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Use of contrast-enhanced computed tomography to detect kidney infarction in dogs

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Abstract

Background: Kidney infarction is a renovascular disease diagnosed by contrast-enhanced computed tomography (CECT) in humans.

Objectives: To describe the frequency of kidney infarction and to determine the detection of kidney infarction with CECT in dogs.

Animals: Eight hundred and twenty-six abdominal CECT studies of 826 dogs.

Methods: A cross-sectional retrospective study. Dogs with abdominal CT scans including CECT were retrospectively retrieved. Kidney infarction was classified into 3 grades based on the extent of infarction relative to total kidney area. The location and number of kidney infarctions in each kidney were expressed as number and percentage. The ability of visualization of kidney infarction in each multiplanar reconstruction (MPR) image plane was evaluated by agreement of 2 observers.

Results: The frequency of kidney infarction in dogs was 3.15% (26/826 dogs; 95% CI = 2.05-4.61). Most kidney infarctions were classified as grade 1, or the lesions were less than 25% of the kidney (47/56, 83.93%) and most were detected at the caudal pole of the kidney (31/56, 55.35%) on the sagittal plane. On MPR image planes, the sagittal plane had the highest proportion (34/56, 60.71%) of excellent visual category to detect kidney infarction.

Conclusions and Clinical Importance: The CECT, especially the sagittal plane, is a useful diagnostic tool for the detection of kidney infarction in dogs.

KEYWORDS
canine, contrast medium, CT, ischemia, kidney

1 | INTRODUCTION

Kidney infarction is a renovascular disease that is caused by sudden occlusion of the kidney blood flow. It results in acute kidney injury and alters kidney function and kidney failure.[1,2] The frequency of kidney infarction in humans ranges from 0.007% in 3 years[3] to 1.4% in 9 years.[4] The incidence rate of kidney infarction in dogs has not been reported. Clinical signs of this abnormality are

Abbreviations: ALP, alkaline phosphatase; ALT, alanine aminotransferase; BUN, blood urea nitrogen; CECT, contrast-enhanced computed tomography; DICOM, Digital and Communications in Medicine; FOV, field of view; HIS, hospital information system; LK, left kidney; MPR, multiplanar reconstruction; PACS, Picture Archiving and Communication System; RK, right kidney.

nonspecific in humans, leading to difficulties in diagnosis. Consequently, underdiagnosis, delayed diagnosis, and late treatment are common.[5-8]

Kidney infarction can be diagnosed by using various imaging modalities such as abdominal ultrasound, kidney angiography, contrast-enhanced computed tomography (CECT), magnetic resonance imaging, and kidney scintigraphy.[9,10] Among these techniques, CECT is 1 of the most common imaging modalities to detect kidney infarction in humans due to its availability, high sensitivity and specificity to detect the lesion, and time efficiency.[10-12] Kidney infarction on CECT images presents as a wedge-shaped parenchyma perfusion defect, with or without a cortical rim sign, without mass effect, or major perirenal stranding.[7,13,14] Characteristics of experimentally induced kidney infarction in dogs are peripheral wedge-shaped hypoattenuating areas without a cortical rim sign, similar to that in humans.[15]

To the best of our knowledge, the frequency of kidney infarction in dogs has not been reported. Also, there are no studies on the use of CECT to detect kidney infarction and the common location of kidney infarction in dogs. In this context, we investigated the frequency and location of kidney infarction in dogs using CECT, including multiplanar reconstruction (MPR). We tested the hypotheses that (a) MPR can increase the detectability of kidney infarction on CECT and (b) the distinctness of kidney infarction on CECT is different among MPR planes.

2 | MATERIALS AND METHODS

2.1 | Animals

This study was designed as a cross-sectional retrospective review of CT images and medical records. All CT images and medical records of dogs from November 2013 to January 2019 were recruited from the Diagnostic Imaging Unit, the Small Animal Hospital, Faculty of Veterinary Science, Chulalongkorn University. This study was approved by the hospital institutional review board (approval number: S226/2563). We included all abdominal CT images of dogs with contrast enhancement where the field of view (FOV) was covered from the cranial edge of the diaphragm to the cranial area of the pelvic inlet and the kidneys were clearly observable. The exclusion criteria were CT images that revealed abnormal kidney structures including kidney atrophy, a mass in the kidney, or low-quality CT images due to motion artifact or thick-slice thickness for performing the MPR. Clinical information and laboratory data of dogs with kidney infarction were obtained from the medical record on the hospital information system (HIS). Clinical information, including age, breed, sex (including neuter status), and body weight, was retrieved from medical records. Laboratory data, including CBC, blood urea nitrogen (BUN), creatinine, alanine aminotransferase (ALT), alkaline phosphatase (ALP), total protein and albumin concentration, were recorded. Dogs were classified into 3 groups of breed, based on the American Kennel Club, as small breed, medium breed, and large breed.

2.2 | Analysis of computed tomographic images

All CT images were retrieved from the Picture Archiving and Communication System (PACS) in the Digital and Communications in Medicine (DICOM) format and re-analyzed by using the DICOM viewer software (Osirix, Geneva, Switzerland) at a non-CT unit workstation with 2560×1440 pixels of the monitor. The CT images were obtained from dogs that were subjected to general anesthesia and scanned by a 64-slices, helical CT scanner (Optima CT660, GE Healthcare, Tokyo, Japan); the matrix was 512×512, and the slice thickness ranged from 0.625 to 1.25 mm, depending on the body size. To identify kidney infarction, a window width of 350 Hounsfield units and a window level of 150 HU were set. Kidney infarction and concavity of the kidney margin were evaluated, and the location was defined using MPR to enhance kidney visualization. The characteristics of the lesion were classified as follows: (a) kidney infarction with normal contour and (b) kidney infarction with concavity of the kidney margin. Kidney infarction with normal contour was defined as a wedge-shaped or segmental hypoattenuating area with surrounding hyperattenuation contrast enhancement at the kidney cortical parenchyma or extending into the medulla with a smooth kidney contour, or both.[16] Kidney infarction with concavity of the kidney margin was defined as presenting of former described kidney infarction lesion accompanied with concavity of the kidney margin, irregular kidney margin due to focal parenchyma loss of the cortex with normal kidney size and shape. Additionally, kidney infarction was classified into 3 grades based on the degree of the affected kidney infarction area to the kidney area as follows: (a) grade 1 (less than 25% of the affected kidney); (b) grade 2 (25-50% of the affected kidney); and (c) grade 3 (more than 50% of the affected kidney).[1] The location of kidney infarction was recorded based on MPR images as follows: (a) cranial, middle, and caudal areas on the sagittal plane (Figure 1A); (b) dorsal and ventral areas on the transverse plane (Figure 1B); and (c) medial and lateral areas on the dorsal plane (Figure 1C). The number of kidney infarction lesions found in each kidney was also noted.

The visual category for detecting kidney infarction on each MPR plane (sagittal, transverse, and dorsal planes) was established by agreement of 2 experienced observers (P.S. and S.S.) to compare the ability to detect kidney infarction on each MPR image plane. The visual category was classified as follows: (a) poor visualization: an unclear visualization of a non-wedge-shape hypoattenuating margin; (b) moderate visualization: an unclear visualization of a wedge-shaped hypoattenuating margin; and (c) excellent visualization: a clear visualization of a wedge-shaped hypoattenuating margin (Figure 2A-C).

2.3 | Statistical analysis

Statistical analysis was performed by using GraphPad Prism 7.0 (GraphPad Software, San Diego, California). All clinical data of enrolled dogs were presented as descriptive data. Continuous data were assessed for normal distribution by using the Shapiro-Wilk normality

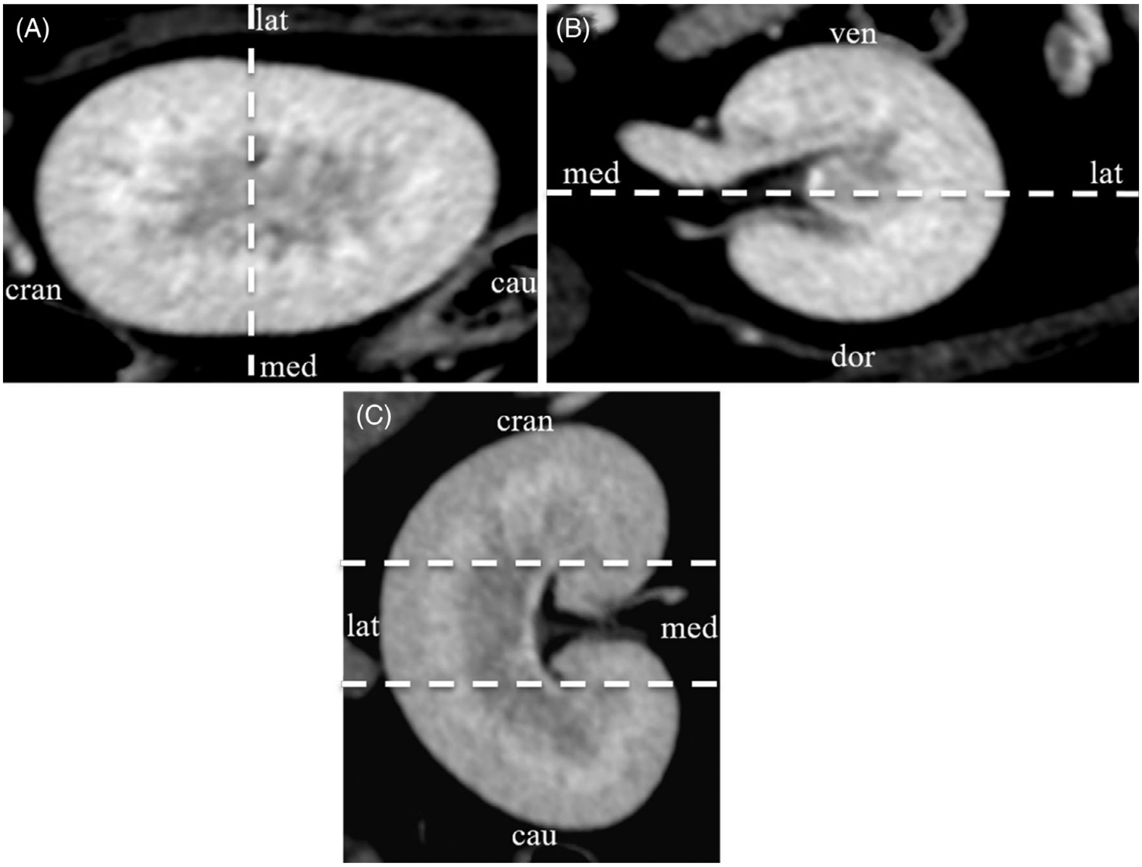

FIGURE 1 The location of kidney infarction that was determined based on multiplanar reconstruction image planes (A-C). Kidney infarction was located to cranial (cran), middle (med), and caudal (cau) part on the sagittal plane (A). Kidney infarction was located to lateral (lat) and medial (med) part on the transverse plane (B). Kidney infarction was located to ventral (ven) and dorsal (dor) part on the dorsal plane (C)

test. Normally distributed data were reported as mean ± SD and non-normally distributed data were reported as median and range. The categorical data including the number and location of kidney infarctions and kidney infarctions with concavity of the kidney margin were expressed as number and percentage, respectively. The χ^2 test was used to compare the proportional distributions of visual categories in different MPR image planes; *P*-values less than .05 were considered statistically significant.

3 | RESULTS

3.1 | Clinical demographic data

Of the 826 dogs that underwent CECT scans, 42 were excluded because of kidney atrophy. A total of 26 dogs affected with kidney infarction met the inclusion criteria. Among them, 9 (34.62%) dogs were small, 9 (34.62%) dogs were medium, and 8 (30.76%) dogs were large breeds. There were mixed-breed dogs (n = 7), Shih Tzus (n = 5), Poodles (n = 4), Golden Retrievers (n = 3), beagles (n = 2), and 1 each of Labrador retriever, cocker spaniel, Rottweiler, Siberian husky, and Thai Bangkaew. There were 13 intact males, 3 castrated males, 5 intact females, and 5 spayed females. Of the 26 dogs, mean ± SD of age and body weight was 9.41 ± 4.5 years and 15.82 ± 9.29 kg, respectively.

Of 56 lesions of 38 kidney infarctions were considered as incidental findings. The final diagnoses were neoplastic disease (n = 25; nasal adenocarcinoma (n = 3), squamous cell carcinoma (n = 3), splenic mass (n = 3), gastric wall mass (n = 2), mast cell tumors (n = 2), melanomas (n = 2), adrenal mass (n = 1), brain tumor (n = 1), cranial mediastinal mass (n = 1), hard palatine mass (n = 1), hepatic mass (n = 1), histiocytomas (n = 1), oropharyngeal mass (n = 1), perianal adenoma (n = 1), prostatic mass (n = 1), and thyroid carcinoma (n = 1)). One dog had hyperplasia of the ear wall.

Laboratory data of 15 of 26 dogs were recorded from HIS such as hematocrit, white blood cell count, platelets, as well as ALT, ALP, BUN, creatinine, total protein, and albumin concentration. Almost all blood variables were within the normal ranges, except for a decrease in albumin concentration in 7 of 15 dogs (mean ± SD, 2.17 ± 0.23 g/dL; normal range, 2.60-4.00 g/dL), and an increase in ALP activity in 12 of 15 dogs (median, 159 U/L; range, 78-1352 U/L; normal range, 3-60 U/L). All blood results are presented in Table S1.

3.2 | Computed tomography imaging and kidney infarction

The frequency of kidney infarction detectable by CECT in this sample of dogs was 3.15% (26/826 dogs; 95% CI = 2.05-4.61). Kidney

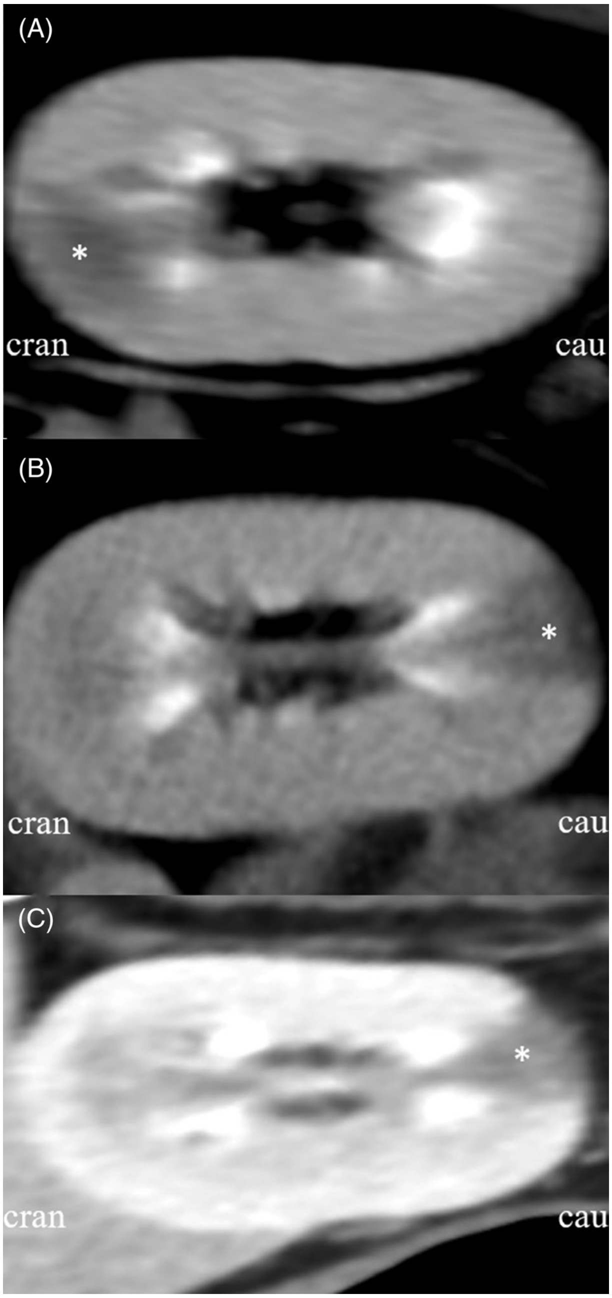

FIGURE 2 The visual category of kidney infarction (A-C). Kidney infarction with normal contour and unclear visualization of a non-wedge-shape hypoattenuating area (asterisk); poor visualization (A). Kidney infarction with normal contour and unclear visualization of a wedge-shaped hypoattenuating areas (asterisk); moderate visualization (B). Kidney infarction with normal contour and clear visualization of a wedge-shaped hypoattenuating area (asterisk); excellent visualization (C)

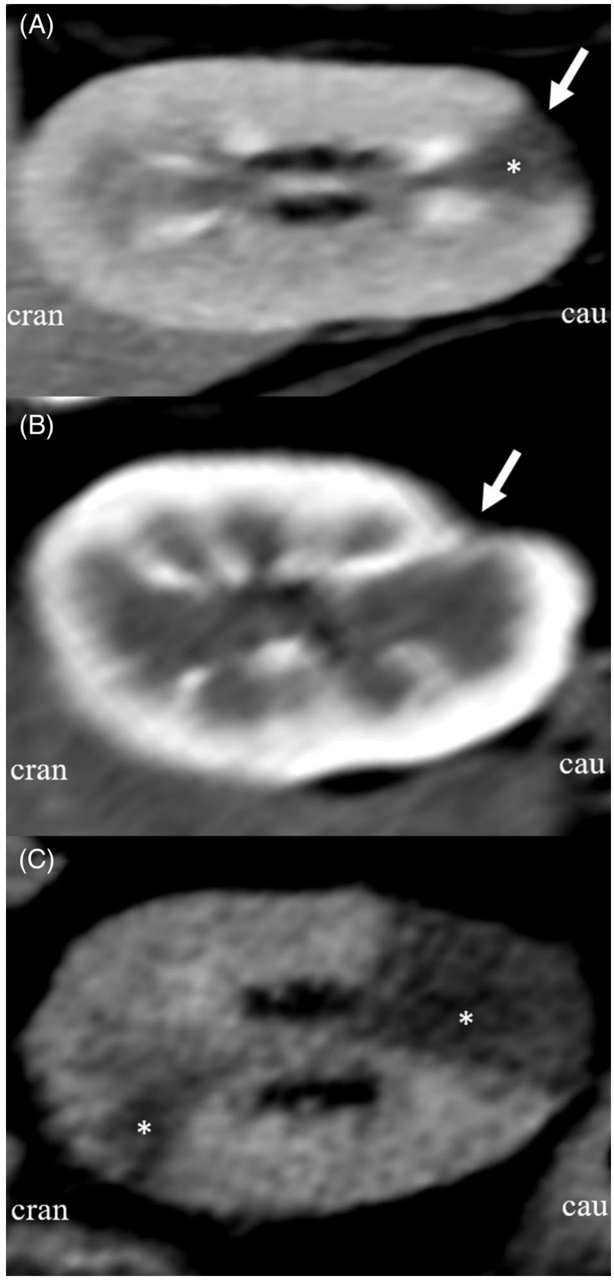

FIGURE 3 On the sagittal plane, contrast-enhanced computed tomography images show grade 1 and 2 of infarction with concavity of the kidney margin (A-C). Grade 1 kidney infarction (asterisk) with mild degree of concavity of the kidney margin (arrow) (A). Grade 1 kidney infarction with severe degree of concavity of the kidney margin (arrow) (B). Grade 2 kidney infarction (asterisk) with mild degree of concavity of the kidney margin (C)

infarction with normal kidney contour was detected in 20 dogs (20/26, 76.93%) and found in 15 right (RKs) and 13 left kidneys (LKs) (Figure 2C). Kidney infarction with concavity of the kidney margin was detected in 6 dogs (6/26, 23.08%) and found in 5 RKs and 5 LKs (Figure 3A-C). The LKs were affected in 6 dogs (6/26, 23.08%), the RKs in 8 dogs (8/26, 30.77%), and both kidneys in 12 dogs (12/26, 46.15%). Kidney infarction was identified in 38 kidneys (20 RKs and 18 LKs). There were single lesions in 13 dogs and multiple lesions in 13 dogs.

From total of 52 kidneys, 38 kidneys had infarction. The total number of kidney infarction was 56 lesions (Table 1). Kidney infarction with grade 1 was most common (Figure 3A), followed by grade 2 (Figure 3C). Grade 3 lesion was not detected in this study. The location and number of kidney infarctions detected on each MPR image plane of sagittal, transverse, and dorsal plane are shown in Table 2.

TABLE 1 The grading and number of lesions in infarct-affected kidneys

Classification	Total	Right kidney	Left kidney
Grade 1	47/56 (83.93%)	26/56 (46.43%)	21/56 (37.50%)
Grade 2	9/56 (16.07%)	5/56 (8.93%)	4/56 (7.14%)
Grade 3	-	-	-

Note: The grading of kidney infarction was classified based on the degree of the affected kidney infarction area to the kidney area as follows: grade 1 (less than 25% of the affected kidney); grade 2 (25%-50% of the affected kidney); and grade 3 (more than 50% of the affected kidney).

TABLE 2 The number of lesions of kidney infarction based on the location that was detected by multiplanar reconstruction

Location	Total	Right kidney	Left kidney
Sagittal plane			
Cranial area	22/56 (39.29%)	12/56 (21.43%)	10/56 (17.86%)
Middle area	3/56 (5.36%)	-	3/56 (5.36%)
Caudal area	31/56 (55.35%)	19/56 (33.93%)	12/56 (21.42%)
Transverse plane			
Dorsal area	29/56 (51.79%)	19/56 (33.93%)	10/56 (17.86%)
Ventral area	27/56 (48.21%)	12/56 (21.43%)	15/56 (26.78%)
Dorsal plane			
Medial area	29/56 (51.79%)	14/56 (25%)	15/56 (26.79%)
Lateral area	27/56 (48.21%)	17/56 (30.36%)	10/56 (17.85%)

From 56 lesions on MPR image planes of CECT, the proportion of visual categories on the sagittal plane (poor visualization 1/56, 1.78%; moderate visualization 21/56, 37.51% and excellent visualization 34/56, 60.71%) was significantly different from those on the transverse plane (poor visualization 1/56, 1.78%; moderate visualization 34/56, 60.71% and excellent visualization 21/56, 37.51%) ($P = .05$) and the dorsal plane (poor visualization 1/56, 1.78%; moderate visualization 38/56, 67.86% and excellent visualization 17/56, 30.36%) ($P = .005$). No significant difference was found between the proportion of visual categories observed on the transverse and the dorsal planes ($P = .73$). The proportion of excellent visual category on MPR image planes was mostly found on the sagittal plane (34/56, 60.71%), followed by the transverse plane (21/56, 37.50%) and the dorsal plane (17/56, 30.36%).

4 | DISCUSSION

In the present study, the frequency of kidney infarction, detected by CECT, was 3.15% of examined dogs. All dogs (26/26) with kidney infarction were asymptomatic and the lesion was found incidentally. The most common location of kidney infarction was the caudal part of the kidney. This study reports the frequency and the location of kidney infarction in dogs. Furthermore, this study revealed that CECT is a valuable modality for the detection of kidney infarction in dogs, which is similar to humans. MPR image planes, especially the sagittal plane, can increase the detection of kidney infarction lesions.

The prevalence of kidney infarction in humans ranges from 0.013 to 1%.[7,16,17] The prevalence of kidney infarction on autopsy was 1.4%.[4] Although the frequency of kidney infarction in dogs and cats has not been reported, the frequency of kidney infarction in 600 cats based on ultrasonographic examination and necropsy was 51.5% .[9] The current study reports the frequency of kidney infarction in dogs presented to our referral animal hospital; hence, it cannot be compared with the previous prevalence in humans. However, our results show that kidney infarction can be found in dogs and could be underdiagnosed due to nonspecific clinical signs and laboratory findings. Kidney infarction is more common in older humans.[5,11,17,18] We found no association between sex and the frequency of kidney infarction, likely because of the small sample size of affected dogs. Sex does not influence the frequency of kidney infarction in humans.[1,5,19]

Assessment of clinical signs does not assist in the diagnosis of kidney infarction as they are nonspecific. Humans with kidney infarction tend to have nonspecific clinical signs such as abdominal pain, nausea, vomiting, and fever.[3,5-7,20] Clinical signs of dogs with kidney infarction include abdominal pain, vomiting, diarrhea, anorexia, polyuria, oliguria, and dysuria likely due to acute kidney injury.[21,22] Laboratory data can support the diagnosis of kidney infarction in humans, for example, leukocytosis, abnormally high lactate dehydrogenase, aspartate aminotransferase, BUN, creatinine, and hematuria. These variables are nonspecific for the diagnosis of kidney infarction.[3,5-7] Dogs in this study, most laboratory findings, were within the normal range, except for the low albumin concentration and the high ALP activity, which are nonspecific for the diagnosis of kidney infarction. Laboratory data were not retrieved from all enrolled dogs because some dogs were referred from other hospitals for CT only, and the data were therefore not recorded in HIS. Additionally, dogs with kidney infarction with increased BUN and creatinine concentration might not undergo CT or

CECT due to high risks of anesthesia and contrast-induced nephropathy. The small sample size of the current study precluded investigation of the correlation between laboratory findings and the occurrence of kidney infarction.

Most kidney infarctions were classified as grade I (47/56, 83.93%) suggesting focal infarctions. These are likely to be caused by the occlusion of small branches of the kidney artery. Grade 2 of kidney infarction refers to segmental infarction and generally occurs because of the blockage of the major branches of the kidney artery.[10,13,23] Kidney infarction was more likely to be identified at the caudal part of the kidneys (31/56, 55.35%). The anatomical difference of kidney vessels among kidney parenchymal area could have contributed to this phenomenon.[7,24,25] The caudal branches of the kidney artery directly supply the caudal part of the kidney and play an important role in kidney arterial supply,[24] in contrast to humans, where the caudal part of the kidneys receives blood from both of the posterior and anterior segmental arteries.[25] Grade 3 of kidney infarction was not observed in the current study. Dogs with grade 3 kidney infarction (more than 50% of the infarct area) might have impaired in kidney function, with increased in BUN and creatinine concentration. As a result, these dogs might not have undergone CT or CECT scan due to the high risk from anesthesia and the administration of contrast medium and were not included in this study. Conversely, anesthesia is not required for CT scans in humans, and hence, Grade 3 kidney infarction is more easily detectable in humans than in dogs.[13,15,23] Further, bilateral kidney involvement was commonly detected in dogs with kidney infarction (12/26, 46.15%). This finding differs from those for humans, where kidney infarction is frequently unilateral.[7,17,18,20]

Diagnostic imaging can be used as an antemortem diagnosis for kidney infarction. Although several methods can be used for the detection of kidney infarction, there is no consensus on the gold standard. Abdominal ultrasonography is widely used in both human and veterinary medicine due to its low cost, availability, and because it does not require anesthesia. Most studies in humans usually applied CECT as the modality of choice for the diagnosis of kidney infarction.[11,15,16,18,26,27] The CECT scan can reveal the kidney perfusion defect that presents as a wedge-shaped or segmental hypoattenuation area that is not perfused by contrast-enhanced blood and surrounding hyper-attenuation contrast enhancement at the cortex. Kidney infarction can be accompanied by a cortical rim sign that corresponds to the maintenance of the blood flow through capsular arteries.[11,12,15,28] In addition, the CT angiogram can assist in identifying the location of kidney arterial occlusion.[12,23] Furthermore, MPR of CT images is a useful function to reconstruct the transverse CT image to sagittal and dorsal image planes, enhancing the ability to detect the lesion.[29,30] Since the utility of each MPR image plane for the diagnosis of kidney infarction has never been reported, here, we show that the ability to detect and localize lesions of kidney infarction on the sagittal plane is superior to the localization, on the transverse and dorsal planes. As most of the kidney infarctions were found at the kidney pole, the sagittal plane is a useful MPR plane to differentiate kidney infarction from other lesions, especially kidney cyst.

The most common characteristic of kidney infarction of dogs in this study was a wedge-shaped or segmental hypoattenuating area with surrounding hyperechoic contrast enhancement in the cortex, which is in agreement with previous findings.[13,15] This appearance has been explained by the disease changes after blockage of the kidney artery.[15] At 1 hour after blockage of an arcuate or interlobar artery, a triangular hyperemic area presents, with its apex pointing toward the medulla, showing as a wedge-shaped hypoattenuating area on CECT. In the next 7 days, the kidney infarction shrinks because the fibrous tissue deposits and begins to contract. After 28 days, the cortex subsequently compresses below the surface, which is defined as a concavity of the kidney margin.[3,15,31] We found kidney infarction with concavity of the kidney margin in 6 dogs (6/26, 23.7%), indicating that these dogs have had experienced kidney infarction at least 1 month before the CT.

Our study has limitations. First, this is a cross-sectional retrospective study, and therefore, some dogs with kidney infarction that did not perform CECT were not included in this study and the lack of some clinical and laboratory data, especially the referred client animal for performing only CT. Dogs with abnormal laboratory data, such as increased BUN and creatinine concentration, were excluded from this study because of the high risk of anesthesia. Second, the phases of contrast-enhancement could not be controlled in this study, although all including CECT images could clearly to identify the lesions of kidney infarction. Third, the causes of kidney infarction were not determined in our study due to a lack of clinical data and laboratory findings. In addition, histopathologic examination of all kidneys was not performed. Finally, although neoplastic diseases were mostly found in dogs with kidney infarction in this study, it cannot be concluded whether neoplastic diseases relate to the presence of kidney infarction due to the small number of enrolled dogs.

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CONFLICT OF INTEREST DECLARATION

Authors declare no conflict of interest.

OFF-LABEL ANTIMICROBIAL DECLARATION

Authors declare no off-label use of antimicrobials.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Approved by the hospital institutional review board of the Small Animal Hospital, Faculty of Veterinary Science, Chulalongkorn University, approval number S226/2563.

HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not required for this study.

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SUPPORTING INFORMATION

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