%$ , which indicated that they were the most reliable for distinguishing stifles of dogs from small breeds with medial patellar luxation from healthy stifles. The patellar morphology parameters had no practical diagnostic value. In conclusion, evaluation of trochlear groove morphology and patellofemoral alignment on tangential radiographs is recommended in dogs suspected to have low-grade medial patellar luxation with respect to treatment decision-making, as well as in sexually mature, clinically healthy dogs from susceptible small breeds, especially in breeding animals.

## DECLARATIONS

### Competing interests statement

The author declares no competing interests.

### Ethics statement

The study was performed after obtaining informed consent from the owners of the participating dogs.

### Author contributions

Conceptualization, methodology, measurements, analysis, original draft preparation, review and editing, and visualization – RG.

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