

Radiographic evaluation of kidney size in cats: Effects of sex and gonadal status

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Abstract

Radiographic evaluation of kidney size using the kidney-to-second lumbar vertebral body length (K/L2) ratio is a standard method for assessing kidney size in cats. However, current reference values underdetermine biological factors such as sex and gonadal status, which may influence kidney and lumbar length. Reproductive hormones are known to influence kidney and vertebral development, but their specific effects on radiographic kidney and vertebral measurements in cats are unclear. This retrospective study aimed to assess the effects of gonadal status on kidney length, L2 vertebral length, and the K/L2 ratio in clinically healthy cats. A total of 285 cats were included and categorized by sex and gonadal status. Kidney and L2 measurements were obtained from ventrodorsal abdominal radiographs, and K/L2 ratios were calculated. Associations with age and body weight (BW) were also evaluated. Results showed that the right kidney was significantly longer than the left in all groups. Intact male cats had significantly longer kidneys and higher K/L2 ratios compared to neutered males. Spayed females exhibited longer kidneys than intact females, although no significant difference in K/L2 ratios was observed. Neutered cats of both sexes demonstrated longer L2 vertebrae than intact cats. Both kidney and L2 lengths showed weak positive correlations with BW, but no correlation with age. The K/L2 ratio also correlated weakly with BW and was unaffected by age. These findings exhibited the influence of sex and gonadal status on kidney and vertebral length in cats and highlight the need to consider these factors when interpreting radiographic kidney measurements in clinical practice.

Keywords: feline, gonadal status, kidney, radiography, second lumbar vertebra

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Introduction

Chronic kidney disease (CKD) is a commonly diagnosed condition in cats and is particularly prevalent, affecting around 3% of the feline population (Reynolds and Lefebvre, 2013). This disease tends to occur more commonly in aging cats, affecting at least 30–40% of those over 10 years old (Lulich *et al.*, 1992). The median survival time of this disease approximately 103 to 1,151 days after diagnosis depended on CKD stage (Boyd *et al.*, 2008). In clinical practice, the diagnostic evaluation of kidney disease is typically based on serum biochemistry, hematology, and urinalysis (Sparkes *et al.*, 2016). However, diagnostic imaging modalities such as radiography also play a critical role by providing essential information on the position, size, and shape, particularly in detecting structural changes associated with CKD (Behmanesh and Sorouri, 2024).

Abdominal radiography is commonly modalities for evaluated kidney characteristics, because it is simple, non-invasive and provides information about their location, size, shape and contour (Seiler and Thrall, 2024). Normal feline kidneys have smooth margins and a rounded shape and are typically located between the first and fourth lumbar vertebrae. Kidney size is commonly assessed on a ventrodorsal (VD) radiographic view using the kidney-to-second lumbar vertebral body length (K/L2) ratio (Barrett and Kneller, 1972; Seiler and Thrall, 2024). The normal K/L2 ratio has been reported to range from 2.4 to 3.0, with no significant correlation to age or sex (Barrett and Kneller, 1972; Shiroma *et al.*, 1999). However, subsequent studies have indicated that sex and neuter status can influence this ratio, with male and intact cats generally showing higher values than female and neutered cats (Shiroma *et al.*, 1999; Behmanesh and Sorouri, 2024).

Moreover, gonadectomy performed before 7 months of age has been shown to affect skeletal development, including the vertebrae, by delaying growth plate closure (Root *et al.*, 1997). In cats, neutering is traditionally performed between 5 and 8 months of age or during the prepubertal period to help control overpopulation. Early neutering or prepubertal gonadectomy has been associated with increased falciform fat, body mass, and body condition score, particularly in male cats, compared to those of intact cats (Sloth, 1992; Colliard *et al.*, 2009). Additionally, the absence of reproductive hormones may contribute to delayed epiphyseal closure, potentially affecting vertebral column length (Root *et al.*, 1997).

Currently, there is no published information that investigates the relationship between kidney length and the length of the L2 with respect to gonadal status in healthy cats. Therefore, the objective of this study was to establish reference values for radiographic measurements of kidney and vertebral length, and to evaluate the effect of gonadal status on the lengths of kidney and L2 including the K/L2 ratio in clinically healthy cats. This study hypothesized that gonadal status may influence the lengths of the kidney and L2, including the K/L2 ratio.

Materials and Methods

Image Data: This retrospective study was conducted using clinical records, abdominal radiographs, and blood test results of cats presented to [Blinded for review] between March 2021 and February 2023. This study received Institutional Review Board approval [Blinded for review]. Inclusion criteria were: (i) complete clinical records, blood test results and abdominal radiographs; (ii) evidence of complete physeal (growth plate) closure; and (iii) serum creatinine levels within the normal range (<1.4 mg/dL). Exclusion criteria included a history of renal and/or urinary tract disease, abnormal kidney morphology (e.g., irregular margins, renal masses, renal calculi), or abnormal vertebral shape on abdominal radiographs. In addition, if vertebral growth plates, defined as a radiolucent line at the epiphyseal plate, especially the lateral abdominal radiograph was detected, these cats were excluded from the study. Subsequently, cats were classified into four groups based on gonadal status: G1, intact males; G2, neutered males; G3, intact females; and G4, neutered females.

Kidney and L2 measurement on abdominal radiograph: VD and lateral abdominal radiographs of all cats were retrieved from the Picture Archiving and Communication System (PACS) in Digital Imaging and Communications in Medicine (DICOM) format and reanalyzed using DICOM viewer software (OsiriX, Geneva, Switzerland). All radiographic images were then examined to confirm the image quality including the complete region of interest extending from the cranial border of the diaphragmatic cupula to the greater trochanter of the femur and unveiled clearly kidney margins.

Subsequently, kidney and L2 lengths were measured on VD radiographs using digital calipers. Both measurements were done at the longest dimensions along anatomical longitudinal axes (Fig. 1). The kidney-to-second lumbar vertebral ratio (K/L2) was then calculated by dividing the kidney length by the length of the L2 vertebral body.

Statistical analysis: Statistical analyses were performed using GraphPad Prism version 7.0 (GraphPad Software, San Diego, CA, USA). Clinical and demographic data from each group were summarized using descriptive statistics. The normality of each dataset was assessed using the Shapiro-Wilk test. Data variables including age, BW, kidney length, L2 length, and the K/L2 ratio were reported as mean $\pm$ standard deviation (SD). Comparisons of kidney length and K/L2 ratio between intact and neutered groups within the same gonadal status were conducted using unpaired t-tests. Comparisons of kidney length between contralateral sides within the same group were analyzed using paired t-tests. A *P*-value of <0.05 was considered statistically significant.



Figure 1 Ventrodorsal abdominal radiograph of a cat illustrating morphometric measurements. Kidney length was measured at the maximum dimension from the cranial to the caudal pole (white dotted lines). The length of the second lumbar vertebra was measured from the cranial to the caudal endplate of the vertebral body (black line). The kidney-to-second lumbar vertebral ratio was determined by dividing the kidney length by the length of the L2 vertebral body.

Results

Clinical demographic data: A total of 285 cats were included in this study. There were 144 males (75 intact, 69 castrated) and 141 females (69 intact, 72 spayed). The most common breeds were Domestic Shorthair ($n = 228$; 80.00%), Persian ($n = 34$; 11.92%), Scottish Fold ($n = 11$; 3.86%), American Shorthair ($n = 6$; 2.11%), and other breeds ($n = 6$; 2.11%). The mean $\pm$ SD of age and BW of all cats were 3.43 ± 0.33 years and 4.15 ± 0.10 kg, respectively. Clinical and demographic data for all cats, including each data of gonadal statuses, are presented in Table 1.

Kidney and L2 length: Among 285 cats, only 471 kidneys were clearly visualized on VD radiograph, comprising 195 right kidneys and 276 left kidneys. A summary of detected kidney numbers, kidney lengths, L2 vertebral lengths, and K/L2 ratios categorized by gonadal statuses is presented in Table 2. The mean length of the right kidney was significantly greater than that of the left kidney ($P = 0.002$ for all cats; $P < 0.001$ for intact males; $P < 0.001$ for neutered males; $P = 0.026$ for intact females; and $P = 0.045$ for spayed females, respectively). Intact male cats exhibited significantly longer kidneys compared to neutered

males ($P = 0.001$ for the right kidney and $P = 0.003$ for the left kidney). In contrast, spayed female cats had significantly longer kidneys than intact females ($P = 0.030$ for the right kidney and $P = 0.007$ for the left kidney). Kidney length exhibited a weak positive correlation with BW ($R = 0.033$ for the right kidney and $R = 0.209$ for the left kidney).

The average L2 length for each gonadal status group is presented in Table 2. Male cats had significantly longer L2 lengths compared to female cats ($P < 0.001$). Neutered cats exhibited significantly longer L2 lengths than intact cats in both sexes ($P = 0.022$ for males; $P = 0.006$ for females). L2 length was not correlated with age ($R < 0.001$) but showed a weak positive correlation with BW in all cats ($R = 0.263$).

K/L2 ratio: The K/L2 ratios for each gonadal status group are summarized in Table 2. Intact male cats had significantly greater K/L2 ratios compared to neutered males ($P < 0.001$ for both right and left kidneys). In contrast, no significant differences of K/L2 ratios were observed between intact and spayed female cats ($P = 0.222$ for the right kidney and $P = 0.356$ for the left kidney). The K/L2 ratio was not correlated with age but demonstrated a weak positive correlation with BW ($R = 0.033$ for the right kidney and $R = 0.026$ for the left kidney).

Table 1 Number of cats and mean $\pm$ standard deviation of age and body weight (BW), including subgroup analyses based on gonadal status.

Parameters	Male		Female	
	Intact	Castrate	Intact	Spay
Number	144		141	
	75	69	69	72
Age (years)	3.15 $\pm$ 0.24		3.67 $\pm$ 0.39	
	2.49 $\pm$ 0.29	3.88 $\pm$ 0.37	2.28 $\pm$ 0.23	5.08 $\pm$ 0.48
BW (kg)	4.36 $\pm$ 0.09		3.45 $\pm$ 0.7	
	4.09 $\pm$ 0.10	4.66 $\pm$ 0.13	3.23 $\pm$ 0.10	3.66 $\pm$ 0.10

Table 2 Number of kidneys and mean $\pm$ standard deviation of kidney lengths, second lumbar vertebral (L2) lengths, and kidney-to-L2 (K/L2) ratios, categorized by sex and gonadal status.

Parameters	Male		Female	
	Intact	Castrate	Intact	Spay
RK (cm)	Total n = 101		Total n = 94	
	4.61 $\pm$ 0.38		3.92 $\pm$ 0.31	
	n = 60	n = 41	n = 44	n = 50
LK (cm)	4.71 $\pm$ 0.36	4.64 $\pm$ 0.36	3.85 $\pm$ 0.28	3.99 $\pm$ 0.32
	Total n = 141		Total n = 135	
	4.45 $\pm$ 0.32		3.88 $\pm$ 0.26	
L2 length (cm)	n = 74	n = 67	n = 65	n = 71
	4.53 $\pm$ 0.32	4.37 $\pm$ 0.30	3.82 $\pm$ 0.25	3.95 $\pm$ 0.26
	1.79 $\pm$ 0.09		1.67 $\pm$ 0.08	
RK/L2	1.77 $\pm$ 0.09	1.81 $\pm$ 0.09	1.65 $\pm$ 0.08	1.69 $\pm$ 0.09
	2.59 $\pm$ 0.23		2.35 $\pm$ 0.20	
	2.67 $\pm$ 0.23	2.48 $\pm$ 0.18	2.33 $\pm$ 0.16	2.38 $\pm$ 0.22
LK/L2	2.50 $\pm$ 0.21		2.32 $\pm$ 0.18	
	2.56 $\pm$ 0.21	2.42 $\pm$ 0.19	2.31 $\pm$ 0.15	2.34 $\pm$ 0.20

K/L2, kidney-to-L2 length ratio; LK, Left kidney; LK/L2, Left kidney-to-L2 length; RK, Right kidney; RK/L2, Right kidney-to-L2 length.

Discussion

Our study showed that intact male cats exhibited significantly longer kidneys than neutered males, whereas spayed female cats had significantly longer kidneys than intact females. L2 length was also significantly greater in male cats compared to females. In addition, longer L2 lengths in neutered male and female cats comparing with those of intact cats were also detected. While kidney length and L2 length were not correlated with age, both showed a weak positive correlation with BW. The K/L2 ratio was significantly greater in intact male cats compared to those of neutered males. However, this evidence was not detected between intact and spayed females. These findings highlight the influence of sex and gonadal status on kidney length, vertebral length, and the K/L2 ratio.

Kidney disease is a common condition in domestic cats (Reynolds and Lefebvre, 2013). Measurement of kidney size is a crucial component of imaging-based assessment for both diagnosis and treatment planning (Lefebvre, 2010; Brown *et al.*, 2016). Alterations in renal size, shape, and contour are often indicative of underlying pathology. For example, renomegaly is commonly associated with acute kidney disease, whereas reduced kidney size with irregular contours indicated CKD (Lefebvre, 2010; Brown *et al.*, 2016; Seiler and Thrall, 2024). Radiography is a commonly used imaging modality to evaluate kidney size in general veterinary practice (Seiler and Thrall, 2024). Both kidneys were visible on abdominal radiographs in most cats in this study. However, in some cases, only one kidney could be visualized. The left kidney was more consistently assessable radiographically than the

right. This discrepancy is likely attributable to the more cranial position of the right kidney, with its cranial pole closely associated with the liver parenchyma, leading to the superimposition that reduces its radiographic visibility (Burk and Feeney, 2003; Stocco *et al.*, 2016; Mattoon *et al.*, 2020; Seiler and Thrall, 2024). Additionally, the caudal pole of the right kidney may be obscured by the silhouette of overlying intestinal contents, further complicating its radiographic assessment (Burk and Feeney, 2003; Eshar *et al.*, 2013).

To evaluate the kidney size, kidney length is considered more reliable than kidney width (Shiroma *et al.*, 1999). This study demonstrated that the right kidney was longer than the left, consistent with previous studies (Debruyne *et al.*, 2013; Stocco *et al.*, 2016). Clinically, it is typically compared to the length of the L2 on abdominal radiograph (Shiroma *et al.*, 1999). In dogs and cats, the length of L2 has been used as an anatomical landmark for calculating the K/L2 ratio, providing a size index that is independent of body size variation. An increased kidney dimension is proportionally offset by increases in L2 length. Consequently, the interpretation of kidney size using the K/L2 ratio is considered independent (Hackendahl and Citino, 2005; Eshar *et al.*, 2013). For this reason, the K/L2 ratio is frequently employed in clinical practice for the evaluation of kidney size in clinical practice (Thrall and Robertson, 2016; Seiler and Thrall, 2024). However, kidney and L2 size may still be influenced by factors such as sex, gonadal status, age, and BW (Hackendahl and Citino, 2005). Therefore, the present study aims to establish radiographic measurements of kidney and L2 length in healthy cats with different gonadal statuses, providing data that may help

elucidate the relationship between reproductive status and kidney size.

In cats, physeal closure of the lumbar vertebrae typically occurs between 7 and 10 months of age; however, the influence of reproductive status on the timing of this process remains unclear (Thrall and Robertson, 2016). In the present study, the average L2 length in male cats was greater than those in female cats. This is likely attributable to the generally larger body size of males, consistent with previous findings (Shiroma *et al.*, 1999; Debruyne *et al.*, 2013). Furthermore, our results indicated that neutered cats exhibited longer L2 lengths than intact cats in both sexes. This may suggest that reproductive hormones influence the timing of physeal closure. Estrogen plays a key role in endochondral ossification. Elevated estrogen levels accelerate physeal closure by promoting calcium deposition at the growth plates, thereby inhibiting further longitudinal bone growth (Korenchevsky and Dennison, 1934; Kilborn *et al.*, 2002). These findings align with previous studies reporting that prepubertal gonadectomy delays physeal closure, as evidenced by increased radial bone length in gonadectomized cats compared to those of intact cats (Root *et al.*, 1997). Therefore, the longer of the L2 and subsequent the lower K/L2 ratio might be possible in the adult cats whose were done for prepubertal gonadectomy.

Significant differences of kidney sizes were observed between intact and neutered cats, likely influenced by the presence or absence of reproductive hormones. Testosterone has been reported to affect kidney length and the development of the proximal renal tubules (Kilborn *et al.*, 2002). In male cats, both kidney length and the K/L2 ratio were greater in intact individuals compared with those of neutered cats. These findings are consistent with previous studies indicating that intact male cats have larger kidneys than those of neutered cats (Shiroma *et al.*, 1999; Debruyne *et al.*, 2013). Moreover, a similar association between reproductive hormones and kidney size has been demonstrated in mice. Both intact males and neutered males treated with exogenous testosterone exhibited greater kidney size compared to untreated neutered males. The enlarged kidney after exogenous testosterone treatment may induce the hypertrophy and hyperplasia of the epithelial cells in the proximal and distal renal tubules (Jean-Faucher *et al.*, 1987; Kilborn *et al.*, 2002). In contrast, neutered female cats in this study exhibited longer kidney lengths compared to intact females. This difference may be attributable to increased fat accumulation in the retroperitoneal space and renal hilum following neutering, which could affect the apparent kidney size on radiographs (Scott *et al.*, 2002; Griffin, 2019). However, no significant difference in the K/L2 ratio was observed between intact and neutered female cats.

Our study revealed a weak positive correlation between kidney length and BW, consistent with previous studies that have reported positive associations between either renal length or the K/L2 ratio and BW. These findings likely reflect the greater overall tissue mass in heavier cats, including increased

kidney size (Debruyne *et al.*, 2013; Behmanesh and Sorouri, 2024; Maher *et al.*, 2024). Additionally, no correlation was observed between age and kidney length, including age and the K/L2 ratio, in either sex. Discrepancy result was found in dogs that a positive correlation between the K/L2 ratio and age was observed in dogs under one year old, but with no significant association was observed beyond that age (Lee and Leowijuk, 1982).

This study has several limitations. First, due to its retrospective design investigated on the abdominal radiography and history of blood test result, symmetric dimethylarginine levels and urinalysis were not available for all enrolled cats. It would limit the ability to exclude early-stage kidney disease. Second, ultrasound examinations were not performed, which restricted an assessment of internal renal architecture. Although cat selection was based on clinical history and serum creatinine levels, the presence of subclinical renal disease cannot be definitively ruled out. Future prospective studies are warranted to enable comprehensive evaluation of renal function and internal kidney morphology for more accurate exclusion of early or subclinical renal pathology. Lastly, information regarding the age at neutering was not available in almost all cats. Given that the timing of gonadectomy may affect renal development, future studies should consider on this variable.

In conclusion, the present study revealed an association between gonadal status and renal length in cats. Intact male cats exhibited greater kidney length and higher K/L2 ratios compared to neutered males. Among females, neutered cats had longer kidneys than those of intact cats, although no significant difference in K/L2 ratio was observed between the groups. These findings suggest that gonadal status may influence both kidney size and vertebral length. Therefore, gonadal status should be considered when evaluating renal size on radiographic imaging. However, due to overlapping confidence intervals among groups, renal length and K/L2 ratio should not be used as definitive reference values based solely on reproductive status.

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Data availability statement: The data used to support the findings of this study are available from the corresponding author upon request.

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