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Prevalence of canine renal crest hyperattenuation in precontrast computed tomography

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Abstract

Normal canine kidneys are relatively homogeneous soft tissue attenuating structures on nonenhanced CT images. However, visible differences in attenuation between the renal crest and medulla are occasionally observed. This finding and its potential clinical implications have not been previously investigated. This study aimed to estimate the prevalence of renal crest hyperattenuation (RCH) and investigate possible associations with signalment and laboratory parameters. Abdominal CT studies from 100 dogs, with biochemistry and urinalysis data obtained within 48 h before the CT acquisition, were categorized by two radiologists into those with and without visible RCH. The attenuation in Hounsfield units (HU) of the renal crest and renal medulla were measured. Signalment, biochemical, and urinalysis data were analyzed for associations with RCH. Correlation coefficients were calculated for measured HU and associated continuous parameters. Prevalence of RCH was 42.42% (42/99 dogs, 95% CI, 33–52%). Urinary specific gravity (USG) was significantly different between dogs with and without RCH ($P = .034$). Weak positive correlations were identified between left and right renal crest attenuation and USG ($r = 0.233$ and 0.253, respectively; $P = .05$). Renal crest hyperattenuation is a common finding in dogs undergoing abdominal CT. Although the correlation between the USG and renal crest HU is weak, the dogs with RCH have significantly higher USG. Renal crest hyperattenuation might, therefore, not be associated with renal insufficiency. No other specific associations of RCH were identified with parameters typically altered in a variety of diseases. Further investigation may be warranted for its relevance to specific diseases or if it indeed represents a physiological variant.

KEYWORDS
CT, dog, kidney, renal crest

1 | INTRODUCTION

In abdominal CT studies, the urinary tract is routinely assessed. In the veterinary literature, there have been extensive reports on the evaluation of renal size and anatomy using radiography,[1] ultrasound,[2] and CT.[3] CT can provide accurate information about the size, shape, density, location, and number of the kidneys. In unenhanced CT studies of healthy dogs, the kidneys have been reported to have a homogeneous soft-tissue attenuation with fat in the region of the hilus.[4] A review of precontrast CT studies is important to assess the urinary tract, including the kidneys, for evidence of nephrolithiasis or ureterolithiasis, structures that may be obscured by the addition of contrast medium.

In human medicine, the measurement of attenuation in different regions of the kidney on precontrast studies is performed routinely for the analysis of nephrolithiasis.[5] Renal medullary hyperattenuation has been reported in humans and has been described as a variant detected in patients with higher urinary specific gravity.[7] However, there are also reports that different attenuation values can be a result of hydration status,[6] furosemide administration,[8] or drug precipitation (e.g., antibiotics) in the collecting tubules.[9] Similarly, several authors have suggested different attenuation values for the renal medulla, which can be used as an indicator for higher susceptibility for developing future renal calculi[5] or for the presence of medullary nephrocalcinosis.[10] Comparing our population directly with human studies poses a challenge due to the lack of renal crest in human kidneys.

At this institution, the authors have observed a difference in precontrast CT attenuation between the renal crest and the remaining renal parenchyma in canine kidneys. The renal crest was subjectively hyperattenuating to the remainder of the kidney. To our knowledge, this finding has not been previously described in dogs, and therefore, its association—or lack thereof—with physiological or pathological changes is unknown.

The objectives of the study were to (1) determine the prevalence of renal crest hyperattenuation (RCH) in a referral population of dogs undergoing CT examination and (2) to investigate possible associations with signalment, biochemical parameters, and urinalysis results between dogs with and without RCH and the measured attenuation in Hounsfield units. The authors hypothesized that RCH is a common finding in canine precontrast CT studies.

2 | MATERIALS AND METHODS

2.1 | Study design and subject selection

This was a retrospective and observational study. Ethical approval for the current study was obtained by the University of Liverpool Veterinary Research Ethics Committee. One hundred dogs with an available abdominal CT study were identified using the authors' institutional imaging database. To be included in the study, each dog had to have an abdominal CT study with pre- and postcontrast sequences available for review, alongside a biochemistry and full urinalysis performed within 48 h prior to the CT study. Cases that had structural renal disease distorting the normal renal anatomy, such as nodules at the level of the renal medulla and/or the renal crest, were excluded from the study. The information recorded for review included: age, breed, sex, neuter status, weight, urea, creatinine, glucose, albumin, globulins, total protein, calcium, potassium, sodium, chloride, urinary specific gravity (USG), urinary protein, pH, urine protein:creatinine ratio (UPCR), and current medication at the time of the scan, excluding anesthetic drugs used in the procedure.

2.2 | CT technique and image interpretation

All studies were performed with the dogs under sedation or general anesthesia and positioned in sternal recumbency. Drugs used for this purpose, as well as intravenous fluid therapy, were chosen and administered at the discretion of the attending anesthetist. The CT was performed on an 80-slice multidetector row CT scanner (Aquilion Prime, Toshiba Medical Systems Corporation). Pre- and postcontrast images were acquired using a 0.5 s rotation time, 1 mm slice thickness, 512 × 512 matrix dimensions, 120 kVp, and automatic modulation of the tube current. The reconstruction field of view depended on body size. Postcontrast images were obtained after intravenous injection of iodinated contrast medium (300 mg I/mL, Optiray 300, Guerbert) administered using an automatic injector at a dose of 600 mg I/kg, flow rate of 2 mL/s, and a pressure limit of 325 psi. Pre- and postcontrast images were reconstructed using a standard soft tissue algorithm.

CT images were retrieved from the institution's PACS (Carestream software, Carestream Health Inc.) and anonymized (B.S.G.). The studies were reviewed by two ECVDI board-certified radiologists (F.S. and R.M.), who were aware of the purpose of the study but blinded to the patient signalment and history. The images were assessed only in the transverse plane, using DICOM viewing software, either RadiAnt DICOM or Horos viewers. Window width, window level, and magnification could be adjusted according to the personal preference of the reviewers. Both radiologists assessed the study for the subjective presence of hyperattenuation in the renal crest and objectively recorded a measurement of the HU (Hounsfield units) in the crest and adjacent medulla for each kidney and patient. The subjective renal crest hyperattenuation findings were compared between the two reviewers, and a consensus was reached for discordant cases.

Renal crest hyperattenuation was considered present when the attenuation within the renal crest was visibly higher than the adjacent renal parenchyma in precontrast images. This was qualitatively categorized as being present (Y) (Figure 1A) or not (N) (Figure 1B) by the reviewers. Attenuation (in HU) of the renal crest and renal medulla (Figure 2A and B) was measured and recorded by placing a circular region of interest (ROI) over the renal crest and adjacent medulla, respectively. The reviewers agreed beforehand on the location for the ROI measurements. The size of the ROI was adjusted to include only the renal crest, and a similar size was then used to measure the attenuation of the medulla (Figure 2). The renal crest is defined as the triangular-shaped free edge of the medulla, which faces the renal

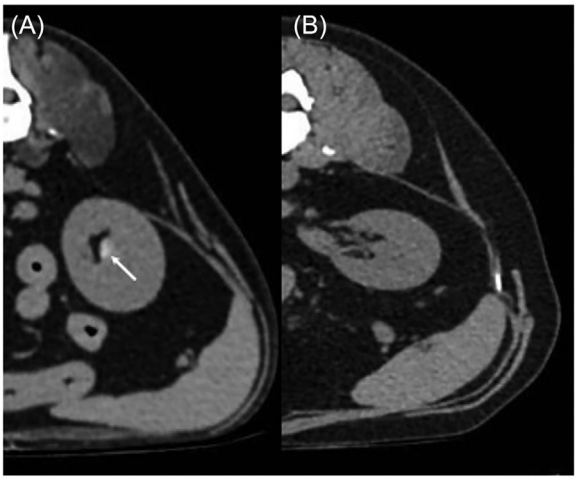

FIGURE 1 Transverse, precontrast CT images of the abdomen at the level of the left renal crest from two dogs with (A) and without (B) renal crest hyperattenuation. 1A: a small, moderately defined area of hyperattenuation is present in the region of the renal crest (arrow). 1B: The renal crest in this dog is isoattenuating to the medulla and cortex. Helical mode acquisition, 120 kVp, automatically modulated mAs, image matrix 512 × 512, 1 mm slice thickness.

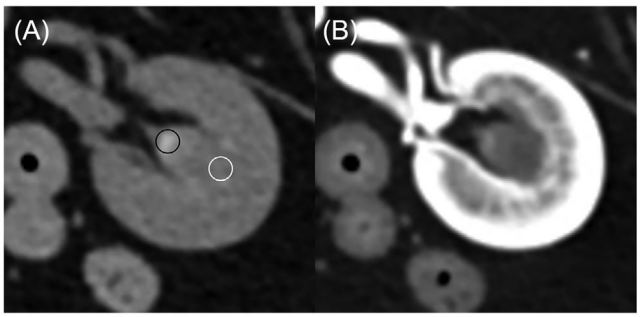

FIGURE 2 Transverse, precontrast (A), and postcontrast (B) CT images of the abdomen at the level of the renal crest from a dog with renal crest hyperattenuation. It shows how the ROI was positioned in the renal medulla (white circle) and the renal crest (black circle) of the dogs without inadvertently including the renal cortex in the measurement.

pelvis.[11] Postcontrast images were used as a reference to accurately determine the location of the renal medulla ROI.

2.3 | Statistical analysis

Statistical analyses were performed using commercially available software (IBM SPSS Statistics for Windows, Version 29.0). Independent variables were derived from information obtained from the signalment data, clinical records, and CT images. Variables assessed included those associated with the patient (age, weight (kg), breed, urea (mmol/L), creatinine (umol/L), glucose (mmol/L), albumin (g/L), globulins (g/L), total proteins (g/L), potassium (mmol/L), sodium (mmol/L), chloride (mmol/L), calcium (mmol/L), USG, urinary protein, pH and UPC), renal crest hyperattenuation qualitatively assessed on CT images, and HU measurements of renal crest and medulla. A mean value of the attenuation between the two reviewers was determined for further analysis. The ratio between the mean renal crest and medullary attenuation was calculated for each kidney. The normality of distribution for continuous variables was assessed using the Kolmogorov–Smirnov test. Descriptive statistics were calculated; continuous data were summarized as median values [interquartile ranges], and categorical data were expressed as frequencies with 95% confidence intervals (95% CI). The study population was subdivided into two groups based on subjective assessment: (1) renal crest hyperattenuation in at least one kidney and (2) renal crest isoattenuation compared with the adjacent medulla in both kidneys. A comparison of continuous variables described above between groups was performed using either the Student's t-test or Mann–Whitney *U*-test, depending on the result of the normality test. Pearson's Chi-squared test was used for comparison of the categorical variable (sex) between groups. Correlation between mean measured HU, as well as the ratio of the attenuation values of the left and right renal crest and significantly different variables, was assessed by Spearman's rank correlation coefficient (rho). A P-value $< .05$ was considered statistically significant.

3 | RESULTS

Ninety-nine of the 100 recruited dogs met the inclusion criteria; one was excluded due to the presence of nodules that altered the renal anatomy. Of these, 40 were female (13 entire, 27 neutered) and 59 were male (19 entire, 40 neutered). The mean age was 8 years (2 years 9 months–14 years 11 months). The mean body weight was 20.6 kg (3–67 kg). The breeds most frequently represented in the study population were mixed breeds (19), followed by cocker spaniels (11), Labrador retrievers (10), English springer spaniels (6), Staffordshire bull terriers (4), Shih Tzu (3), Border collie (3), amongst others.

Of the 99 dogs that met the study inclusion criteria, 42 had either uni- (1/99) or bilateral (42/99) RCH (prevalence 42.42%, 95% CI, 33–52%) based on subjective assessment. For further evaluation, the study population was subdivided into two groups: (1) subjective renal crest hyperattenuation in at least one kidney (RCH group) and (2) renal crest isoattenuation compared with the adjacent medulla in both kidneys (RCI group). The chi-square test for evaluating the effect of sex on the presence of the RCH group revealed no significant difference between the groups [$X^2(3, N = 99) = 1.978$, $P > .05$]. The mean results of the age, weight, biochemistry parameters, and urinalysis were obtained and compared for each group (summarized in Table 1).

Results from the objective measurements of renal crest and renal medulla attenuation are summarized in Table 2.

The median HU of renal crests for kidneys with RCH was 50.25 HU (IQR, 43.50–60.63) for right kidneys (42/99) and 49.50 HU (IQR, 45.50–60.13) for left kidneys (41/99). The adjacent medulla measured a mean of 30.50 HU (IQR, 30.38–37.00) for the right kidneys and 33.75 HU (IQR, 31.00–36.25) for the left kidneys with RCH. These values were significantly different between groups for both kidneys ($P < .001$).

TABLE 1 Median values and interquartile ranges for age, weight, and clinicopathological data from dogs with either renal crest hyperattenuation in at least one kidney (RCH group) or bilateral renal crest isoattenuation (RCI group).

	RCH group	RCI group
Age (years)	9.75 (6.79–11.63)	8.50 (4.41–11)
Weight (kg)	17.0 (9.5–22.75)	19.0 (10–27.75)
Urea (mmol/L)	5.97 (4.50–8.46)	5.01 (3.99–6.64)
Creatinine (μmol/L)	69.25 (55.03–95.35)	73.45 (60.88–96.95)
Glucose (mmol/L)	5.79 (5.41–6.32)	5.90 (5.32–6.19)
Albumin (g/L)	29.27 (26.87–32.33)	30.53 (28.16–91.91)
Globulin (g/L)	31.30 (27–35.30)	31.85 (28.18–35.25)
Total Protein (g/L)	61.75 (56.70–65.88)	62.10 (56.73–66.98)
Potassium (mmol/L)	4.56 (4.30–4.93)	4.49 (4.18–4.76)
Sodium (mmol/L)	147.95 (146.23–149.9)	147.70 (147.75–148.88)
Chloride (mmol/L)	112.35 (109.70–114.50)	111.50 (109.78–113.90)
Total calcium (mmol/L)	2.51 (2.42–2.63)	2.55 (2.44–2.64)
USG[a]	1.033[a] (1.020–1.048)	1.026[a] (1.018–1.035)
Urinary protein (g/L)	0.30 (0.18–1.2)	0.30 (0.18–0.54)
pH	7.50 (6.0–8.5)	7.50 (7.0–8.5)
UPCR	0.23 (0.11–0.67)	0.2 (0.12–0.56)

[a]The statistically significant variable.
Abbreviations: UPCR, urine protein:creatinine ratio; USG, urine specific gravity.

TABLE 2 Median HU value and attenuation ratio with interquartile ranges (IQR) for the right and left renal crest and medulla of kidneys with and without RCH.

	Kidneys with RCH	Kidneys without RCH
Median HU (IQR) right renal crest	50.25 (43.50–60.63)	30.00 (26.50–33.50)
Median HU (IQR) right renal medulla	30.50 (30.38–37.00)	30.50 (27.50–37.50)
Median attenuation ratio right kidney	1.49 (1.35–1.67)	1.00 (0.84–1.17)
Median HU (IQR) left renal crest	49.50 (45.50–60.13)	30.50 (26.25–35.75
Median HU (IQR) left renal medulla	33.75 (31.00–36.25)	33.75 (29.50–37.00)
Median attenuation ratio left kidney	1.51 (1.31–1.78)	0.96 (0.87–1.10)

The median HU of the renal crest for kidneys without RCH was 30.00 HU (IQR, 26.50–33.50) for right kidneys and 30.50 HU (IQR, 26.25–35.75) for left kidneys, while the medulla measured a median of 30.50 HU (IQR, 27.50–37.50) for right kidneys and 33.75 HU (IQR, 29.50–37.00) for left kidneys (Figure 3). A significant difference between the measured attenuation of the renal medulla of kidneys with and without RCH was detected in the right kidney ($P = .02$) but not the left ($P = .06$).

We also calculated the ratio of the attenuation values between the renal crest and medulla (Table 2) as it was considered likely that the ratio of the attenuation of the two regions would discriminate the two groups better. The median attenuation ratio in kidneys with RCH was 1.49 (IQR, 1.35–1.67) and 1.51 (IQR, 1.31–1.78) for right and left kidneys, respectively. For kidneys without RCH, the attenuation ratios were 1.51 (IQR, 1.31–1.78) and 0.96 (IQR, 0.87–1.10) for the right and left kidneys, respectively.

The only variable found to be statistically significantly different between groups was the urine-specific gravity ($P = .034$). The median urinary specific gravity (USG) of dogs in the RCH group was 1.033 (IQR, 1.020–1.048), and for the RCI group was 1.026 (IQR, 1.018–1.035). The correlation between the mean measured HU of the right and left renal crest and USG was also assessed with Spearman's rho test, which resulted in a value of 0.253 and 0.233 for the right and left renal crest, respectively ($P < .05$).

The correlation between the attenuation ratios and the USG was calculated as 0.352 and 0.368 for the right and left kidney, respectively ($P < .001$).

This signified a weak positive correlation between the USG and attenuation values as well as attenuation ratios.

Although all current medications were recorded, 74% of dogs were not receiving any medication at the time of the CT scan and this data was considered insufficient for further statistical analysis.

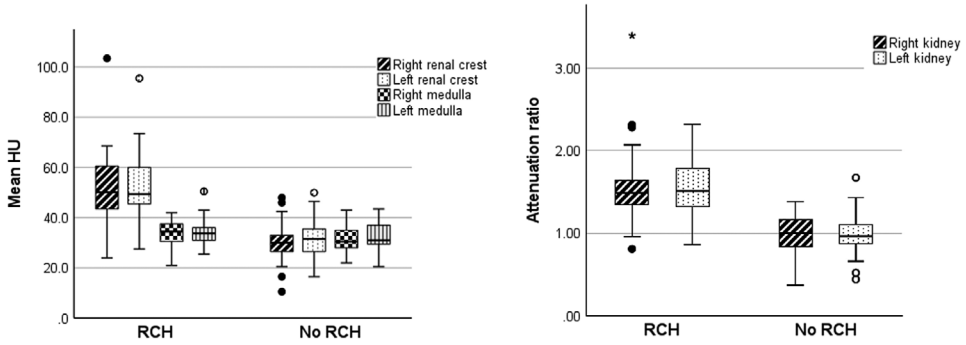

FIGURE 3 Boxplots of the mean measured HU and the attenuation ratio with medians, interquartile ranges, and outliers. Data are presented for kidneys with and without renal crest hyperattenuation (RCH) and divided into right and left kidneys as well as regions within the kidney for mean measured HU.

4 | DISCUSSION

The prevalence of dogs with RCH in at least one kidney was 42.42% in precontrast CT studies. This finding supported our hypothesis that RCH is a common finding in our canine population. Based on our review of the literature, this is the first published study describing hyperattenuation of the renal crest in precontrast CT images in a canine population.

In this study, the authors investigated the possible association with signalment, biochemical parameters, and urinalysis results between dogs with and without RCH. A significant difference in USG was detected between dogs with and without RCH. Furthermore, a positive weak correlation was found between the USG and the renal crest HU, as well as the attenuation ratio. Differences in other variables investigated in the study were not found to be statistically significant.

Our findings indicate that the physiological process of concentrating urine may be associated with the occurrence of RCH. The mammalian kidney uses an osmotic gradient to modulate the urine concentration during anti-diuresis. This gradient increases from the corticomedullary boundary to the papillary tip (humans) or renal crest (dogs).[12] The renal cortex is nearly isotonic to plasma while the renal crest/papillary tip is hypertonic to plasma. The main factor responsible for this osmotic gradient is sodium chloride (NaCl)[12, 13] Interestingly, Hsu et al.[7] designed phantoms to assess the main urinary component affecting attenuation values and measured the attenuation of NaCl solutions ranging from 0 to 2000 mosm/kg and gradual dilution of urea, respectively. A positive correlation was found between the increase in attenuation value with higher concentrations of NaCl, whereas the attenuation did not change with different concentrations of urea. This was reported to be most likely due to a lack of attenuation of X-rays by urea (CON2H4). Urea is an organic compound with a 1000-fold lower k edges than sodium (1.7 keV) and chloride (2.8 keV).[7]

A higher concentration of highly attenuating constituents may be the reason for the RCH as observed in the present study. However, the RCH group also included iso- and hyposthenuric dogs. Therefore, the physiological osmotic gradient within the kidney may not be the sole cause of RCH.

As mentioned in the introduction, medullary hyperattenuation has been studied in people. Direct comparison of our population with human studies is challenging due to the anatomical differences in kidneys between species (unilobar-multipapillary in humans[14] and unilobar-unipapillary in dogs[15]); the ambiguity in the regions measured (focal[5,7] or general[6,8–10]) in multiple published human studies. However, the causes for hyperattenuation in this region may still be similar in people and dogs. Tublin et al.[6] hypothesized that dehydration, and with that, increased urine concentrating action and higher USG, may contribute to increased attenuation of this region, as postulated above. Similarly, the observation that administration of furosemide (diuresis) was associated with the resolution/lack of hyperattenuation could be explained by the opposite physiological mechanism.

A good concentrating ability is generally considered equivalent to adequate renal function, and therefore, the authors propose that finding RCH in precontrast CT studies is more likely not associated with renal insufficiency.

The median HU of renal crests with RCH was 50.25 and 49.50 HU for the right and left kidneys, respectively. Whereas the median HU of renal crest without RCH was 30.00 HU in the right kidney and 31.50 HU in the left kidney. These values were significantly different between groups for both kidneys. The correlation with the USG was only weak; it raises the question of whether the measured HU in the renal crest could give us any additional information about the hydration status of dogs. That said, the interquartile ranges of the measured HU were overlapping between groups.

Other studies in people compared the attenuation of the renal papilla in patients with and without urolithiasis, hypothesizing that hyperintensity in this area may be able to predict so-called "stone formers".[5] This was outside the scope of the current study. Future investigation into RCH in dogs with urolithiasis with serial CT studies could be helpful to investigate if this finding is also applicable to dogs.

A slightly perplexing finding from this study was the disparity between the measured attenuation of the medulla between the left and right kidneys with renal crest hyperattenuation, which was significantly different in the right kidney ($P = .02$) compared with kidneys without RCH, but it was not for the left ($P = .06$). The authors were unable to find a physiological reason for this. We concluded this finding

to be most likely related to the lack of statistical power in this study population and hypothesize that a larger number of dogs may have shown consistent results across both kidneys.

There were several limitations in this study. First, as addressed above, it was unclear why a difference between the medullary attenuation between kidneys was documented. Second, while a positive association between USG and renal crest hyperattenuation was identified, this correlation was only weak. It would be interesting to assess what, if any, influence increasing the number of subjects recruited to this study would have on these findings. A further limitation of this study was the inherent lack of animals with concurrent severe renal disease (e.g., acute kidney injury) and/or animals with severe systemic disease (e.g., patients with severe dehydration and shock). Evaluation of these patient populations may help to provide further insights into the association between urine concentration and RCH. Iodinated intravenous contrast medium is known to induce or exacerbate renal failure and is, therefore, unsuitable in this population. However, at the authors' institution, abdominal CTs without postcontrast studies are rarely performed due to the limited information obtained from these studies. Finally, a variation in the hydration status between dogs is possible. Most dogs at our institution are sedated and do not receive intravenous fluid therapy prior to the scan unless they are unstable.

In conclusion, canine RCH in at least one kidney is a common finding, with a prevalence of 42.4%. There was a significant difference in USG between dogs with and without RCH, and the density of this region in HU, as well as the attenuation ratio, had a weak positive correlation with the USG. Renal crest hyperattenuation might, therefore, be a normal variant indicating adequate urine concentrating ability, and it was not associated with renal insufficiency. Further studies could address other contributing causes for RCH, for example, concurrent medication, its use as a predictor for urolithiasis, or indeed whether this finding could be utilized to assess the hydration status of dogs undergoing CT studies. Histopathology of the region and correlation with clinical findings would be needed to achieve a definitive cause of RCH.

LIST OF AUTHOR CONTRIBUTION

Category 1

(a) Conception and design: Marwood, Schiborra
(b) Acquisition of data: Serra
(c) Analysis and interpretation of data: Serra, Marwood, Schiborra

Category 2

(a) Drafting the article: Serra
(b) Revising article for intellectual content: Marwood, Schiborra

Category 3

(a) Final approval of the completed article: Serra, Marwood, Schiborra.

Category 4

(a) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Serra, Marwood, Schiborra

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Professor Thomas Maddox, BVSc, PhD, CertVDI DipECVDI MRCVS RCVS Specialist in Small Animal Diagnostic Imaging and EBVS European Specialist in Small Animal Diagnostic Imaging.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data supporting the results of the study are available from the corresponding author upon reasonable request.

PREVIOUS PRESENTATION OR PUBLICATION DISCLOSURE

Portions of this study were presented at the IVRA EVDI Joint Scientific Conference, Ireland, in June 2023.

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