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# Reference values for dynamic radiographic measurements of lumbosacral junction width in cats

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## Abstract

Lumbosacral instability (LSI) in cats is an important condition which may precede development of degenerative lumbosacral stenosis (DLSS). Pain in the lumbosacral region often causes discomfort, changes in physical activity, behavioral disturbances, and defecation problems. The disease may be missed in its early stages in both two- and three-dimensional static examinations. Dynamic radiographic examination may reveal excessive mobility of the lumbosacral junction (LSJ) but is rarely used in feline medicine. This study aimed to determine LSJ width and its change depending on the radiographic position in healthy adult cats and to develop reference intervals (RIs). The study included 60 clinically healthy cats (23 males and 37 females) of several breeds (including 47 domestic shorthair cats), aged from 9 months to 18 years (median 17 months), weighing from 2.5 to 7.4 kg (median 3.5 kg). Dynamic plain radiography was performed in general anesthesia in three lateral positions (neutral, flexed, and extended), simulating the behavior of the LSJ during cat’s movement. RIs were determined using both parametric and non-parametric method. LSJ width was 2.0±0.2 mm in the neutral position, 2.3±0.2 mm in the flexed position, and 1.7±0.1 mm in the extended position. LSJ width measurements were not significantly different between males and females, were not significantly correlated with the cat’s age or body weight, and did not appear to differ between breeds. The RIs obtained with the two methods were almost perfectly consistent. This study provides practical grounds for the interpretation of radiographic images of the LSJ in cats and in the future may also turn out to be useful in diagnosing LSI in this species.

**Keywords:** degenerative lumbosacral stenosis, dynamic radiography, lumbosacral instability

## Introduction

The lumbosacral junction (LSJ) in cats plays a crucial role in spinal stability and mobility, and it is a common site of pathology known as degenerative lumbosacral stenosis (DLSS). This disease is well understood in dogs, where DLSS can manifest as pain, pelvic limb weakness, or urinary and fecal incontinence. Information on DLSS in cats is much scarcer, but it clearly indicates that DLSS is a clinical problem (Danielski et al. 2013, Soteras et al. 2024). The main clinical signs include hyperesthesia of the skin in the lumbar region, reluctance to jump, pelvic limb ataxia, low tail carriage, difficulty in taking a defecation position, and behavioral abnormalities (Muñana et al. 2001, Cariou et al. 2008). Cats with LSJ disease have also been observed to be more susceptible to defecation disorders and a predisposition to abnormal bowel movements (Thanaboonnipat et al. 2021, Kowalczyk et al. 2025). The significance of pathology involving the LSJ may be even greater in cats than in dogs due to the structure of the spinal cord, which extends much further than in dogs – the conus medullaris (reaching S1-S3) is located at the level of the LSJ, not only the cauda equina as it is in dogs (Dyce et al. 2009, Richter et al. 2024). Since the S1-S3 segment is the source of pelvic nerves that carry autonomic (sympathetic and parasympathetic) nerves to the descending colon and rectum, pressure in this region may influence the motor activity of these organs and hinder defecation process (instead of being only be associated with anal sphincter paralysis as it usually happen in dogs).

Studies in humans have shown that DLSS may be preceded and facilitated by development of excessive mobility of the LSJ (Sielatycki et al. 2022), referred to as lumbosacral instability (LSI). LSI may result in the occurrence of intermittent clinical symptoms and can be revealed in dynamic flexion-extension radiographs (Beazell et al. 2010) although interpretation of results of radiographic examinations remains challenging (Sielatycki et al. 2022). Therefore, this diagnostic modality might capture developing pathology before lesions detectable in static imaging examinations, which are the mainstay of DLSS diagnosis, become apparent. Dynamic radiographs in dogs have shown that the LSJ width (LSJW) varies with spinal position, being greatest in flexion and smallest in full extension (Worth et al. 2017). Various surgical methods have been developed to treat the LSI in dogs (Kurkowska et al. 2025).

If dynamic radiography is about to be effectively used as a diagnostic test in cats, basic information on the LSJW needs to be available. It is, however, currently very limited. A recent cadaveric study have shown that the LSJ is the widest of the intervertebral space, with an average dimension (± standard deviation) of 2.9 ± 0.5 mm (Richter et al. 2024). There is no data regarding the changes in LSJ dimensions depending on the position of the spine. Therefore, we decided to conduct a study to determine LSJW and its change in healthy adult cats across radiographic positions and use the obtained data to develop reference intervals (RIs) of several types of LSJW measurements.

## Materials and Methods

### Eligibility criteria

The study included clinically healthy cats scheduled for neutering as well as cats scheduled for diagnostic and other procedures requiring general anesthesia, such as orthopaedic examination, intra-articular injections, and dental treatments. No cat underwent general anesthesia solely for the purposes of this study, no stress or physical suffering was attributable to the study procedures, and radiographic procedures did not significantly prolong the time in general anesthesia. Therefore, no ethics commission approval was required. All cat owners provided informed consent for participation of their cat in the study.

To be enrolled in the study, a cat had to satisfy the following inclusion criteria: i) known age >6 months; ii) negative routine clinical examination and basic blood check-up (including at least complete blood count, alanine aminotransferase activity, total protein, glucose, urea, and creatinine concentration); iii) lack of clinical signs that could possibly indicate LSJ disease, especially lack of pelvic limb ataxia, reluctance to jump, skin hyperesthesia in the lumbar region, low tail carriage, and defecation disorders, based on owner's account and results of physical examination performed by the investigator (PK).

A cat was excluded from the study if radiographic examination revealed any congenital abnormality (such as transitional sacral vertebra or 8th lumbar vertebra) or pathological process (such as intervertebral disc disease or spondylosis deformans) involving the LSJ.

### Anesthetic and radiographic protocol

The radiographic examination was performed in general anesthesia according to the standard anesthetic protocol (Simon and Steagall 2020). Briefly, premedication was achieved by intramuscular administration of dexmedetomidine at a dose of 3 µg/kg (Dexdomitor, Orion Pharma, Finland) and midazolam (Dormazolam, Dechra, Netherlands) at a dose of 0.3 mg/kg. Then, an intravenous catheter was placed on

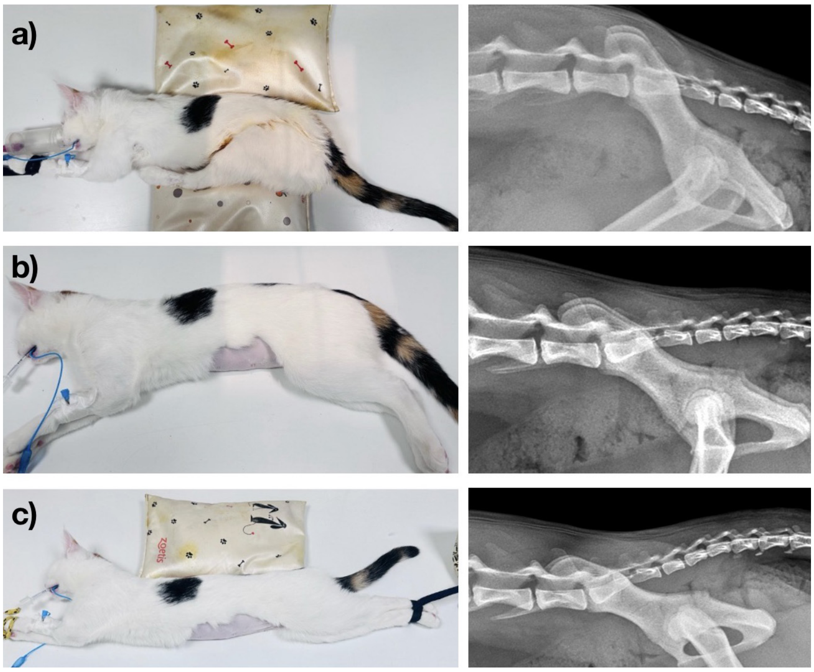

Fig. 1. Patient positioning in a right lateral recumbency for radiographic examination of the lumbosacral spine in three radiographic positions: a) flexed P1 position, b) neutral P2 position, and c) extended P3 position. Radiographic examination in the right lateral projection

the cephalic vein and propofol (Propomitor, Orion Pharma, Finland) was administered at a dose of 1 mg/kg i.v. for induction of anesthesia. A tracheal tube (size 3.0-5.0 mm) was routinely placed.

Radiographs were taken before the main medical procedure by a single examiner (PK), who was responsible for performing the entire radiographic procedure, including measuring LSJW on radiographic images. The cats were placed on right side in lateral recumbency (right lateral view). A digital direct X-ray machine (PCMAX-100CAH, POSKOM, South Korea) was used and the following radiographic parameters were applied: tube voltage = 46-50 kilovolts (kV), tube current and exposure time = 8-10 milliampere-seconds (mAs), and the source image receptor distance (SID) = 100 cm. The radiographs were taken in the following positions (one image in each position): i) flexed P1 position – with the hind limbs pulled cranially so that they maintained direct contact with the sternal region to maximally flex the LSJ (Fig. 1a), ii) neutral P2 position – with the right angle between hind limbs and trunk (Fig. 1b), and iii) extended P3 position – with the hind limbs pulled caudally so that the proximal part of hind limbs formed a straight line with the spine to maximally extend the LSJ (Fig. 1c). No technical aids were used during positioning of a cat to standardize force with which the LSJ was flexed (P1 position) or extended (P3 position).

## Radiographic measurements of the lumbosacral junction width (LSJW)

The LSJW was determined by measuring the distance between the dorsal edge in contact with the spinal canal of the caudal endplate of the 7th lumbar vertebra (L7) and the dorsal edge of the cranial endplate of the 1st sacral vertebra (S1) (Fig. 2). The measurements were taken using computer software for radiographic image analysis (VXvue, Vieworks Co., Ltd, USA) at the precision of two decimal places. In each of 60 cats, the LSJW was measured in each radiographic position three times: the first measurement was performed by the main examiner (PK) and this data was used to determine RIs. The second and third measurement were performed several months later by the main examiner (PK) and another veterinarian (MD), respectively, in order to determine intra-examiner repeatability (1st measurement by PK [PK1] vs. 2nd measurement by PK [PK2]) and inter-examiner repeatability (PK1 vs. 3rd measurement by MD [MD3]).

RIs were calculated for primary LSJW measurements in P1, P2 and P3 position as well as three types of secondary measurements: i) absolute differences (modulus) of LSJW in pairs of positions (P1-P2, P3-P2, P1-P3) [mm]; ii) ratios of LSJW in pairs of positions: P1/P2, P3/P2, P3/P1 [dimensionless]; overall variability of LSJW in 3 positions expressed as the coefficient of variation (CV) [dimensionless]. CV was calculated as the ratio of standard deviation to arithmetic mean of LSJW measurements in 3 positions in a parti-

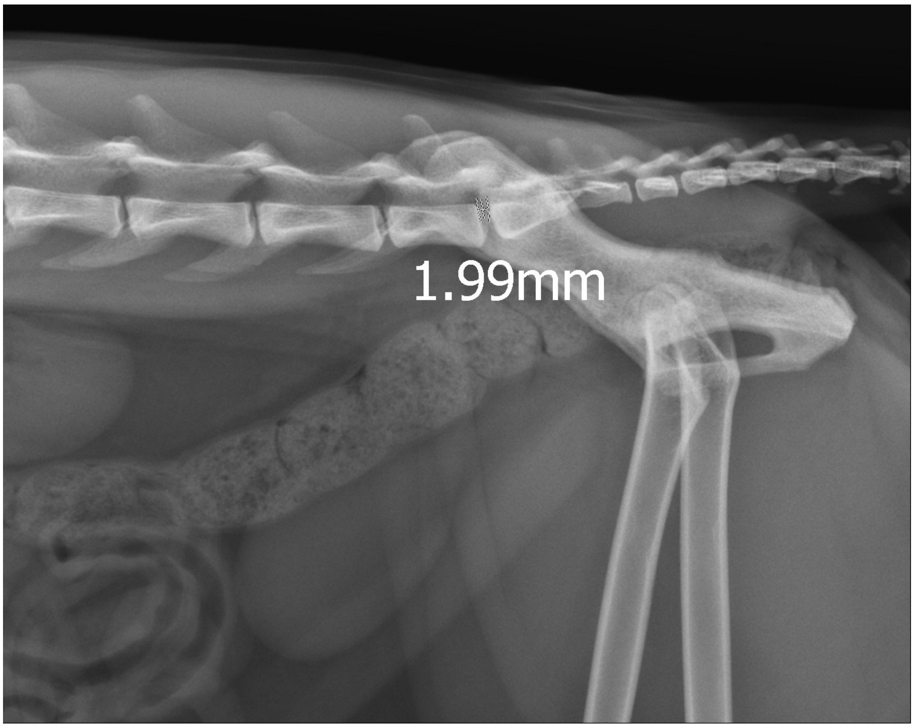

Fig. 2. The exact place where measurements of the lumbosacral junction width (LSJW) were performed in the study. Radiographic examination in the right lateral projection

cular cat. In total, 10 radiographic LSJW measurements were analyzed.

### Statistical analysis and determination of reference intervals (RIs)

LSJW measurements were summarized using the arithmetic mean (M) with standard deviation (±SD), the median (Me) with interquartile range (IQR), and the minimum to maximum range. Extreme measurements (outliers) were identified according to Tukey's interquartile fences method. A measurement was considered extreme if its value was $<(Q_1 - 3\times\text{IQR})$ or $>(Q_3 + 3\times\text{IQR})$, where $Q_1$ and $Q_3$ denoted the lower and upper quartile, respectively. Outliers were checked for correctness and could only be removed if proved to have resulted from measurement error. Otherwise, they were retained in the analysis. Symmetry and shape of distribution of LSJW measurements were assessed using the coefficient of asymmetry (CoA) and kurtosis (both with 95% confidence intervals [CI]), respectively (Zar 2010). LSJW measurements were examined for normality of distribution by visual inspection of the normal probability Q-Q plots and, more formally, by the Shapiro-Wilk W test at the level of significance (α) of 0.15.. If normality of distribution was violated, the cause of violation was identified by assessing deviation of CoA and kurtosis from zero (by the means of CI 95% of CoA and kurtosis). Then, attempts were made to restore normality of distribution by logarithmic transformation (with e basis) in the case of measurements with significantly right-hand asymmetric distribution (Zar 2010) or Box-Cox transformation in the case of measurements whose distribution was significantly deviated from the Normal distribution due to either left-hand asymmetry or non-mesokurtic (leptokurtic or platykurtic) shape (Box and Cox 1964).

Correlations between the LSJW measurements and body weight or age as well as between LSJW measurements in three radiographic positions were evaluated using Pearson's product-moment correlation coefficient (r). Age and body weight had significantly deviated from normality ($p<0.001$ for both) left-hand asymmetric distribution and thus, they were compared between males and females using the Mann-Whitney *U* test. The LSJW measurements were compared between three positions using paired-sample Student's t-test. The LSJW measurements (raw or transformed, as appropriate) were compared between males and females using unpaired-sample Student's t-test with equality of variances verified by the Brown-Forsythe test. All p-values were two-sided and considered to be statistically significant at $\alpha=0.05$, except for the Shapiro-Wilk W test of normality in which $\alpha=0.15$. A higher than standard α was used in the Shapiro-Wilk W test to minimize probability of committing a type II statistical (β) error and maximize test's power. The Shapiro-Wilk W test relies on the null hypothesis ($H_0$) stating that the variable's distribution does not differ from the theoretical Normal distribution. As a result,

Table 1. Breeds of studied cats (n=60) and their basic demographic characteristics.

| Breed | Number of cats (% of study population) | Number (%) of females | Age [months] | Body weight [kg] |
|---|---|---|---|---|
| Domestic shorthair (DSH) | 47 (78.3%) | 28 (59.6%) | 20, 10 – 48<br>(9 – 144) [a] | 3.5, 3.0 – 4.2<br>(2.5 – 7.4) [a] |
| Scottish Fold | 5 (8.3%) | 3 (60%) | 12 (9 – 24) [b] | 3.5 (2.4 – 4.8) [b] |
| British shorthair | 4 (6.7%) | 2 (50%) | 11 (9 – 13) [b] | 3.6 (3.2 – 3.8) [b] |
| Maine coon | 1 (1.7%) | 1 | 9 | 4.0 |
| Cornish Rex | 1 (1.7%) | 1 | 9 | 2.7 |
| Birman | 1 (1.7%) | 1 | 216 (18 years) | 4.0 |
| Ragdoll | 1 (1.7%) | 1 | 95 (7.9 years) | 4.0 |

[a] presented as median, interquartile range (IQR), and range
[b] presented as median and range

the normality of distribution is considered as evidenced when the $H_0$ is not rejected, contrary to standard statistical principle to consider a statement as evidenced when $H_0$ is rejected (Linnet 1987, Zar 2010). As β error is negatively associated with α, increasing α reduces β.

RIs were first determined using non-parametric method in which the lower ($RL_L$) and upper limit ($RL_U$) of the RI corresponded to the 2.5th and the 97.5th percentile, respectively. However, given relatively low number of cats, precision of estimation of the limits could not be directly determined. Therefore, RIs were also calculated by parametric method on raw data (P1, P1-P2, P1/P2, P3/P1, CV), log-transformed data (P1-P3), and Box-Cox transformed data (lambda [λ] parameter of the transformation was as follows: P2: $\lambda = -2.40$, P3: $\lambda = -1.65$, P3-P2: $\lambda = -0.20$, P3/P2: $\lambda = 5.00$), depending on their distribution (Friedrichs et al. 2012). In the case of transformed measurements, inverse functions were applied to obtain the RI. Precision of estimation of $RL_L$ and $RL_U$ was evaluated by computing respective CI 90% according to the parametric formula (Braun et al. 2013). The quality of estimations was assessed by calculating ratio of the width of the CI 90% (WCI) to the width of RI (WRI) (WCI/WRI ratio) and was regarded as satisfactory when WCI/WRI ratio was <0.2 (Braun et al. 2013). Agreement between limits of RI calculated by parametric and nonparametric method was determined with Lin's concordance correlation coefficient ($R_c$) (Lin 1989, Zar 2010).

Repeated primary LSJW measurements (PK1 vs PK2 and PK1 vs MD3) were compared using a paired-sample Student's t-test and the $R_c$. Repeatability was expressed as the coefficient of repeatability (CoR) indicating the range within which at least 95% of repetitions were expected to fall (Barlett and Frost 2008, Zar 2010). Statistical analysis was performed in TIBCO Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA, USA).

## Results

### Study population

The study population included 60 cats, 23 males (38.3%) and 37 females (61.7%), aged from 9 months to 18 years (Me: 17 months, IQR: 10 – 36 months). Age did not differ significantly between males and females (p=0.495). Forty seven of 60 cats were domestic shorthair (78.3%), remaining 13 belonged to 6 breeds of which most common were Scottish Fold (5 cats) and British shorthair (4 cats) (Table 1). Body weight of cats ranged from 2.5 to 7.4 kg (Me: 3.5 kg, IQR: 3.0-4.0 kg). Males were significantly heavier than females (Me: 4.0 kg, IQR: 3.5-5.0 kg vs. Me: 3.2 kg, IQR: 3.0-3.6 kg; p<0.001).

None of the 60 cats enrolled in the study had radiographic findings of congenital abnormality or a pathological process in the LSJ.

### Lumbosacral junction width (LSJW)

In the study population, LSJW varied between 1.5 and 2.9 mm, depending on a cat and radiographic position. LSJW in the neutral P2 position (2.0±0.2 mm) was significantly smaller than in the flexed P1 position (mean difference = -0.30 mm, CI 95%: -0.32, -0.28 mm, p<0.001) and significantly larger than in extended P3 position (mean difference = 0.27 mm, CI 95%: 0.24, 0.29 mm, p<0.001) (Table 2, Fig. 3). Flexion of the LSJ (change from the neutral P2 position to the flexed P1 position) increased the LSJW by 15%±4% of the initial value at the neutral P2 position. Extension of the LSJ (change from the neutral P2 position to the extended P3 position) decreased LSJW by 13%±4% of the initial value at the neutral P2 position. Change of the position from the flexed P1 (at which LSJW was the largest: 2.3±0.2 mm) to the extended P3 (at which LSJW was the smallest: 1.7±0.1 mm) reduced the LSJW by 0.6±0.1 mm which accounted for 25%±4% of

Table 2. Descriptive statistics of the lumbosacral junction width (LSJW) of 60 healthy cats.

| LSJW measurement | Arithmetic mean (SD) | Median (IQR) | Range | Coefficient of asymmetry (CI 95%) | Kurtosis (CI 95%) | Shapiro-Wilk W test |
|---|---|---|---|---|---|---|
| Primary measurements | | | | | | |
| P2 [mm][a] | 1.97 (0.19) | 1.95<br>(1.82, 2.08) | 1.69, 2.55 | 0.94<br>(0.34, 1.55)* | 1.19<br>(0.00, 2.38)* | 0.002 |
| P2 [b] | 0.332 (0.018) | 0.333<br>(0.317, 0.345) | 0.298, 0.372 | 0.02<br>(-0.58, 0.63) | -0.21<br>(-1.40, 0.98) | 0.118 |
| P1 [mm] | 2.27 (0.22) | 2.25<br>(2.10, 2.41) | 1.82, 2.89 | 0.37<br>(-0.23, 0.98) | 0.09<br>(-1.10, 1.28) | 0.506 |
| P3 [mm][a] | 1.71 (0.14) | 1.71<br>(1.60, 1.75) | 1.47, 2.08 | 0.57<br>(-0.03, 1.18) | 0.23<br>(-0.96, 1.42) | 0.030 |
| P3 [b] | 0.351 (0.032) | 0.356<br>(0.327, 0.365) | 0.285, 0.425 | 0.01<br>(-0.59, 0.62) | -0.23<br>(-1.43, 0.96) | 0.212 |
| Absolute differences | | | | | | |
| P1-P2 [mm] | 0.30 (0.08) | 0.28<br>(0.26, 0.37) | 0.13, 0.51 | 0.16<br>(-0.45, 0.76) | -0.09<br>(-1.29, 1.10) | 0.168 |
| P3-P2 [mm][a] | 0.27 (0.09) | 0.26<br>(0.22, 0.31) | 0.11, 0.62 | 1.56<br>(0.96, 2.17)* | 4.08<br>(2.88, 5.27)* | <0.001 |
| P3-P2 [b] | -1.605 (0.423) | -1.548<br>(-1.802, -1.321) | -2.78, -0.502 | -0.01<br>(-0.62, 0.59) | 0.61<br>(-0.59, 1.80) | 0.387 |
| P1-P3 [mm][a] | 0.57 (0.13) | 0.54<br>(0.50, 0.63) | 0.30, 0.94 | 0.76<br>(0.16, 1.37)* | 0.97<br>(-0.22, 2.17) | 0.013 |
| P1-P3 [b] | -0.593 (0.222) | -0.616<br>(-0.693, -0.462) | -1.204, -0.062 | -0.04<br>(-0.64, 0.57) | 0.67<br>(-0.52, 1.86) | 0.229 |
| Ratios | | | | | | |
| P1/P2 | 1.153 (0.040) | 1.151<br>(1.132, 1.176) | 1.071, 1.245 | 0.02<br>(-0.58, 0.63) | -0.14<br>(-1.33, 1.05) | 0.561 |
| P3/P2[a] | 0.867 (0.035) | 0.869<br>(0.850, 0.888) | 0.757, 0.940 | -0.75<br>(-1.36, -0.15)* | 1.00<br>(-0.20, 2.19) | 0.047 |
| P3/P2[b] | -0.100 (0.019) | -0.101<br>(-0.111, -0.09) | -0.150, -0.054 | -0.21<br>(-0.81, 0.40) | 0.19<br>(-1.01, 1.38) | 0.740 |
| P3/P1 | 0.753 (0.037) | 0.755<br>(0.731, 0.776) | 0.660, 0.835 | -0.29<br>(-0.90, 0.31) | 0.38<br>(-0.81, 1.57) | 0.319 |
| Variability | | | | | | |
| CV | 0.143 (0.025) | 0.14<br>(0.129, 0.155) | 0.090, 0.208 | 0.38<br>(-0.23, 0.98) | 0.47<br>(-0.72, 1.66) | 0.328 |

CI – confidence interval, CV – coefficient of variation, IQR – interquartile range, SD – standard deviation, P1 – flexed position, P2 – neutral position, P3 – extended position

* significantly deviated from 0

[a] normality assumption violated

[b] descriptive statistics after transformation of data

the initial value at the flexed P1 position. The LSJW in three positions were strongly positively linearly correlated (r=0.85 to 0.93; Fig. 4).

Assumption of normality of distribution was violated in 5 of 10 LSJW measurements: two (P2, P3-P2) had right-hand asymmetric, leptokurtic distribution, two (P3, P1-P3) had significantly right-hand asymmetric, normokurtic distribution, and one had left-hand asymmetric, normokurtic distribution (P3/P2). Despite violations to the normality assumption, no outliers were identified in any of LSJW measurements. Appropriate transformations changed the distributions of all the aforementioned LSJW measurements into the Normal distribution (Table 2).

None of the LSJW measurements differed significantly between males and females or were significantly correlated with cats' age or body weight (Table 3). Neither did they appear to differ between breeds (Fig. 5), although due to the small number of cats of each breed, statistical analysis was not feasible.

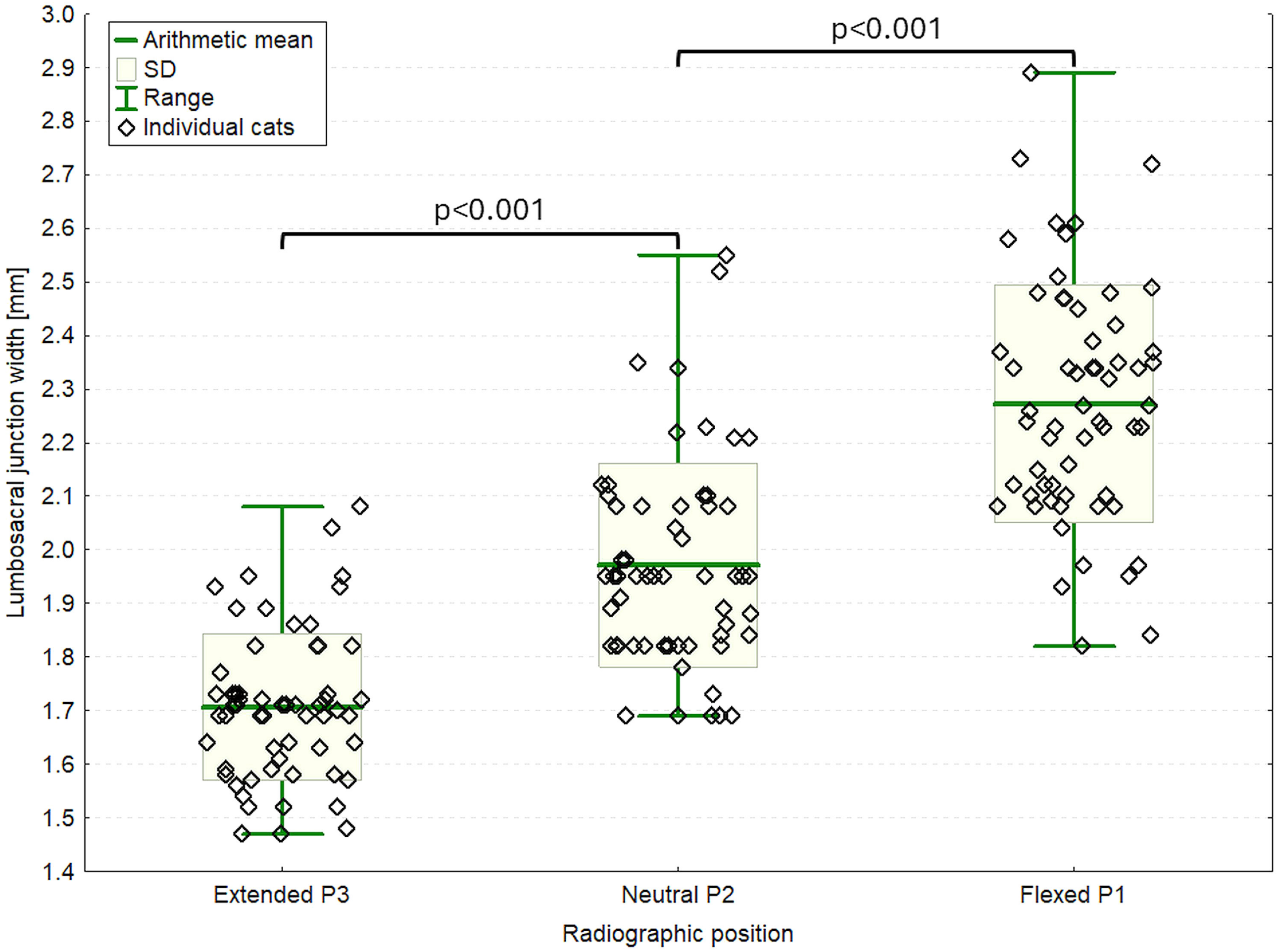

Fig. 3. Lumbosacral junction width (LSJW) of 60 healthy cats in three radiographic positions: flexed P1 position, neutral P2 position, and extended P3 position. The P-values come from a paired-sample Student's t-test. SD – standard deviation

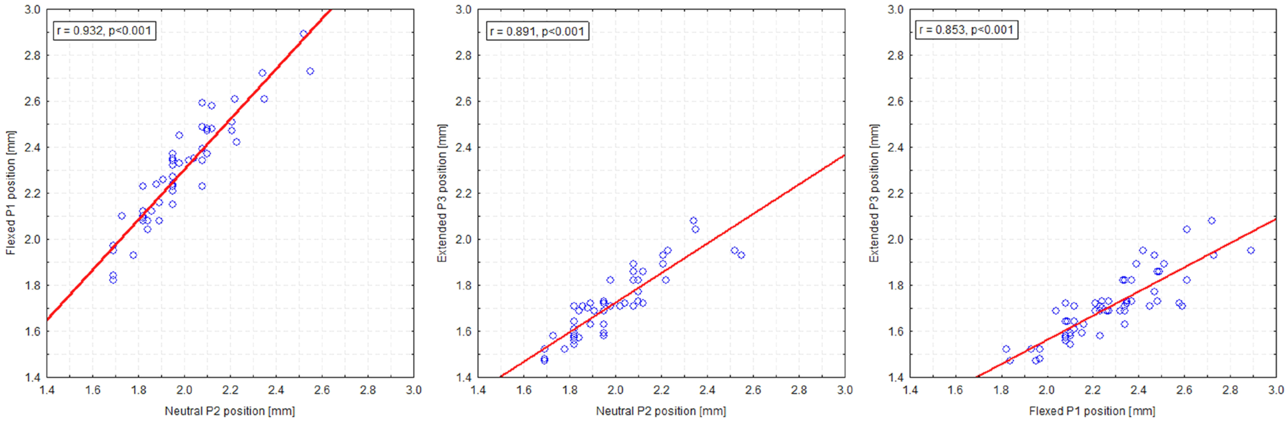

Fig. 4. Correlations between the lumbosacral junction width (LSJW) measured in 60 healthy cats in three radiographic positions: flexed P1 position, neutral P2 position, and extended P3 position

## Reference intervals (RIs)

The RIs for three primary and seven secondary LSJW measurements are presented in Table 4. Limits of the RI determined with parametric and non-parametric methods were perfectly consistent ($R_c$ = 0.999 for both $RL_L$ and $RL_U$) (Fig. 6). WCI/WRI ratio was 0.18 for all the RIs determined using parametric method, including the RIs calculated on transformed data. The width of the RI corresponded to 71% to 94% (Me: 85%) of the minimum to maximum range in the parametric method and 80% to 97% (Me: 87%) of the minimum to maximum range in the non-parametric method.

Table 3. Association of the lumbosacral junction width (LSJW) with individual characteristics of 60 healthy cats.

| LSJW | Arithmetic mean (SD) | | Unpaired t-test p-value | Correlation with age | | Correlation with body weight | |
|---|---|---|---|---|---|---|---|
| | Males (n=23) | Females (n=37) | | r | p-value | r | p-value |
| Primary measurements | | | | | | | |
| P2 [mm] | 2.01 (0.20) | 1.95 (0.18) | 0.218 | -0.114 | 0.388 | 0.018 | 0.893 |
| P1 [mm] | 2.32 (0.20) | 2.24 (0.23) | 0.154 | -0.101 | 0.442 | 0.052 | 0.693 |
| P3 [mm] | 1.73 (0.13) | 1.69 (0.14) | 0.280 | -0.035 | 0.793 | 0.089 | 0.501 |
| Absolute differences | | | | | | | |
| P1-P2 [mm] | 0.32 (0.08) | 0.29 (0.08) | 0.272 | -0.011 | 0.932 | 0.100 | 0.448 |
| P3-P2 [mm] | 0.28 (0.10) | 0.26 (0.09) | 0.268 | -0.183 | 0.162 | -0.095 | 0.469 |
| P1-P3 [mm] | 0.60 (0.12) | 0.55 (0.13) | 0.122 | -0.139 | 0.288 | -0.004 | 0.974 |
| Ratios | | | | | | | |
| P1/P2 | 1.159 (0.043) | 1.149 (0.039) | 0.367 | 0.022 | 0.865 | 0.104 | 0.431 |
| P3/P2 | 0.863 (0.035) | 0.870 (0.036) | 0.410 | 0.192 | 0.142 | 0.130 | 0.323 |
| P3/P1 | 0.745 (0.036) | 0.758 (0.038) | 0.204 | 0.142 | 0.280 | 0.039 | 0.767 |
| Variability | | | | | | | |
| CV | 0.148 (0.024) | 0.140 (0.024) | 0.204 | -0.141 | 0.284 | -0.024 | 0.855 |

CV – coefficient of variation, SD – standard deviation, P1 – flexed position, P2 – neutral position, P3 – extended position, r – Pearson's product-moment correlation coefficient

Table 4. Reference intervals (RI) of the lumbosacral junction width (LSJW) measurements determined using two different methods.

| LSJW measurement | Reference intervals | | | |
|---|---|---|---|---|
| | Nonparametric method | | Parametric method | |
| | Lower limit | Upper limit | Lower limit (CI 90%) | Upper limit (CI 90%) |
| P2 [mm] | 1.69 | 2.52 | 1.68 (1.64, 1.72) [a] | 2.45 (2.33, 2.60) [a] |
| P1 [mm] | 1.84 | 2.73 | 1.82 (1.74, 1.91) | 2.72 (2.64, 2.80) |
| P3 [mm] | 1.47 | 2.04 | 1.47 (1.44, 1.51) [a] | 2.03 (1.96, 2.11) [a] |
| P1-P2 [mm] | 0.15 | 0.47 | 0.14 (0.11, 0.17) | 0.47 (0.44, 0.50) |
| P3-P2 [mm] | 0.15 | 0.57 | 0.14 (0.12, 0.15) [a] | 0.50 (0.44, 0.57) [a] |
| P1-P3 [mm] | 0.35 | 0.88 | 0.35 (0.33, 0.39) [b] | 0.86 (0.80, 0.94) [b] |
| P1/P2 | 1.072 | 1.237 | 1.072 (1.057, 1.086) | 1.235 (1.220, 1.249) |
| P3/P2 | 0.774 | 0.919 | 0.790 (0.770, 0.806) [a] | 0.929 (0.920, 0.938) [a] |
| P3/P1 | 0.667 | 0.828 | 0.678 (0.665, 0.692) | 0.828 (0.814, 0.841) |
| CV | 0.095 | 0.201 | 0.094 (0.085, 0.102) | 0.192 (0.183, 0.201) |

CV – coefficient of variation, P1 – flexed position, P2 – neutral position, P3 – extended position

[a] parametric method on data transformed using the Box-Cox transformation

[b] parametric method on logarithmically transformed data

### Repeatability of LSJW measurements

When performed by the same examiner, paired primary LSJW measurements did not differ significantly in any of radiographic positions. When performed by two different examiners, paired primary LSJW measurements did not differ significantly in the neutral P2 or flexed P1 position and were significantly different in the extended P3 position (p=0.003; Table 5). However, the size of the main difference was below 0.02 mm and all the measurements were very highly consistent ($R_c$ 0.93 to 0.99). Regardless of the pair of primary LSJW measurements, the radiographic position analyzed or the combination of examiners who had taken the measurements, CoRs were usually below ±0.1 mm (typically between ±0.5 and ±0.9 mm; Table 5).

## Discussion

To the best of our knowledge, no other studies, have been conducted to analyze in detail the LSJW in its most dorsal part (closest to the vertebral canal) and the change of LSJW associated with different spine posi-

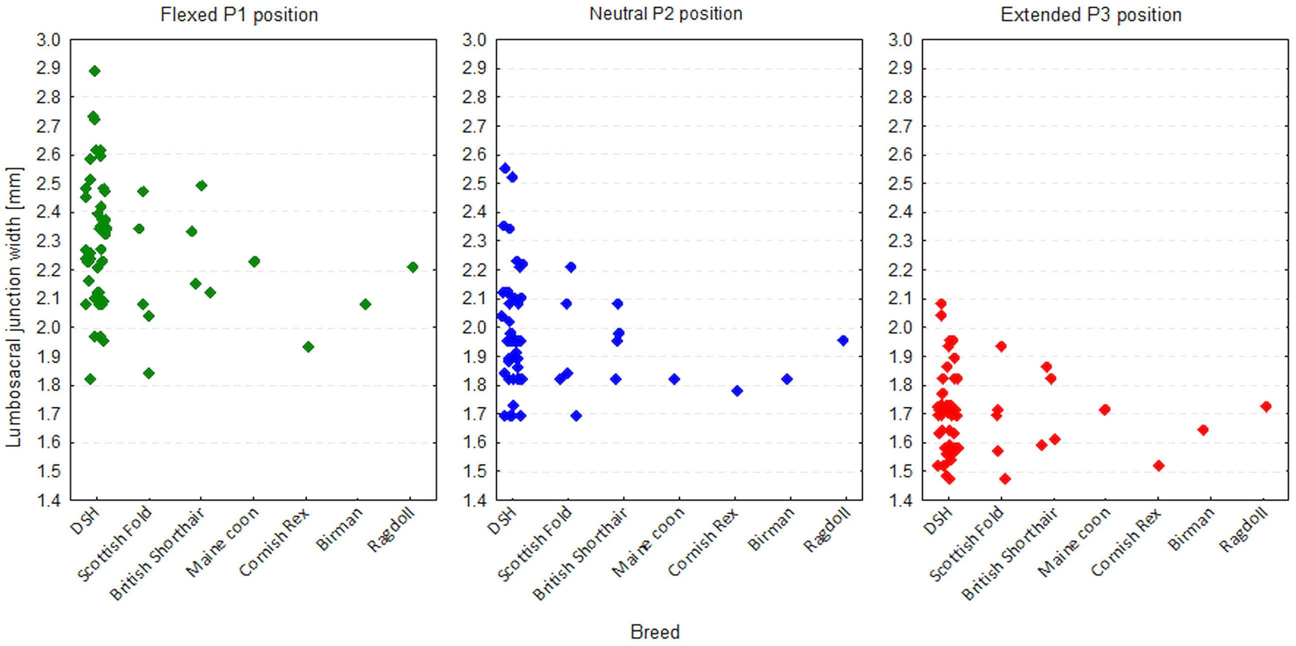

Fig. 5. Lumbosacral junction width (LSJW) measured in three radiographic positions (flexed P1 position, neutral P2 position, and extended P3 position) in domestic shorthair (DSH) cats and pedigree cats of 6 breeds represented in the study

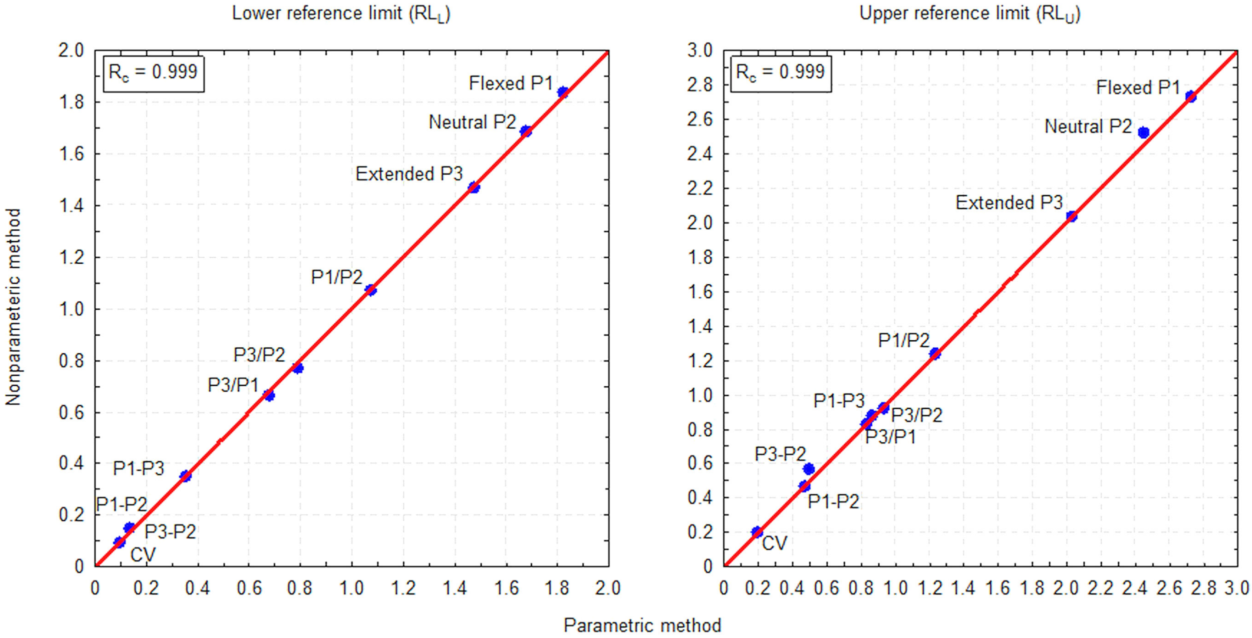

Fig. 6. Concordance (agreement) between limits of reference intervals of ten lumbosacral junction width (LSJW) measurements determined using nonparametric and parametric method

tion in healthy cats. On the X-ray, the LSJW in our cohort was approximately 2 mm. It widened by approx. 0.3 mm when LSJ was flexed and narrowed by approx. 0.3 mm when LSJ was extended. Neither LSJW nor the magnitude of its change appears to be linked with cat's age, body weight or breed. Measurements were highly consistent when repeated by the same or a different examiner – they can be expected to vary by not more than ±0.1 mm. On this basis, we developed the RIs to provide practically recommendations for assessing LSJW in plain lateral X-ray views.

This study was designed to use dynamic X-ray imaging to evaluate the LS spine in healthy cats. We evaluated the use of dynamic LSJ radiographs to determine the width of this space. Determining the LSJW is crucial for diagnosing diseases of this region, particularly LSI. To date, there is a significant gap in the literature regarding standardized dimensions of this intervertebral space. The current literature includes only anatomical studies of cross-sections of the LSJ in cats, with no imaging data on its dimensions (Richter et al. 2024). Diagnosing LSI in cats can be

Table 5. Repeatability of the lumbosacral junction width (LSJW) measurements performed by the same examiner (intra-examiner repeatability) and by two different examiners (inter-examiner repeatability).

| LSJW measurement | Mean difference ± SD (CI 95%) [mm] | Paired-sample Student's t-test p-value | Lin's concordance correlation coefficient (CI 95%) | Coefficient of repeatability (CI 95%) [mm] |
|---|---|---|---|---|
| Intra-examiner repeatability | | | | |
| P2 [mm] | -0.009 ± 0.037<br>(-0.019, 0.000) | 0.053 | 0.980<br>(0.967, 0.987) | 0.07<br>(0.06, 0.09) |
| P1 [mm] | -0.002 ± 0.047<br>(-0.014, 0.011) | 0.804 | 0.977<br>(0.963, 0.985) | 0.09<br>(0.08, 0.11) |
| P3 [mm] | -0.003 ± 0.037<br>(-0.013, 0.007) | 0.534 | 0.960<br>(0.938, 0.975) | 0.09<br>(0.08, 0.11) |
| Inter-examiner repeatability | | | | |
| P2 [mm] | 0.002 ± 0.026<br>(-0.005, 0.009) | 0.585 | 0.991<br>(0.985, 0.994) | 0.05<br>(0.04, 0.06) |
| P1 [mm] | 0.002 ± 0.037<br>(-0.007, 0.012) | 0.622 | 0.986<br>(0.977, 0.991) | 0.07<br>(0.06, 0.09) |
| P3 [mm] | 0.013 ± 0.032<br>(0.004, 0.021) | 0.003 | 0.968<br>(0.950, 0.979) | 0.07<br>(0.06, 0.08) |

CI – confidence interval, SD – standard deviation, P1 – flexed position, P2 – neutral position, P3 – extended position

challenging for several reasons. Regardless of the imaging diagnostic method used (X-ray, computed tomography [CT], magnetic resonance imaging [MRI]) most studies of the LSJ are performed in the neutral position and are static. Imaging studies have shown that changes in the LSJ can be detected incidentally. One study demonstrated clinical DLSS in 12/114 cats (10%), and additional 16 cats had subclinical LSJ changes detected incidentally on MRI (Soteras et al. 2024). These results indicate that LSJ pathology may often go undetected. Radiographic evidence of excessive LSJ narrowing on dynamic radiographs appears to be of the greatest clinical significance. Although diagnosing LSI in cats in clinical practice can be challenging, dynamic radiography appears to be a promising method.

Some purebred cats are prone to developing LS anomalies (Deforest and Basrur 1979). Despite this, various cat breeds were included in this study to standardize the examination for as broad array of domestic cats as possible. Therefore, the results of this study are likely to properly describe LSJW of most cats with a normal spine. As previously mentioned, none of the primary or secondary LSJW measurements were correlated with age, sex, or body weight. The same was observed when comparing cats of different breeds. Therefore, there was no need for partitioning the study population with respect to any individual characteristics and common RIs for a population of adult cats could be developed.

The incidence of defecation disorders, constipation, and consequently megacolon syndrome has been shown to be significantly increased in cats with LSJ disease (Thanaboonnipat et al. 2021). Until recently, it was believed that intervertebral disc herniation at the LSJ in cats was rare (Johanson et al. 1992). Preliminary data obtained during treatment of the LSJ may suggest that DLSS (secondary to LSI) and lumbosacral intervertebral disc disease (IVDD) may play a more significant role than previously thought in the incidence of bowel dysfunction and defecation reflex (Harris and Dhupa 2008, Kowalczyk et al. 2025). Therefore, we concluded that examining the LSJ in cats for changes in its width depending on limb position was crucial in diagnosing these disorders. Intestinal motility disorders leading to idiopathic constipation and/or megacolon may be associated with generalized smooth muscle dysfunction of the large intestine, but the etiology remains unclear (Foley 2017). It is widely assumed that the most common cause of idiopathic megacolon is damage to the lumbosacral plexus, located between L4 and S3, which can affect the autonomic function of the pelvic organs, causing atony of the terminal colon. There are many causes of this condition, including sacralization, or abnormalities of the last lumbar vertebrae (Dyck and Windebank 2002, Rossi et al. 2018).

Imaging studies of the lumbar spine have long been performed in humans to rule out or confirm segmental instability. Traction-compression radiography has proven to be a simple and practical method for diagnosing and measuring segmental instability (Friberg 1987). Dynamic radiography (flexion-extension X-rays) of the LS spine is a diagnostic tool designed to detect existing, pre-functional instability rather than induce new, permanent instability in humans. It is widely used to identify abnormal movement, such as spondylolisthesis (slippage of vertebrae), which can cause pain. However, because these tests require patients to move their spine to maximum flexion and extension, they can temporarily provoke symptoms in individuals with underlying structural issues (Friberg 1989, Lin et al. 2022).

All quantitative measurements were smaller when the spine was in an extended position and larger when it was flexed. This type of observation has also been described in studies of the lumbar spine in dogs (Raynolds et al. 2014, Worth et al. 2017, Lampe et al. 2020). Clinical signs of DLSS in dogs develop and/or worsen during spine-extending movements. These include jumping onto elevated surfaces or climbing stairs and may be exacerbated by increased instability (Scharf et al. 2004, Suwankong et al. 2006, Jeffery et al. 2014). Positioning cats in an upright position with the pelvic limbs extended caudally during imaging allows for mimicking positions that often exacerbate clinical signs, which may allow for the acquisition of images more representative of clinical scenarios. Based on the proven effectiveness of studies in dogs, our study supports the theory that dynamic imaging can provide additional clinical information. LSI has been shown to play a significant role in dogs. It is interpreted as a major risk factor for DLSS in this species. This instability leads to soft-tissue injuries in the LS spine, including the articular capsule, ligamentum flavum, dorsal longitudinal ligaments, and intervertebral discs. It also predisposes to intervertebral disc degeneration in the lower lumbar spine, exacerbating instability (Seiler et al. 2002, Carballo et al. 2024). The well-documented nature of LSI using three-dimensional imaging provides a basis for using these techniques in cats as well. It should also be emphasized that, to standardize the measurement method, it would be necessary to develop an appropriate methodology using a measuring tool to regulate the tension of the limbs under the required force to perform the test (e.g. a dynamometer). The authors of this article acknowledge that X-ray is a two-dimensional examination with numerous limitations, but they believe they provide a starting point for further research and may be useful as a diagnostic tool in correlation with clinical signs. Based on current knowledge and literature, this study is the first to document the range of LSJW in cats in three positions (neutral, flexed, and extended) using X-ray. In other studies, documenting an increased incidence of subclinical spinal cord compression in the extended position in dogs, it is interesting to consider MRI examinations in a similar body position that simulates movement in cats (Lampe et al. 2020). They exhibit greater physical activity, including frequent jumping onto elevated surfaces. This approach can be used to diagnose patients with subclinical LSJ disease.

The number of cats enrolled in our study was sufficient for reliable RI determination, using both parametric and nonparametric methods (Friedrichs et al. 2012). Therefore, both methods were used to control for differences associated with some deviations from perfect Normal distribution, even after appropriate transformations. The limits of RIs were perfectly consistent. On the other hand, 60 cats is considerably fewer than the optimal number of ≥120 (Friedrichs et al. 2012). As a result, the lower and upper RI limits are very close to the minimum and maximum values, respectively, and the RIs are only slightly narrower than the ranges. Undoubtedly, this is an important limitation of this study, as it runs the risk of being overly influenced by the lowest and highest observations. This risk is, however, greatly mitigated by careful statistical data processing.

LSJW measurements proved to be similarly and highly repeatable when taken by the same and two different examiners. Repeatability was not affected by the fact that one of examiners was a surgeon specializing in small animal orthopaedics (PK) while the another one was a veterinarian specializing in soft tissue surgery (MD). The differences between two measurements are unlikely to exceed ±0.1 mm which indicates that any difference by more than 0.1 mm should be considered as true and potentially clinically meaningful. On the other hand, we did not evaluate repeatability and reproducibility of the entire radiographic examination. The procedure of positioning a cat may be an important source of variability, especially given the fact that we did not provide any objective method of determination of force with which the LSJ should be flexed or extended. In our study, the positioning relied only on descriptive recommendations as to location of limbs and trunk. We do not know to what extent the lack of objective criteria of flexing and extending of LSJ would impede repeatability of obtained radiographic images. In the future, objective methods of positioning cats, perhaps analogical to methods used in radiographic examination of hip dysplasia in dogs, should be developed and implemented. And last but not least, while conventional radiography is a standard initial tool for evaluating the LSJ, it is limited by superimposing osseous structures and poor soft-tissue contrast. Cross-sectional modalities such as MRI and CT are preferred for detailed evaluations, as they provide high-resolution views that allow for precise spinal canal measurements and clear identification of neural tissues. Nevertheless, X-ray examination remains most available and cost-effective diagnostic method in veterinary medicine, especially outside large municipalities. Therefore, we believe our study may provide useful clinical knowledge.

## Conclusion

The changes of LSJW in cats associated with flexing and extending of the lumbosacral spine are evident and can be precisely measured on plain lateral radiographs. Both the measurements and their changes appear to be independent of individual characteristics of cats. Therefore, RIs developed in this study may turn out be applicable in a relatively wide population of cats. The results of this preliminary study provide grounds for future investigations of clinical usefulness of LSJW measurements in diagnosing LSI in cats.

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## Author Declarations

### Ethical approval and informed consent

The work described in this manuscript involved the use of non-experimental (owned) animals. Established internationally recognised high standards ('best practice') of veterinary clinical care for the individual patient were always followed. Ethical approval from an ethics committee was therefore not required.

### Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors declare that no generative AI tools or AI-assisted technologies were used in the preparation of this manuscript, including text creation, data analysis, or image generation.

### Conflict of interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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