Evaluation of a quantitative radiographic technique for differentiating normal and unilateral luxation of sacroiliac joints in cats: a pilot study analysis

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Objective: The objective of this study was to evaluate a radiographic technique for differentiating normal feline sacroiliac joints from those with unilateral luxation.

Materials and Methods: Fifty normal feline pelvic radiographs (control group) and 50 radiographs with unilateral sacroiliac luxation (luxation group) were assessed. Three angles were measured on each radiograph using a reference line connecting the most cranial aspect of the iliac wings and three anatomical landmarks: the cranial endplate of lumbar vertebra 6, the caudal endplate of lumbar vertebra 6 and the cranial endplate of lumbar vertebra 7. Study feasibility was assessed by a single observer on 20 radiographs per group. In the second phase, measurements were obtained from 30 radiographs per group and recorded twice by three blinded observers, with a 4-week interval between assessments. Angular differences between groups were analysed, along with optimal cut-off values, diagnostic performance and inter- and intra-observer reliability.

Results: All three measured angles were significantly smaller in the control group than in the luxation group. Specifically, angular measurements exceeding 2.3° at the cranial endplate of lumbar vertebra 6, and 2.4° at both the caudal endplate of lumbar vertebra 6 and the cranial endplate of lumbar vertebra 7, were indicative of unilateral sacroiliac luxation. The respective sensitivity and specificity values of the aforementioned cut-off angles were 90% and 97% for the first, 90% and 94% for the second and 86% and 94% for the third. These thresholds were associated with consistently high inter- and intra-observer reliability.

Clinical Significance: These proposed angular cut-offs provide a reliable diagnostic criterion for identifying unilateral sacroiliac luxation in cats and may enhance diagnostic confidence and accuracy, particularly in primary care settings where radiography remains the preferred imaging modality for feline pelvic injuries.

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INTRODUCTION

Pelvic fractures account for approximately 32% of all fractures in the feline patient (Bird & de Vicente, 2019; Flanders & Bookbinder, 1992). A retrospective study from the early 1990s found that sacroiliac (SI) luxation was the second most common traumatic pelvic injury, accounting for 27.3% of all pelvic fractures (Flanders & Bookbinder, 1992). Sacroiliac luxation is reported to be bilateral in 23% to 37% of cases (Bird & de Vicente, 2019; Meeson & Geddes, 2016; Shales et al., 2010). The degree of displacement in SI luxation depends on the type and severity of the associated pelvic fractures (Lembersky et al., 2022). The diagnosis of SI luxation is primarily based on radiographic imaging or advanced techniques such as computed tomography (CT). Cranial displacement of the iliac wing and a step between the ilium and the caudal sacral wing on the affected side, as well as asymmetry of the pelvic box and narrowing of the pelvic canal, are usually indicative of SI fracture luxation (Moens & DeCamp, 2018).

A recent study proposed a novel radiographic method for distinguishing normal canine sacroiliac joints from those affected by luxation (Lembersky et al., 2022). This technique involves measuring the angle between a line parallel to the cranial endplate of the sixth lumbar vertebra (L6) on ventrodorsal radiographs of the canine pelvis, and a line tangential to the most cranial aspect of the iliac wings. The study determined that a cut-off angle of 2° or greater provided the highest accuracy, sensitivity and specificity in distinguishing between luxated and normal SI joints (Lembersky et al., 2022).

The aim of this study was to adapt and validate this radiographic technique for the diagnosis of unilateral SI luxation in cats, and to establish a clinically applicable diagnostic cut-off angle, even in cases where the degree of displacement is minimal and radiographic changes are subtle. In specific, this study tested the following hypotheses: (1) The measured angles differ significantly between cats with normal SI joint alignment and those with unilateral SI luxation, and (2) inter- and intra-observer measurements are precise and consistent, regardless of observer experience.

MATERIALS AND METHODS

Medical records and radiographs of cats presenting to one single referral hospital with pelvic trauma between February 2019 and September 2024 were retrospectively reviewed. Cats with bilateral SI luxation or skeletal abnormalities (e.g. transitional vertebrae) were excluded. All radiographs were anonymised, exported in Digital Imaging and Communications in Medicine (DICOM) format and analysed using veterinary imaging software (Asteris Keystone Omni, Montreal, Canada).

The cats included in this study were classified into two groups: normal and abnormal. Cats in the normal group (CTRL) had ventrodorsal abdominal or pelvic radiographs taken for reasons unrelated to trauma. Their pelvic conformation was assessed as normal by an ECVDI-diplomate radiologist. The abnormal group (LUX) included cats with unilateral SI luxation confirmed via radiography, CT or surgical exploration, with or without concurrent pelvic fractures (Lembersky et al., 2022).

First phase: method validation

In the initial phase, an ECVS diplomate assessed ventrodorsal pelvic radiographs from 20 cats in the CTRL group and 20 cats in the LUX group to evaluate the applicability of a recently developed canine radiographic assessment method in feline cases. Three specific angles were measured based on the intersection of a line tangential to the most cranial aspect of the iliac wings with three anatomical landmarks: CrL7, the angle between a line parallel to the cranial endplate of the seventh lumbar vertebra (L7) and the iliac wings; CdL6, the angle between a line parallel to the caudal endplate of the sixth lumbar vertebra (L6) and the iliac wings; and CrL6, the angle between a line parallel to the cranial endplate of L6 and the iliac wings (Figs 1 and 2).

Second phase: clinical application and observer reliability

A separate set of ventrodorsal pelvic radiographs (30 from the CTRL group and 30 from the LUX group) was selected for further analysis. To ensure an unbiased assessment, images were cropped to include only the most cranial aspect of the iliac wings and the entirety of L6 and L7 (Fig 3). Each radiograph was then

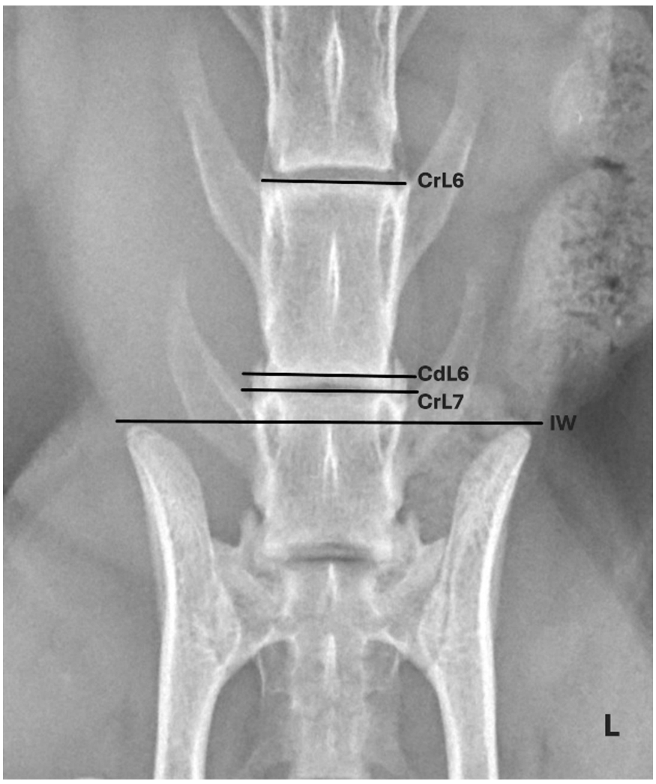

FIG 1. Ventrodorsal radiographs of the normal pelvis of a cat. Three lines have been drawn parallel to the cranial end plate of L6 (CrL6), of the caudal end plate of L6 (CdL6) and the cranial end plate of L7. A line has also been drawn tangential to the most cranial point of both ilium wings.

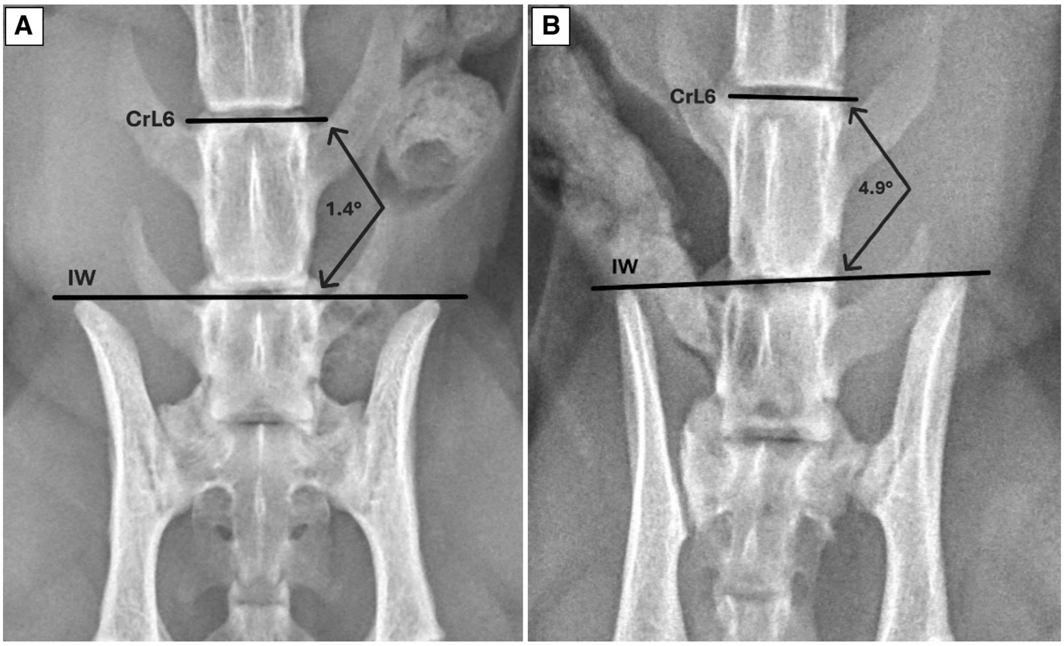

FIG 2. Ventrodorsal radiograph of the normal pelvis of a cat (A) and of the pelvis with unilateral sacroiliac (SI) luxation (B). The angle measured between a line parallel to the cranial endplate of the sixth lumbar vertebra (CrL6) and the line tangential to the ilium wings is 0.9° for the normal pelvis and 5.4° for the pelvis with unilateral SI luxation.

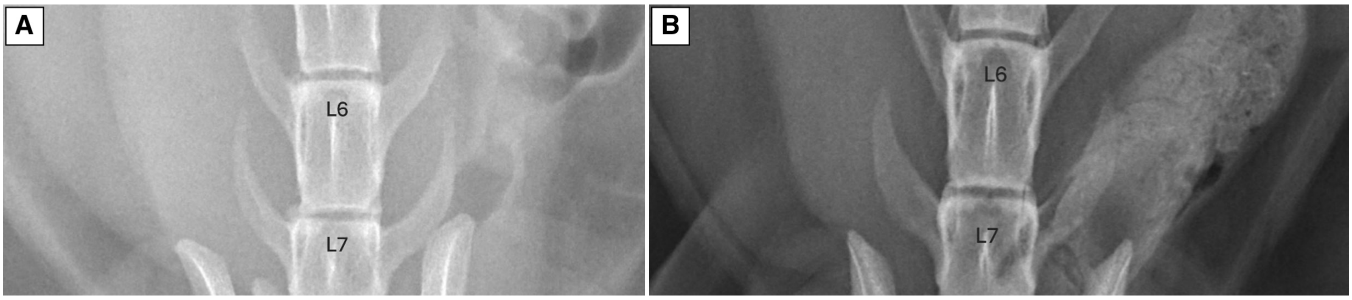

FIG 3. Cropped ventrodorsal radiographs of the pelvis of a normal cat (A) and of a cat with sacroiliac luxation (B). This allowed the observer to perform unbiased measurements of the three lines parallel to the end plates of L6, L7 and of the line tangential to the most cranial point of both ilium wings.

randomly assigned a number using an online random number generator (Google, Mountain View, CA, USA) and uploaded into a single folder for analysis.

All assessments were performed twice by three blinded observers: a surgical intern, a second ECVS diplomate and an ECVDI diplomate. The three previously described angles (CrL7, CdL6 and CrL6) were measured independently on all images, with each observer repeating the measurements after a minimum interval of 4 weeks to assess intra-observer reliability. To assess the potential influence of pelvic positioning on measurement accuracy, both straight and oblique pelvic radiographs were included. The first ECVS diplomate, who had access to the full radiographic image, determined whether each pelvis was positioned straight or oblique. Radiographs were classified as straight when the two obturator foramina appeared symmetrical, and as oblique when asymmetry was present. This classification allowed for a direct evaluation of the potential impact of pelvic mal-positioning on the angular measurements.

Statistical analysis

Data were assessed for normality using the Shapiro–Wilk test; descriptive statistics for variables not being normally distributed are presented as median (25th to 75th percentiles) [m (Q1 to Q3)].

First phase

Mann–Whitney *U* test was used to investigate differences between groups for each of the studied angles. Independent-samples Hodges–Lehmann median difference was used to calculate the mean estimate and the 95% confidence intervals of the difference between medians of each angle across the groups. To determine the adequacy of the sample size, a post hoc power analysis was performed using the descriptive statistics from this phase. A minimum of nine images per group was calculated, assuming a power of 0.95, an alpha error probability of 0.05 and an effect size of 1.92 for CrL6, 2.11 for CdL6 and 2.06 for CrL7. The effect size was calculated based on each angle's mean and standard deviation in subjects with and without luxation/subluxation.

Second phase

The receiver operating characteristic (ROC) analysis was performed for each studied angle. For this purpose, the median of values that were recorded during the two time points by the three observers was used. The optimal cut-off for each angle was determined based on Youden's J Statistic, and their diagnostic performance is expressed in terms of sensitivity, specificity, positive and negative predictive values and their corresponding 95% confidence intervals. In order to investigate the effect of the animal positioning on the diagnostic performance of the selected cut-offs, for each angle, Fisher's exact test was used to compare the distribution of false-positive plus false-negative *versus* true positive plus true negative results across animals with straight or oblique pelvis.

Inter-observer agreement was tested for each angle at each of the two time points by comparing the measurements of the three different observers, whereas intra-observer agreement was based on the comparison between the measurement of each angle by each of the observers across the two time points. Intraclass correlation coefficients and their 95% confidence intervals were calculated based on a single-rater, absolute-agreement, two-way random-effects model to test inter-rater reliability, and on a single-rater, absolute-agreement, two-way mixed-effects model to test intra-rater reliability. The results were considered excellent with values above 0.9, good if between 0.75 and 0.9, moderate if between 0.5 and 0.75 and poor below 0.5 (Koo & Li, 2016). Statistical analysis was performed with IBM SPSS Statistics (Version 30.0.0.0); statistical significance is based on P-values smaller than 0.05.

RESULTS

First phase

Twenty pelvic radiographs from the CTRL group and 20 from the LUX group were assessed. Descriptive statistics of the angles measured by the first ECVS diplomate are summarised in Table 1.

All measured angles were consistently smaller in the CTRL group than in the LUX group, with an estimated mean difference and 95% confidence intervals for the mean difference being −3.4° (−4.5; −2.5) for CrL6, −4.4° (−5.5; −2.9) for CL6 and − 4.75° (−6; −3.4) for CrL7 ($P<0.001$) (Fig 4).

Second phase

Thirty ventrodorsal pelvic radiographs from each group were assessed and included in the analysis. The ROC curves for the three angles are shown in Fig 5. The area under the curve (AUC) and the diagnostic potential resulted to be excellent for all the three angles. The optimal cut-off angles over which to diagnose SI luxation for

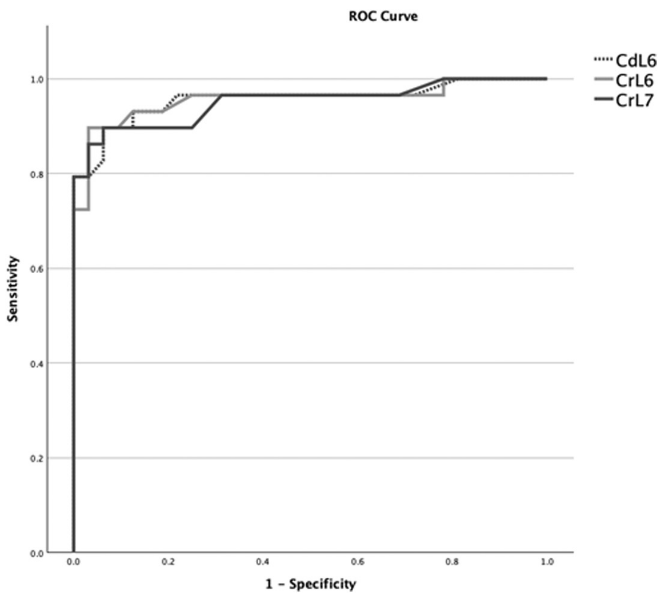

FIG 5. Receiver operating characteristic curve of the three studied angles of the second phase of the study (median values for each measurement from the three observers).

Table 1. Descriptive statistics of the first part of the study

Variable	CTRL (*n*=20) m (Q1 to Q3)	LUX (*n*=20) m (Q1 to Q3)	Median difference estimate	Median difference 95% CI	P
CrL6 (°)	1.2 (0.8 to 1.6)	4.6 (3.4 to 6.3)	−3.4	−4.5; −2.5	<0.001
CdL6 (°)	0.8 (0.3 to 1.3)	5.3 (2.9 to 6.7)	−4.4	−5.5; −2.9	<0.001
CrL7 (°)	0.7 (0.5 to 1.3)	5.6 (3.6 to 7.3)	−4.75	−6; −3.4	<0.001

m (Q1 to Q3) – median (25th to 75th percentiles)
CI Confidence intervals

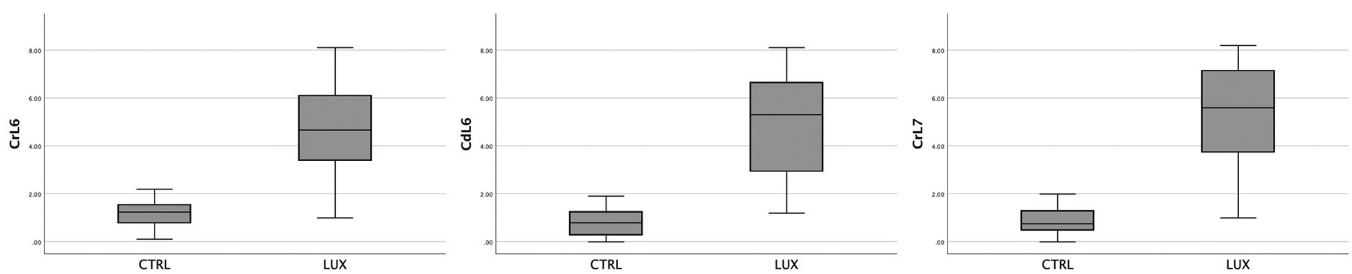

FIG 4. Box and whiskers plot of the three studied angles distribution between groups. For each angle, the difference is statistically significant ($P<0.001$).

Table 2. Best cut-off identified for each studied angle and respective diagnostic properties

Angle	AUC (95% CI)	Best cut-off (°)	Sensitivity (95% CI)	Specificity (95% CI)	PPV	NPV
CrL6	0.956 (0.9 to 1)	2.3	0.897 (0.726 to 0.978)	0.969 (0.838 to 0.999)	0.963	0.912
CdL6	0.956 (0.9 to 1)	2.4	0.897 (0.726 to 0.978)	0.938 (0.791 to 0.992)	0.929	0.909
CrL7	0.951 (0.894 to 1)	2.4	0.862 (0.683 to 0.961)	0.938 (0.792 to 0.992)	0.926	0.880

AUC Area under the curve, CI Confidence intervals, PPV Positive predictive value, NPV Negative predictive value

Table 3. Number of overall false results obtained by each observer for radiographs in which the pelvis was deemed straight versus oblique

	Oblique pelvis false results (*n*/tot)	Straight pelvis false results (*n*/tot)	P
Observer 1			
CrL6	3/31	5/29	0.389
CdL6	4/31	4/29	0.919
CrL7	5/31	3/29	0.510
Observer 2			
CrL6	2/31	4/29	0.369
CdL6	2/31	4/29	0.369
CrL7	2/31	5/29	0.235
Observer 3			
CrL6	2/31	3/29	0.586
CdL6	2/31	2/29	0.945
CrL7	3/31	3/29	0.935

Table 4. Interclass correlation coefficients for inter-rater reliability (first measurement only) and intra-rater reliability

Angle	Interclass correlation coefficient	95% confidence intervals	P
CrL6			
Inter-observer	0.927	0.891 to 0.953	<0.001
Observer 1	0.971	0.952 to 0.982	<0.001
Observer 2	0.983	0.972 to 0.990	<0.001
Observer 3	0.985	0.975 to 0.991	<0.001
CdL6			
Inter-observer	0.944	0.915 to 0.964	<0.001
Observer 1	0.949	0.916 to 0.970	<0.001
Observer 2	0.916	0.860 to 0.950	<0.001
Observer 3	0.986	0.976 to 0.991	<0.001
CrL7			
Inter-observer	0.923	0.885 to 0.950	<0.001
Observer 1	0.959	0.932 to 0.975	<0.001
Observer 2	0.974	0.957 to 0.984	<0.001
Observer 3	0.980	0.966 to 0.988	<0.001

CrL6, CdL6 and CrL7 are described in Table 2. Sensitivity, specificity and their respective 95% confidence intervals for the calculated cut-off angles were 90% (73 to 98) and 97% (84 to 100) for CrL6, 90% (73 to 98) and 94% (80 to 99) for CdL6 and 86% (69 to 96) and 94% (80 to 99) for CrL7. Although the differences were minimal and non-significant, when a cut-off of 2.3° was tested for CrL6, this showed the best diagnostic potential, with a positive predictive value of 96% and a negative predictive value of 91%.

There were 29 cats included in the straightly positioned pelvis group and 31 cats with an obliquely positioned pelvis on the radiographs, these latter being 18/30 in the LUX group and 13/30 in the CTRL group with no significant difference in the prevalence of obliquely positioned radiographs between the two groups (P = 0.2). When compared with cats with a straightly positioned pelvis, subjects with an obliquely positioned pelvis were not associated with a higher proportion of false-positive and false-negative results for each of the optimal cut-offs of the three angles, regardless of the observer's experience (Table 3).

Intraclass correlation coefficients for inter- and intra-rater reliability are shown in Table 4. For each of the studied angles, the agreement between the observers was found to be excellent in both measurement sessions. Similarly, when inter-observer agreement was considered, the coefficients were all in the excellent range. No statistically significant difference was found between inter-observer reliability at the two different time points; therefore, only the coefficients relative to the first measurement are reported.

DISCUSSION

Sacroiliac fracture luxation is a common injury in cats, typically resulting from motor vehicle trauma or falls from heights (Forterre et al., 2004). Due to the rigid, box-like structure of the feline pelvis, unilateral SI luxation typically occurs in conjunction with other pelvic fractures, such as ipsilateral or contralateral pubic fractures, symphyseal separation, ischial fractures or contralateral ilial fractures (Bird & de Vicente, 2019; Montavon & Messmer, 2004). Disruption of the SI joint can lead to pain, impaired ambulation and pelvic canal narrowing, all of which are key indicators for surgical intervention. Although conservative management has been advocated for cats with SI luxation in the absence of concurrent fractures of the weight-bearing axis (Bird & de Vicente, 2019), the majority of studies favour surgical intervention for feline SI luxation cases (Meeson & Geddes, 2016; Moens & DeCamp, 2018; Shales et al., 2010).

Although CT provides a superior means of detailing the type, location and number of bone fragments in pelvic fractures (Sadan et al., 2016), standard radiography (lateral and ventrodorsal or dorsoventral views) remains the diagnostic method of choice in most veterinary primary care practices. The SI joint is a combined cartilaginous and synovial joint, with no bony union between the ilium and the sacrum throughout the animal's life. The cartilage remains unmineralised, creating a region of soft tissue opacity at the level of the joint (Miranda et al., 2019; Monteiro et al., 2013; Sadan et al., 2016), which can sometimes be mistaken for a luxation or subluxation on radiographs (Sadan et al., 2016).

A common qualitative method for diagnosing SI luxation on a well-positioned ventrodorsal radiograph involves observing the curve formed by the caudal aspect of the sacral wing as it transitions to the medial aspect of the iliac wing. The presence of a "step" in this area can indicate SI luxation (Moens & DeCamp, 2018). However, some cases of SI luxation are mild or ambiguous, making accurate diagnosis dependent on the experience of the surgeon.

In this two-part retrospective observational study, the technique described in dogs was applied to a cohort of cats with normal pelvic configuration and with unilateral SI luxation. The first part of the study demonstrated that there was a statistically significant difference between cats with normal SI joints and those with unilateral SI luxation. CrL6, CdL6 and CrL7 were smaller in the CTRL group than in the LUX group. The study also identified cut-off angles greater than or equal to 2.3° for CrL6 and 2.4° for both CdL6 and CrL7 as having excellent diagnostic value, with CrL6 showing the best positive and negative predictive values. The results of our study are similar to the results of the similar study performed in dogs where the identified cut-off angle was 2 for CrL6 (Lembersky et al., 2022). An additional observation from this study was that all three blinded observers found it easier to measure a line parallel to the cranial endplate of L6 compared with the other reference points. This was attributed to the clearer anatomical landmarks of the cranial endplate of L6, which provided a more distinct and reproducible reference for measurement. In contrast, the caudal endplate of L6 and, to an even greater extent, the cranial endplate of L7 were more challenging to delineate. These findings suggest that CrL6 may be the most practical angle for clinical application, further supporting its use and highlighting the relevance of the 2.3° cut-off for diagnosing unilateral SI luxation in cats.

Another factor evaluated was the potential association between pelvic obliquity and reduced diagnostic performance for each of the studied angles. Optimal radiographic positioning is essential for maximising diagnostic accuracy, which can be challenging in general practice, especially when dealing with trauma cases. The findings of this study indicated that, regardless of the observer's level of experience, the proportion of false-positive or false-negative results did not differ between cats with an oblique pelvis and those with a straight pelvis on ventrodorsal radiographs. This finding remained consistent across the optimal cut-off values for all three measured angles.

This study has several limitations related to its retrospective nature, relatively small sample size and study design. The data were collected from a single referral centre over a 5-year period. To ensure a more uniform dataset and minimise heterogeneity, only cats with unilateral SI luxation were included in the abnormal cohort, while those with bilateral SI luxation, spinal fractures or concurrent spinal abnormalities, such as transitional vertebrae, were excluded. Additionally, the study design itself introduces certain limitations. To minimise observer bias, the radiographs used in this two-part study were cropped. However, in a clinical setting, at least two orthogonal radiographs of the affected region should be obtained and properly assessed to ensure accurate positioning and prevent errors such as distortion or magnification (Meomartino et al., 2021; Thrall & Robertson, 2023).

Furthermore, the accuracy of the measurements in this study relied on the assumption that the spinal column remains entire. In cases where concomitant fractures affect the caudal lumbar vertebrae, endplates or iliac wings, the reported cut-off angles may not be reliable.

In conclusion, this study demonstrates that the proposed cut-offs for the three angles provide a reliable diagnostic criterion for unilateral SI luxation in cats, regardless of observer experience, with CrL6 being the most practical angle for clinical application. While further research is needed to confirm the results of this study, the described angles have the potential to be a valuable diagnostic tool in primary care veterinary practice.

Author contributions

T. Kasa was involved in data curation (equal), original draft (lead), writing – review and editing (supporting). A. Danielski was involved in conceptualisation (lead), methodology (lead), data curation (equal), writing – review and editing (lead). M.A. Solano was involved in data curation (equal), formal analysis (equal), writing – review and editing (supporting). F. Santoro was involved in formal analysis (lead), writing – review and editing (supporting). V. Volckaert was involved in data curation (equal), writing – review and editing (supporting).

Conflict of interest

The authors received no financial support for the research, authorship and/or publication of this article. The authors declare no conflicts of interest related to this report.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy restrictions.

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