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ULTRASONOGRAPHIC ABDOMINAL ANATOMY OF HEALTHY CAPTIVE CARACALS (*CARACAL CARACAL*)

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Abstract: Abdominal ultrasonography was performed in six adult captive caracals (*Caracal caracal*) to describe the normal abdominal ultrasonographic anatomy. Consistently, the splenic parenchyma was hyperechoic to the liver and kidneys. The relative echogenicity of the right kidney's cortex was inconsistent to the liver. The gall bladder was prominent in five animals and surrounded by a clearly visualized thin, smooth, regular echogenic wall. The wall thickness of the duodenum measured significantly greater compared with that of the jejunum and colon. The duodenum had a significantly thicker mucosal layer compared with that of the stomach. Such knowledge of the normal abdominal ultrasonographic anatomy of individual species is important for accurate diagnosis and interpretation of routine health examinations.
Key words: Abdomen, anatomy, caracal, *Caracal caracal*, ultrasonography.

INTRODUCTION

Abdominal ultrasonography is a noninvasive technique that can be used for diagnosis of abdominal disorders and pregnancy.[9] The normal ultrasonographic anatomy of abdominal viscera in domestic small animal species is well documented,[1,6,7,10,11,16] providing useful reference for diagnosis of diseases.

The caracal (*Caracal caracal*) is an exotic felid distributed throughout Africa with the exception of the Sahara and Namib deserts and the dense forests of equatorial West Africa and the Democratic Republic of Congo.[19] Because they are free-roaming wild animals in South Africa, they are commonly involved in road accidents and are sometimes presented to small animal or wildlife veterinarians with the resultant injuries. Captive caracals commonly present with similar infectious and noninfectious diseases as domestic cats, so ultrasound may be used for diagnostic purposes.

The role of zoo veterinarians has evolved from a reactive approach primarily dealing with injured or diseased animals, to a more proactive approach where emphasis is placed on preventive medicine. Therefore, regular health examinations, as in health examinations during quarantine or preimportation, annual assessments, or geriatric evaluations may include ultrasonography. The aim of this study was to describe the normal ultrasonographic anatomy of the abdominal viscera in captive caracals and to provide reference ranges for the species.

MATERIALS AND METHODS

Four male and two female healthy adult caracals from the Johannesburg (JHB) zoo, South Africa, were imaged in this study during their routine annual health examinations. This study was approved by the JHB zoo research committee. The age of the animals ranged from 19 to 72 mo (mean, 32.7 ± 22.5 mo). The minimum weight of the animals was 9.7 kg, and the maximum weight of the animals was 12.8 kg (mean, 10.6 ± 1.2 kg).

Animals were considered healthy based on history, physical and clinical examination, complete blood count, peripheral blood smear evaluation, fecal examination, and kidney and liver function tests. Five animals were fasted overnight, but water was given ad libitum until shortly before the examination. One caracal was not fasted, and its results were not included in the gall bladder and gastrointestinal part of this study.

Anesthesia was induced by medetomidine hydrochloride [Domitor, Pfizer Laboratories (Pty) Ltd., Sandton, Republic of South Africa; mean dosage, 0.06 ± 0.01 mg/kg; range, 0.05–0.06 mg/kg i.m.] and ketamine hydrochloride [Kyron Laboratories (Pty) Ltd, Benrose, Republic of South Africa, mean dosage of 5.71 ± 0.58 mg/

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kg; range 4.7–6.2 mg/kg i.m.]. Anesthesia was maintained by isoflurane [Isofor, Safe Line Pharmaceuticals (Pty) Ltd., Roodepoort, Republic of South Africa] in oxygen by endotracheal tube throughout the ultrasonographic examination.

Each caracal was positioned in dorsal recumbency; the ventral abdominal area was clipped of hair and ultrasound coupling gel (Ultrason, Barisan Chemicals, Sandton, Republic of South Africa) was applied. Abdominal ultrasonography was performed using a 7.5–12-MHz multifrequency linear array transducer (Mylab30, Esaote, Indianapolis, Indiana 46250, USA) operated at 7.5, 10, and 12 MHz. Ultrasonography was performed systematically starting with the spleen followed by the left kidney, urinary bladder, right kidney, liver, gastrointestinal tract, left adrenal gland, and right adrenal gland. Ultrasonographic examination was limited to 30 min as a result of the multi-project nature of the study.

Relative echogenicity of the spleen, renal cortex, and liver was recorded. Measurements were taken from sagittal images of all organs, except the stomach, descending colon, spleen, and width of the kidneys, all measured from transverse images. All measurements were performed by electronic calipers on frozen images. The splenic thickness was measured at the level of the splenic hilus. Kidney measurements were taken at the level of the renal sinus. Adrenal gland measurements included both the cortex and medulla. Wall thickness of the urinary bladder was measured at the midventral location. For the gall bladder, the wall thickness was measured on the sagittal images of the liver at the middle of the near wall.

Four anatomic regions of the gastrointestinal tract were evaluated: stomach, descending duodenum, jejunum, and descending colon. The stomach was evaluated at the greater curvature. Luminal patterns were categorized as mucous, fluid, gas or alimentary.[15,16] The mucous pattern is the appearance of the bowel segment in its collapsed state. It is characterized by a bright interface in the lumen without acoustic shadowing. The fluid pattern is characterized by anechoic to uniformly echogenic luminal contents. The gas pattern appears as an intraluminal, highly hyperechoic-reflective interface with acoustic shadowing. The alimentary pattern consists of food particles of variable size and shape in the lumen. It may or may not be associated with imaging artifacts.[15,16] The mural echogenicity of the different layers was described as hyperechoic, hypoechoic, or isoechoic relative to each other.[15] The mural thickness was measured from the inner hyperechoic luminal mucosal interface to the outer hyperechoic serosal surface.[15] Gastric mural measurements were made as described previously.[18]

Table 1. Ultrasonographic measurements of the spleen, kidneys, urinary bladder, gall bladder, and adrenal glands of healthy captive caracals ($n = 6$)

	Mean ± SD (mm)	Range (mm)
Spleen		
Thickness ($n = 6$)	11.1 ± 3.5	7.1–16.0
Width ($n = 4$)	40.5 ± 0.5	40.0–41.2
Left kidney		
Length ($n = 6$)	46.6 ± 4.2	42.2–53.8
Height ($n = 6$)	26.2 ± 4.3	19.9–33.1
Width ($n = 6$)	32.5 ± 2.7	29.2–36.0
Right kidney		
Length ($n = 6$)	47.5 ± 3.1	44.2–52.4
Height ($n = 6$)	28.0 ± 2.8	24.4–32.1
Width ($n = 6$)	31.9 ± 1.5	30.0–34.1
Urinary bladder		
Height ($n = 6$)	13.4 ± 2.6	11.1–17.1
Length ($n = 3$)	40.1 ± 8.8	34.4–50.2
Wall thickness ($n = 6$)	1.3 ± 0.4	0.9–2.0
Gall bladder		
Wall thickness ($n = 5$)	0.6 ± 0.1	0.4–0.8
Left adrenal		
Length ($n = 6$)	15.2 ± 1.9	12.4–16.6
Height ($n = 6$)	5.1 ± 0.8	3.6–6
Right adrenal		
Length ($n = 5$)	14.4 ± 1.1	13.4–16.2
Height ($n = 5$)	5.9 ± 1.0	4.9–7.4

Data were analyzed using StatView® statistical package (SAS Institute, Cary, North Carolina 27513, USA). The mean, range, and standard deviation were calculated for each variable. Paired *t*-tests were used to compare dimensions of the left versus right kidneys; mural thickness of various segments of the gastrointestinal tract; mucosal layer thickness of the stomach, duodenum, and jejunum; and the left versus right adrenal gland dimensions. Statistical significance was accepted at $P \leq 0.05$. Data are expressed as mean ± SD.

RESULTS

Detailed measurements for each organ or region were tabulated (Tables 1, 2) for ease of review.

Table 2. Ultrasonographic measurements of the gastrointestinal tract in healthy captive caracals ($n = 5$).

	Mean ± SD (mm)	Range (mm)
Stomach		
Width (n = 5)	35.1 ± 3.5	32.0–40.0
Height (n = 3)	17.8 ± 5.2	12.2–22.5
Mucosa thickness (n = 5)	1.1 ± 0.3	0.7–1.4
Wall thickness (n = 5)	2.3 ± 0.4	1.7–2.6
Duodenum		
Mucosa thickness (n = 5)	2.1 ± 0.3	1.8–2.5
Wall thickness (n = 5)	3.0 ± 0.5	2.4–3.5
Jejunum		
Mucosa thickness (n = 5)	1.6 ± 0.4	1.1–2.2
Wall thickness (n = 5)	2.5 ± 0.5	2.0–3.1
Colon		
Wall thickness (n = 5)	1.3 ± 0.3	0.9–1.6

Lymphatic system

The spleen was located in the left cranial abdominal quadrant cranial and ventral to the left kidney. It was triangular on transverse images, with fine homogenous echotextured parenchyma compared with that of the liver (Fig. 1). The splenic parenchyma was hyperechoic to the liver and kidneys and surrounded by a thin echogenic capsule (Fig. 1).

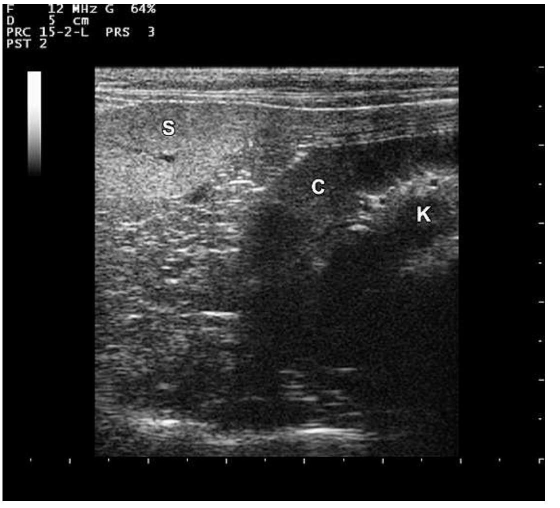

Figure 1. Transverse image of the spleen (S) and sagittal image of the left kidney (K) of a 72-mo-old healthy female captive caracal. The spleen is triangular shaped with fine homogenous echotextured parenchyma surrounded by a thin echogenic capsule. It is hyperechoic to the renal cortex (C).

Urinary system

The kidneys were mostly oval and rarely bean-shaped on sagittal images, whereas on transverse images they appeared oval. They were surrounded by a thin smooth regular echogenic capsule (Fig. 2). The right kidney was located in the right cranial abdominal quadrant caudal to the liver. In 50% of the animals, the right kidney was in close contact with the liver. The right kidney cortex was variably echogenic as hyperechoic (3/6), isoechoic (2/6), and hypoechoic (1/6) to the liver. Generally, good corticomedullary distinction was observed.

The urinary bladder was visualized in all animals and was located cranial to the pelvic canal within the abdomen. It was mainly oblong (5/6) and rarely ovoid (1/6), with anechoic content. The classical three-layered appearance of the urinary bladder wall of the distended urinary as described in domestic cats and dogs was visualized in all caracals (Fig. 3).

Digestive system

The gastrointestinal tract had a classical five-layered ultrasonographic appearance with a hyperechoic lumen–mucosal interface, anechoic mucosa, hyperechoic submucosa, anechoic muscularis and hyperechoic serosa.

The stomach was seen as either collapsed (3/5) or filled with gas (2/5). When the stomach was in a collapsed state, the gastric rugae were prominent as a series of linear hypoechoic structures separated by hyperechoic gas (Fig. 4).

The duodenum and jejunum had a mucous pattern (Fig. 5A). The wall thickness of the duodenum was significantly greater compared with that of the jejunum ($P = 0.01$) and colon ($P < 0.01$). The duodenum had a significantly thicker mucosa compared to the gastric ($P < 0.01$) mucosa. Furthermore, the duodenal mucosa was thicker than the jejunal mucosa although not to a degree that was statistically significant ($P > 0.05$).

In all caracals, the descending colon had a gas pattern (Fig. 5B). The colonic wall was significantly thinner compared with the wall thickness of the stomach ($P = 0.02$), duodenum ($P < 0.01$), and jejunum ($P < 0.01$).

Liver and adrenal gland

The greater proportion of the liver was located in the right cranial abdominal quadrant. The liver parenchyma had a coarser echotexture as compared to the splenic parenchyma. The walls of the portal veins were hyperechoic to the surrounding liver parenchyma, whereas those of the hepatic

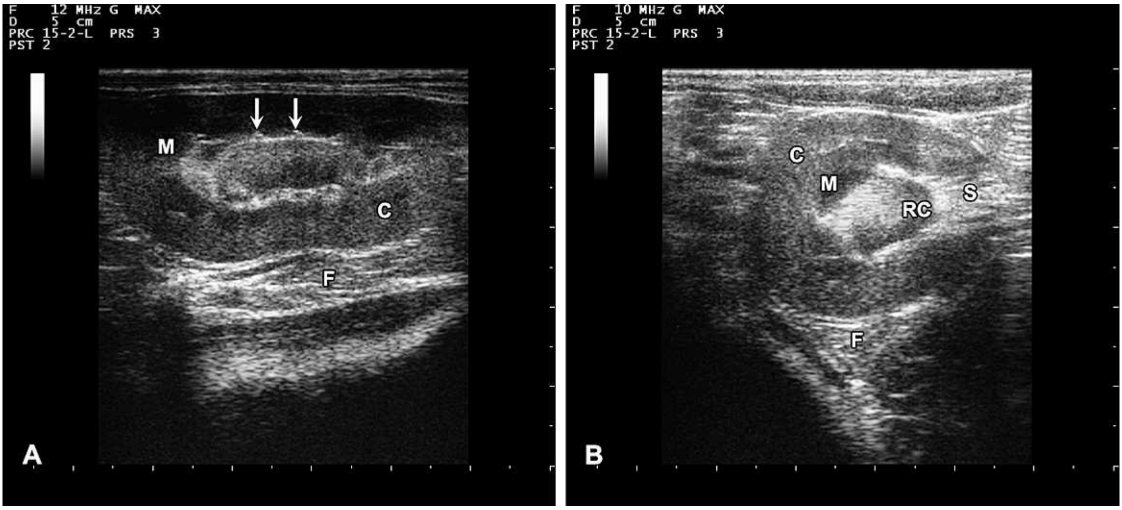

Figure 2. Ultrasonograms of the left (**A**) and right (**B**) normal kidneys of a 19-mo-old healthy male captive caracal that are bean-shaped (A) and ovoid (B) in sagittal and transverse planes, respectively. The kidneys (RC, renal crest; S, renal sinus) are surrounded by a thin and smooth echogenic capsule with hypoechoic medulla (M) in relation to renal cortices (C). The presence of interlobar vessels (arrows) and echogenic retroperitoneal fat (F) dorsal to kidneys is indicated.

veins were isoechoic to the surrounding liver parenchyma. In all five animals that had been fasted, the gall bladder was prominent with anechoic content surrounded by a clearly visualized thin smooth regular echogenic wall (Fig. 6).

Adrenal glands were hypoechoic to surrounding hyperechoic fat. The left adrenal gland was mostly peanut-shaped (5/6) and rarely comma-shaped (1/6). It was located medial to the cranial pole of the left kidney and ventral to the aorta (Fig. 7). A focal hyperechoic area was seen in the cranial pole of one left adrenal gland with an attempt to shadow distally (Fig. 8B). Corticomedullary distinction was observed in 4/6 left (Fig. 7) and 5/5 right (Fig. 8A) adrenal glands with the adrenal medulla being hyperechoic to the adrenal cortex. The right adrenal gland was ovoid (3/5) or ovoid with an enlarged cranial pole (2/5); it was located medial to the cranial pole of the right kidney. A focal hyperechoic area was seen in the cranial pole of one right adrenal gland (Fig. 8A), similar to the left adrenal described above. No significant difference was observed ($P > 0.05$) between the left and right adrenal glands length and thickness.

DISCUSSION

Caracals, like other wild felids, are difficult to handle for routine health examinations without the use of chemical immobilization, which necessitated the use of general anesthesia in this study. The majority of abdominal visceral organs of clinical importance in caracals were visualized clearly.

The echogenicity of the spleen, mostly hyperechoic in relation to the liver and renal cortices, was observed in this study and also has been observed in cheetahs (*Acinonyx jubatus*)[4] and domestic cats and dogs.[12] The triangular-shaped spleen surrounded by a thin smooth echogenic capsule that was observed in caracals is similar to the sonographic appearance of the spleen in domestic cats and dogs.[12] The mean splenic thickness of 11.1 mm observed in this study was lower than the reported thickness in cheetahs (18.9 mm).[4] The difference in splenic thickness in these two species is attributed to the difference in body size.

The presence and absence of contact between the right kidney and the right lobe of the liver that was observed in caracals also has been observed in cheetahs[4] and was attributed to the longer attachment of the kidneys similar to domestic cats.[8] The hyperechoic renal cortices compared with the medulla and good corticomedullary distinction are similar to the sonographic appearance of the kidneys in domestic cats and dogs.[10] The higher echogenicity of the right kidney's cortex compared with that of the right liver lobe parenchyma, observed in 3/6 caracals, is most likely due to accumulation of fat vacuoles in the cortical tubular epithelium as described in normal

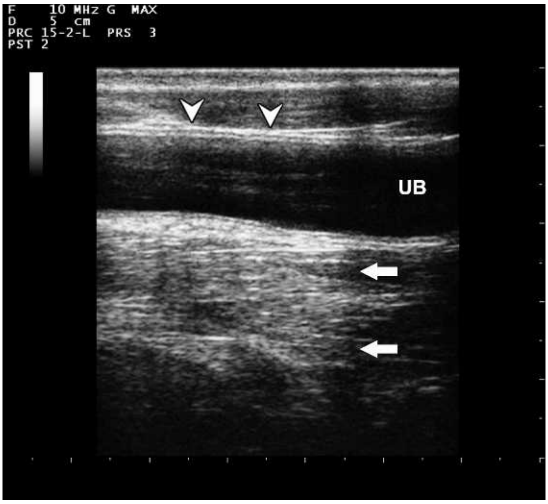

Figure 3. Ultrasonogram of the urinary bladder of a 19-month-old healthy male captive caracal in a sagittal plane. The urinary bladder (UB) is seen as an oblong structure with anechoic content. Distal acoustic enhancement (white arrows) is seen dorsal to the urinary bladder. The urinary bladder wall (white arrow heads) is seen as two thin hyperechoic lines separated in the middle by a thin hypoechoic line.

domestic cats with increased renal cortical echogenicity, although this observation was not proven histologically in this study.[21]

The overall mean length, height, and width of all kidneys observed in this study (47.1, 27.1, and 32.2 mm, respectively) were higher than the reported mean values in domestic cats (44.3, 24.4, and 31.7 mm, respectively)[20] but lower than the reported values in cheetahs (63.9, 38.1, and 42.1 mm, respectively).[4] Variation in size of the kidneys in these species is most likely due to the difference in their body weights. Kidney dimensions have been reported to vary with the weight of the animal in domestic dogs.[1] In a wide variety of domestic dog breeds, kidney dimensions have been shown to increase with the weight of the animal.[1] The ultrasonographic appearance of the caracal's urinary bladder is similar to that of domestic cats and dogs.[10] The mean wall thickness of the urinary bladder observed in this study (1.3 mm) was within the reported range in domestic cats (1.3–1.7 mm)[5] but was lower than the reported range in domestic dogs (1.4–2.3 mm).[6] However, urinary bladder wall thickness depends greatly on the degree of urinary bladder distension.[6]

The coarser echotexture of the liver compared with the spleen also has been reported in domestic cats and dogs.[13] In all five caracals, the wall of the gall bladder was clearly visualized, contrary to domestic cats and dogs in which it is poorly seen or not identified.[3,13] The mean gall bladder wall thickness in caracals (0.6 mm) measured within the reported range in domestic cats (0.4–0.9 mm)[7] but lower than the reported mean in cheetahs (1.1 mm).[4]

Caracals had five characteristic ultrasonographic layers of the gastrointestinal tract similar to

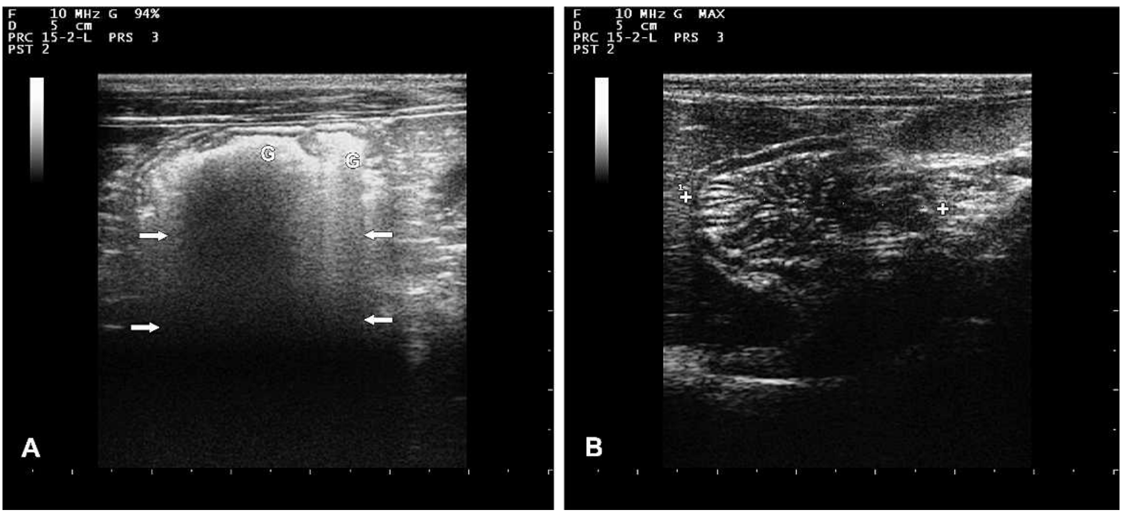

Figure 4. Transverse ultrasonograms of the stomach of a 19- (**A**) and 48 (**B**)-mo-old healthy males' captive caracals. (**A**) Stomach is filled with gas (G) causing "dirty" distal acoustic shadowing (white arrows) that prevents visualization of deeper tissues, although the classical five-layered appearance of the gastric wall is observed ventrally. (**B**) Stomach is in a collapsed state. Rugae radiate toward the center of the stomach.

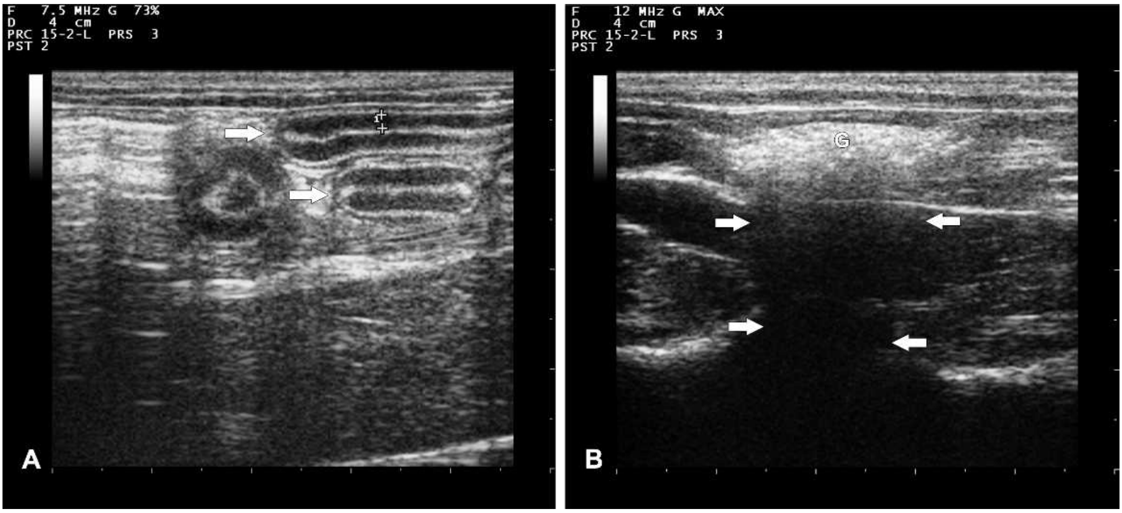

Figure 5. (**A**) Sagittal images of the normal jejunal segments of a 19-mo-old healthy male captive caracal. Note the luminal mucous pattern and the five-layered appearance of the jejunal wall (white arrows). The mucosal layer is outlined by the callipers. (**B**) Transverse image of the normal descending colon of a 19-mo-old healthy male captive caracal. Note "dirty" acoustic shadowing (white arrows) distal to the descending colon due to luminal gas (G) and the thinner colonic wall compared with that of jejunal segments.

those of domestic cats[11] and dogs.[17] The gas and mucous patterns observed in this study also have been seen in fasted domestic carnivores.[15] The mean thickness of the stomach wall in caracals (2.3 mm) is higher than the reported mean thickness of the stomach wall in domestic cats (2 mm)[11] but lower than the reported ranges in domestic dogs (3–5 mm).[15] The mean wall thickness of the duodenum and jejunum obtained in this study (3.0 and 2.5 mm, respectively) was

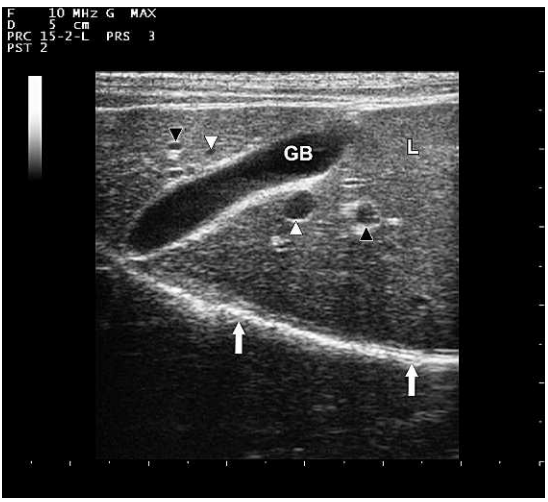

Figure 6. Sagittal ultrasonogram of the normal liver of a 19-mo-old healthy male captive caracal. The liver (L) has coarse echotexture with portal veins (black arrowheads) and hepatic veins (white arrowheads) indicated. The diaphragm–lung interface (white arrows) is seen as a curvilinear echogenic line cranial and dorsal to the liver. The gall bladder (GB) is seen as an oblong structure with anechoic content surrounded by a smooth echogenic wall.

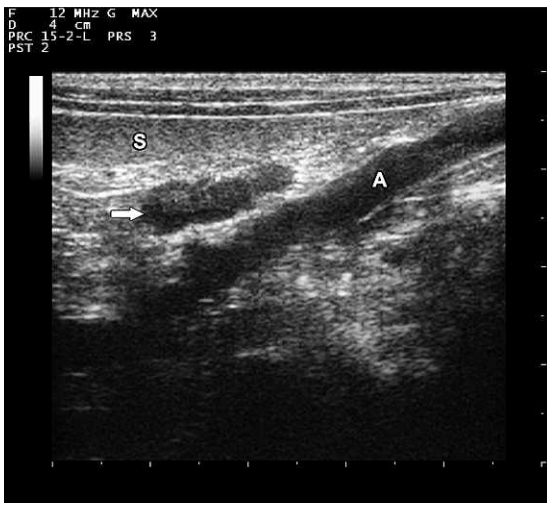

Figure 7. Sagittal ultrasonogram of a normal left adrenal gland of a 19-mo-old healthy male captive caracal. The left adrenal gland is seen as a peanut-shaped hypoechoic structure (white arrow) compared with surrounding mesenteric fat. The spleen (S) is seen ventral to the adrenal gland, and the abdominal aorta (A) is located dorsal to the gland.

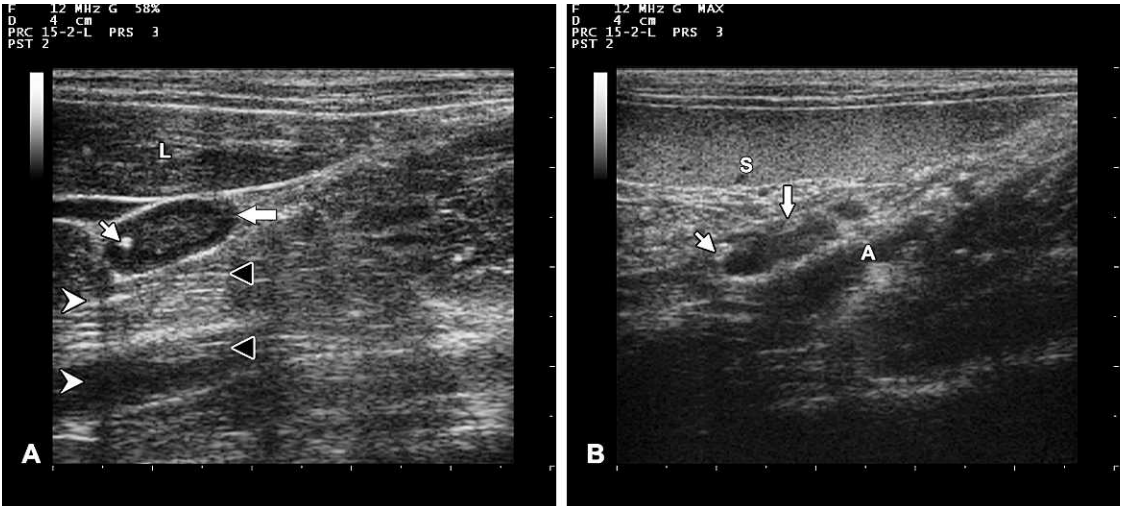

Figure 8. Sagittal ultrasonograms of right (**A**) and left (**B**) adrenal glands of healthy 19-mo-old female and male captive caracals, respectively (large white arrows). The focal hyperechoic area seen on the cranial pole of each gland (small white arrow) with an "attempt to shadow" distally is believed to be a result of early mineralization and an incidental finding. (**A**) The right adrenal gland is seen as an oval, hypoechoic structure compared with surrounding mesenteric fat. Edge shadowing (white arrowheads) and distal acoustic enhancement (black arrowheads) are seen distal to the gland. A distinct corticomedullary distinction is observed in which the adrenal medulla is hyperechoic compared to the adrenal cortex and an echogenic capsule surrounding the gland. Adjacent structures are liver (L), spleen (S), and aorta (A).

within the reported averages in domestic dogs (2.3–3 mm)[17] but higher than the reported means in sedated domestic cats (2.7 and 2.1 mm, respectively).[11] The mean colonic wall thickness of caracals (1.3 mm) is lower than the reported mean in domestic cats (1.7 mm)[11] and reported averages in domestic dogs (2–3 mm).[17] The presence of a significantly greater duodenal wall thickness in caracals compared with the jejunum also has been observed in domestic cats[11] and puppies[18] and is due to the thicker mucosal layer of the duodenum.

Variation in shape of the adrenal glands is also seen in domestic cats and dogs.[2,14] In this study, a focal hyperechoic area with an "attempt to shadow" distally that was seen in the cranial pole of the adrenal glands in two healthy caracals (male and female) aged 19 mo is believed to be a result of early mineralization and an incidental finding. Clean acoustic shadowing is usually seen distal to mineralization. The absence of a classical clean distal acoustic shadow in this study was most likely due to mineralization in its early stage. Conditions such as fibrosis, early nodular hyperplasia, infarcts, and hemorrhage can produce similar ultrasound findings; however, they are less likely because the subjects were healthy and the location of the focal hyperechoic area was consistent to the cranial pole of the adrenal glands. In domestic cats, focal mineralization of the adrenal glands is an incidental finding that has been documented in older domestic cats as an aging phenomenon.[3] To the best of our knowledge, the age of onset of mineralization of the adrenal glands in domestic cats has not been reported. The occurrence of mineralization of adrenal glands in young caracals warrants further research on the mechanism involved. The overall mean length and thickness of the adrenal glands obtained in this study (14.8 and 5.5 mm, respectively) are higher than the reported means in domestic cats (10.7 and 4.3 mm, respectively).[2]

Variations exist in the normal abdominal ultrasonographic appearance of different animal species. Knowledge of the normal abdominal ultrasonographic anatomy of individual species is important for accurate diagnosis and interpretation of routine health examinations.

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