Received: 19 August 2022 | Accepted: 20 August 2022

DOI: 10.1111/ahe.12858

ORIGINAL ARTICLE

Anatomia Histologia Embryologia WILEY

Anatomical variations of the canine adrenal vessels

Nami Watanabe[1,2] | Shin Ono[1,2]

[1]Skyvets, Inagi-city, Japan

[2]Japan Small Animal Medical Center, Saitama, Japan

Correspondence
Nami Watanabe, Skyvets, 2958-4, Yanokuchi, Inagi-city, Tokyo, Japan.
Email: nami-watanabe@sky-vets.com

Abstract

The canine adrenal glands receive blood from the celiac artery, cranial mesenteric artery, caudal phrenic artery, cranial abdominal artery, phrenicoabdominal trunk, abdominal aorta, renal artery and lumbar artery. These are classified into three types: cranial, middle and caudal adrenal branches. It is also known that the adrenal vein flows into the phrenicoabdominal vein. However, individual differences in the branching pattern of adrenal vessels have not been systematically analysed. We evaluated adrenal vessels in dogs that underwent contrast-enhanced abdominal computed tomography (CT). There were 255 arteries travelling to the adrenal glands in 47 cases, with 1–6 arteries travelling per adrenal gland. The arteries included 67 caudal phrenic arteries, 62 aortic arteries, 60 cranial abdominal arteries, 39 renal arteries, 12 phrenicoabdominal trunks, 8 cranial mesenteric arteries, 6 celiac arteries and 1 lumbar artery. Most of the branches were from the aorta and caudal phrenic artery on the left side, and the cranial abdominal and caudal phrenic artery on the right side. A total of 110 adrenal veins were identified. Inflow into the phrenicoabdominal vein and into the right and left renal veins was observed, and we identified no inflow into other veins. This study demonstrated two points: laterality and individual differences in adrenal blood vessels. When evaluating adrenal blood vessels with abdominal contrast-enhanced CT, it is recommended to take images under general anaesthesia with breath-holding and observe them using multiplanar reconstruction.

KEYWORDS
adrenal vessels, anatomical variations, CT, dog

1 | INTRODUCTION

The blood supply of the adrenal glands comprises numerous branches from three types of arteries in humans: the superior adrenal artery, the middle superior adrenal artery and the inferior superior adrenal artery. A review on variations of these three types of adrenal arteries in humans has been published (Priya et al., 2022). In dogs, the adrenal glands are variously but always generously vascularized by small branches from the aorta, as well as the caudal phrenic, cranial abdominal, phrenicoabdominal, cranial mesenteric, celiac, renal and lumbar arteries (Hullinger, 2013; Singh, 2018). Usually, the cranial adrenal branches arise from the caudal phrenic arteries, cranial abdominal arteries and phrenicoabdominal arteries; the middle adrenal branches arise from the abdominal aorta; and the caudal adrenal branches arise from the lumbar and renal arteries (Hullinger, 2013).

The common trunk, formerly known as the phrenicoabdominal vein, receives the caudal phrenic vein and cranial abdominal vein. This phrenicoabdominal trunk is located on the lateral surface of the caudal vena cava, approximately 1 cm cranial to the renal vein ipsilaterally, and passes ventral to the adrenal gland (Bezuidenhout, 2013b). The adrenal veins drain into the trunk on both sides, but some left adrenal veins also drain into the left renal vein (Hullinger, 2013).

The widespread use of multidetector computed tomography (MDCT) in small animal medicine has made it possible to evaluate the abdominal cavity of dogs in detail. Recently, adrenalectomies have frequently been performed surgically, thus requiring detailed information on the adrenal vasculature. In our institution, preoperative computed tomography (CT) scans for adrenal tumour removal are used to confirm intravascular invasion of the tumour and the adrenal gland supply. From our experience, preoperative contrast-enhanced CT scans performed in dogs with adrenal tumours often show left–right and individual differences in the arterial vascular pattern.

However, no information is available regarding whether there are left-right or individual differences in the adrenal vessels. It is also unknown whether adrenal arteries other than the phrenicoabdominal trunk, abdominal aorta, renal artery, caudal phrenic artery, cranial abdominal artery, cranial mesenteric artery, celiac artery or lumbar artery vessels have been reported. Furthermore, it is unknown whether adrenal veins other than those flowing into the phrenicoabdominal vein and the left renal vein exist. The conditions and methods of CT scanning for delineating the adrenal vessels are also unknown.

This study aimed to visualize the adrenal arteries and veins of dogs using CT images and investigate the anatomical information of the vasculature required for adrenal resection in dogs without adrenal tumours.

We hypothesized that lateral and individual differences exist in the blood vessels running through the adrenal glands in dogs without adrenal tumours.

2 | MATERIALS AND METHODS

The subjects were dogs that visited the Japan Small Animal Medical Center and underwent abdominal contrast CT during the 2 months from February to March 2019. CT imaging was performed using an 80-row multi-slice CT scanner (Aquilion PRIME). All dog owners were informed and agreed to the consent form. This study was approved by the Clinic's Institutional Review Board. The target dog was anaesthetised using a general anaesthetic agent, and abdominal contrast-enhanced CT was performed while breathing was held during the scan. Anaesthetics administered included atropine 10 μg/kg iv, midazolam 0.2 mg/kg iv and propofol 10 mg/kg iv, maintained with isoflurane. A nonionic contrast agent, iopamidol injection 300 (750 mgI/kg; 2.5 ml/kg) or 370 (750 mgI/kg; 2.02 ml/kg), was used for contrast examination, and three-phase or four-phase imaging was performed using the bolus tracking method. In the bolus tracking method, we set the region of interest distal to the thoracic aorta as triggered by 150 HU. In three-phase imaging, the delay time was 10 s for the arterial phase, 50 s after the start of injection for the portal vein phase and 120 s after injection for the equilibrium phase. In the four-phase imaging, the delay time was 10 s for the early arterial phase and 3 s after the early arterial phase imaging for the late arterial phase. The images were taken at 120 kV, 350 mAs, slice thickness of 0.5 mm and a scan speed of 0.5. Horos and DICOM Viewer were used to evaluate the images, and the arteries and veins of the adrenal glands were evaluated using multi-planar reconstruction (MPR) images. Based on the anatomical position of the human adrenal artery, the adrenal arteries

TABLE 1 Number of adrenal arteries based on the three types: Cranial, middle, caudal adrenal branches

	Total	Right	Left
Cranial adrenal branches	153	84	69
Middle adrenal branches	62	6	56
Caudal adrenal branches	40	17	23
Total	255	107	148

Note: The cranial adrenal branches were from celiac, cranial mesenteric, caudal phrenic, phrenicoabdominal and cranial abdominal arteries. The middle adrenal branches were from abdominal aortae. The caudal adrenal branches were from renal and lumbar arteries. The adrenal arteries were mainly from cranial abdominal branches from both left and right sides.

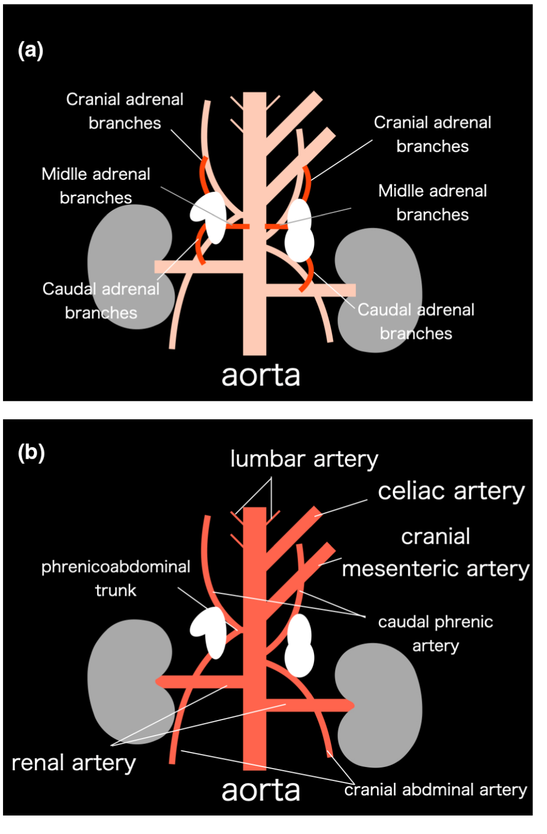

FIGURE 1 Schematic representation of the adrenal arterial supply in ventral view. (a) Normal pattern of adrenal arteries based on three types: cranial, middle and caudal adrenal branches. (b) Schematic representation of the artery system around the adrenal glands

were classified into three types: cranial, middle and caudal adrenal branches. Since the celiac artery and cranial mesenteric artery are not included in the three types, we classified them as cranial adrenal branches because they are located on the cranial side of the adrenal gland. The cranial adrenal branches included the celiac artery, cranial mesenteric artery, caudal phrenic artery, phrenicoabdominal artery and cranial abdominal artery. The aorta was classified as the middle adrenal branch. The renal artery and lumbar artery were included in the caudal adrenal branches.

3 | RESULTS

Fifty-five dogs that underwent abdominal contrast CT during the target period were included in the study. Of the 55 cases, 3 with confirmed adrenal tumours were excluded. In addition, we excluded five cases in which we could not prove the presence of bilateral adrenal arteries and veins. These five cases included ascites retention in one case, gastric distension treatment in two cases and small dogs weighing 2 kg in the remaining two cases. We included cases in which the shape of the adrenal gland was maintained (four cases, five adrenal glands), although there were adrenal nodules. We evaluated the adrenal arteries in 47 cases and 92 adrenal glands. Moreover, we could determine the adrenal veins in 47 cases and 93 adrenal glands. However, it was impossible to evaluate one side of the adrenal gland vessels in two small dogs weighing 2–3 kg. The dog breeds were mixed (n = 9), toy poodles (n = 7), Chihuahua, Welsh Corgi, Pomeranian, French bulldog (n = 4), Miniature Dachshund, Shiba (n = 3), Golden Retriever (n = 2), Shih Tzu, Spitz, Chinese Crested Dog, Kai, Cairn Terrier, Papillon and Scotchteria (n = 1). The median age was 11 ± 3.8 years (range, 0 years [9 months] to 15 years). The median body weight was 7.4 ± 6.3 kg.

A total of 255 adrenal arteries were identified in the 47 dogs. We classified the three types of branches; 153 cranial adrenal branches, 62 middle adrenal branches and caudal adrenal branches (Table 1) (Figure 1). The branches of the adrenal artery were derived from the following arteries: 67 caudal phrenic arteries, 62 aortae, 60 cranial abdominal arteries, 39 renal arteries, 12 phrenicoabdominal trunks, 8 cranial mesenteric arteries, 6 celiac arteries and 1 lumbar artery (Table 2) (Figures 2–4). We identified no adrenal arterial vessels branching from other arteries. Both the left and right sides had the highest blood supply from the cranial adrenal branches. The adrenal glands were not necessarily supplied by the arteries of the three branches. Among the cranial abdominal branches, both the left and right sides were predominantly supplied from the caudal phrenic artery and the cranial abdominal artery, while the supply from the other vessels was variable. The left adrenal gland has many branches arising from the aorta, and the right adrenal gland has many branches arising from the cranial abdominal artery. The phrenicoabdominal trunk, one of the sources of adrenal arteries, was found in only 61 of the 92 adrenal glands in 47 dogs. In the rest of the cases, the caudal phrenic arteries

TABLE 2 Breakdown of vascular supply sources and the percentages of each branch

	Total	Right	Left
Cranial adrenal branches n = 153			
Celiac artery	6	0	6
	3.9%	0.0%	8.7%
Cranial mesenteric artery	8	1	7
	5.2%	1.2%	10.1%
Caudal phrenic artery	67	36	31
	43.8%	42.9%	44.9%
Phrenicoabdominal artery	12	3	9
	7.8%	3.6%	13.0%
Cranial abdominal artery	60	44	16
	39.2%	52.4%	23.2%
Middle adrenal branches n = 62			
Aorta	62	6	56
	100.0%	100.0%	100.0%
Caudal adrenal branches n = 40			
Renal artery	39	16	23
	97.5%	94.1%	100.0%
Lumbar artery	1	1	0
	2.5%	5.9%	0.0%

Note: Caudal phrenic artery, aorta, cranial abdominal artery and renal artery were frequently observed. In particular, lateral differences were found in the adrenal artery from the aorta and cranial abdominal artery. Percentages indicate the proportion of each vessel in each of the cranial, middle and caudal adrenal branches.

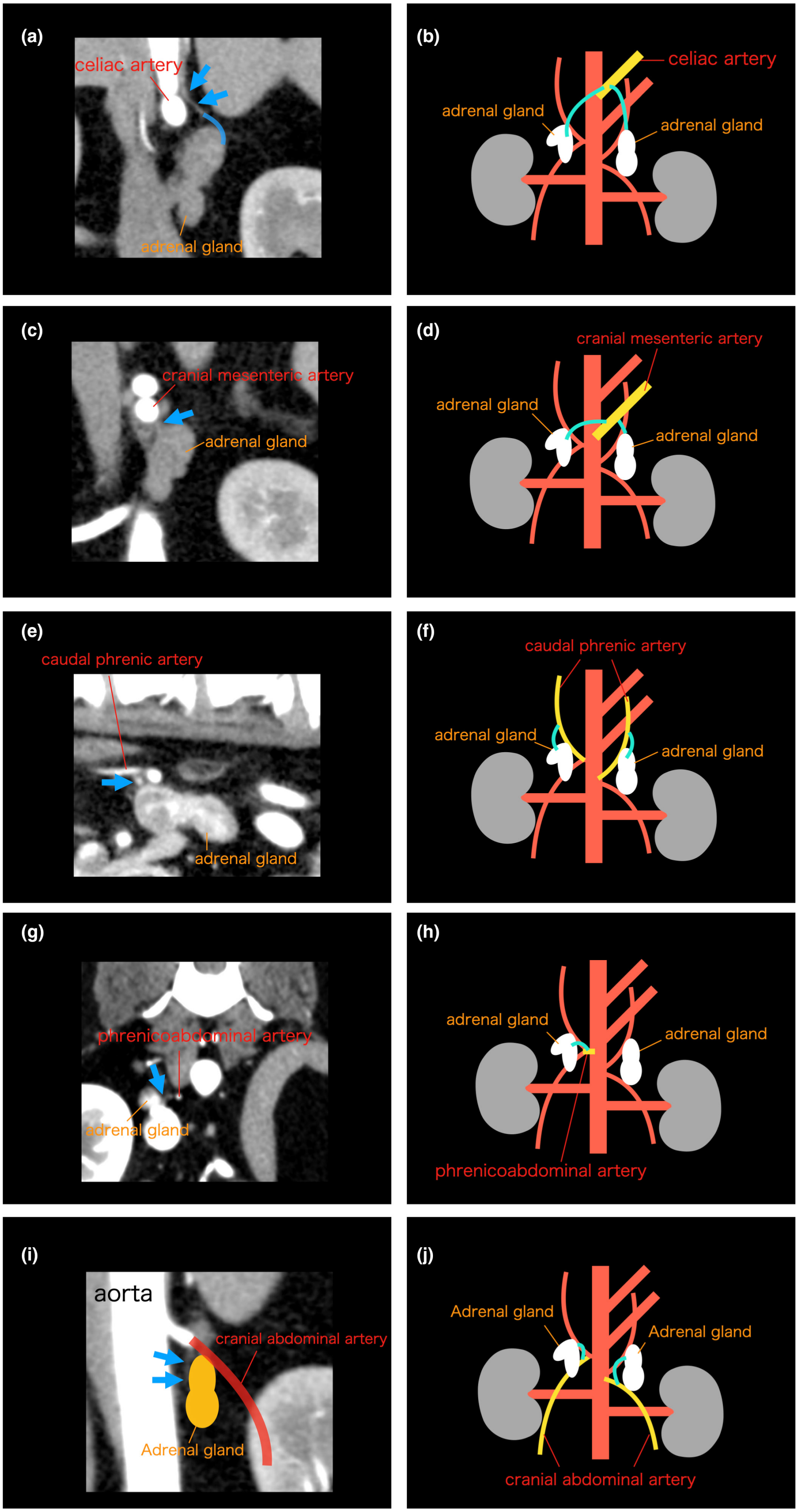
(a)
celiac artery
adrenal gland
(b)
celiac artery
adrenal gland
adrenal gland
(c)
cranial mesenteric artery
adrenal gland
(d)
cranial mesenteric artery
adrenal gland
adrenal gland
(e)
caudal phrenic artery
adrenal gland
(f)
caudal phrenic artery
adrenal gland
adrenal gland
(g)
phrenicoabdominal artery
adrenal gland
(h)
adrenal gland
adrenal gland
phrenicoabdominal artery
(i)
aorta
cranial abdominal artery
Adrenal gland
(j)
Adrenal gland
Adrenal gland
cranial abdominal artery

FIGURE 2 The cranial adrenal branches. In this study, the adrenal arteries from the celiac artery, the cranial mesenteric artery, the caudal phrenic artery, the phrenicoabdominal artery and the cranial abdominal artery were classified as the cranial adrenal branches. (a) A contrast computed tomography image of the cranial adrenal branches from the celiac artery. Arrow: the adrenal artery. (b) Schematic representation of the artery from the celiac artery in the ventral view. Yellow line: celiac artery. (c) A contrast computed tomography image of the cranial adrenal branches from the cranial mesenteric artery. Arrow: the adrenal artery. (d) Schematic representation of the artery from the cranial mesenteric artery in the ventral view. Yellow line: cranial mesenteric artery. (e) A contrast computed tomography image of the cranial adrenal branches from the caudal phrenic artery. Arrow: the adrenal artery. (f) Schematic representation of the artery from the caudal phrenic artery in the ventral view. Yellow line: caudal phrenic artery. (g) A contrast computed tomography image of the cranial adrenal branches from the phrenicoabdominal artery. Arrow: the adrenal artery. (h) Schematic representation of the artery from the phrenicoabdominal artery in the ventral view. Yellow line: phrenicoabdominal artery. (i) A contrast computed tomography image of the cranial adrenal branches from the cranial abdominal artery. Arrow: the adrenal artery. (j) Schematic representation of the artery from the cranial abdominal artery in the ventral view. Yellow line: cranial abdominal artery; light blue line: the adrenal artery

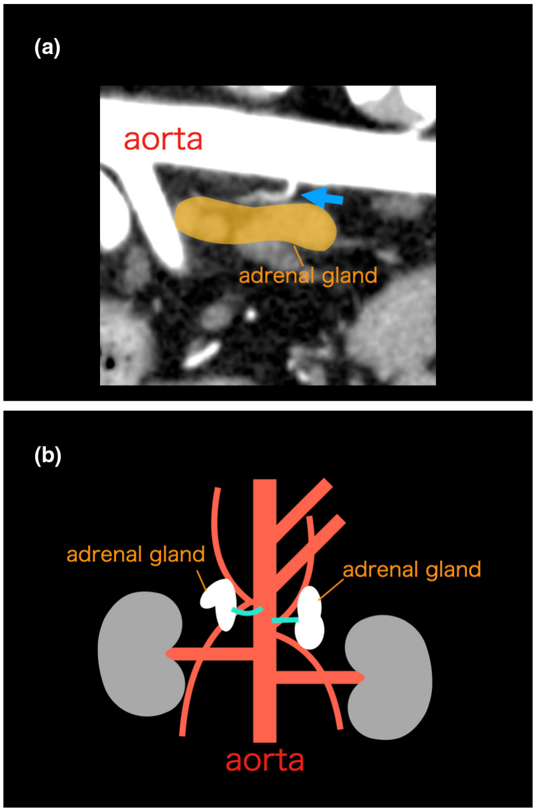

FIGURE 3 The middle adrenal branches from the aorta. (a) A contrast computed tomography image. Arrow: the adrenal artery. (b) Schematic representation of the artery from the aorta in the ventral view. Light blue line: the adrenal artery; yellow line: aorta

and cranial abdominal arteries were raised from the aorta directly or renal arteries without the trunk. The celiac, cranial mesenteric, caudal phrenic, cranial abdominal, renal and lumbar arteries were present in all cases.

In total, 110 adrenal veins were identified. The adrenal veins joined 93 phrenicoabdominal veins and 17 renal veins (Table 3). In all cases, the phrenicoabdominal vein ran through the central part of the adrenal gland. A small number of blood vessels flowing into the renal vein on each side was confirmed (Figures 5 and 6). We confirmed that no adrenal veins flowed into other veins.

The number of arteries and veins found in each adrenal gland was 1–6 and 1–3, respectively (Table 4).

4 | DISCUSSION

In this study, we observed variations in the adrenal arteries and veins of dogs, as well as their laterality and individual differences. No variations in adrenal blood vessels have been systematically studied in dogs previously. This study is the first to demonstrate the presence and frequency of these variations. It diverged in various combinations from the aorta, caudal phrenic artery, cranial mesenteric artery, celiac artery, cranial abdominal artery, phrenicoabdominal trunk, renal artery and lumbar artery. By contrast, the phrenicoabdominal vein ran into the centre of the adrenal glands in all cases, but the left and right adrenal veins flowed into the ipsilateral renal vein in a few dogs. The left adrenal vein may flow into the left renal vein, while the right adrenal vein directly flows into the phrenicoabdominal vein (Hullinger, 2013). However, to the best of our knowledge, there have been no reports of the right adrenal vein flowing into the right renal vein. This study is the first to showcase which right adrenal vein flows into the right renal vein. Malignant adrenal tumours invade the phrenicoabdominal vein, caudal vena cava and renal vein (Barrera et al., 2013.; Chiti et al., 2021.; Pey et al., 2022.; Zini et al., 2019). This study suggests that malignant adrenal tumours invade the renal vein directly via the right renal vein in individuals in whom the right adrenal vein flows directly into the right renal vein.

To date, there have been no reports of the use of CT for adrenal blood vessels in dogs for systematic evaluation of adrenal vasculature. Although the adrenal blood vessels are very thin, we could visualize the adrenal blood vessels by taking a breath-holding image under general anaesthesia with MDCT and using MPR images. When CT is performed without holding the breath, we cannot observe the details of the adrenal blood vessels because of breathing movements. In this study, small blood vessels were recognized by performing general anaesthesia, stopping breathing and performing a scan without motion artefacts. Since the adrenal blood vessels, phrenicoabdominal trunk, cranial abdominal artery and caudal phrenic artery are very finely curved; it was difficult to confirm all adrenal blood vessels by observing only the cross-sectional view. Therefore, MPR images are indispensable for visualizing the adrenal blood vessels. Good-quality CT images are needed to depict small blood vessels with an MPR. Obtaining images with thin slices is vital. The CT imaging method we used this time was able to visualize the major blood vessels of the adrenal gland.

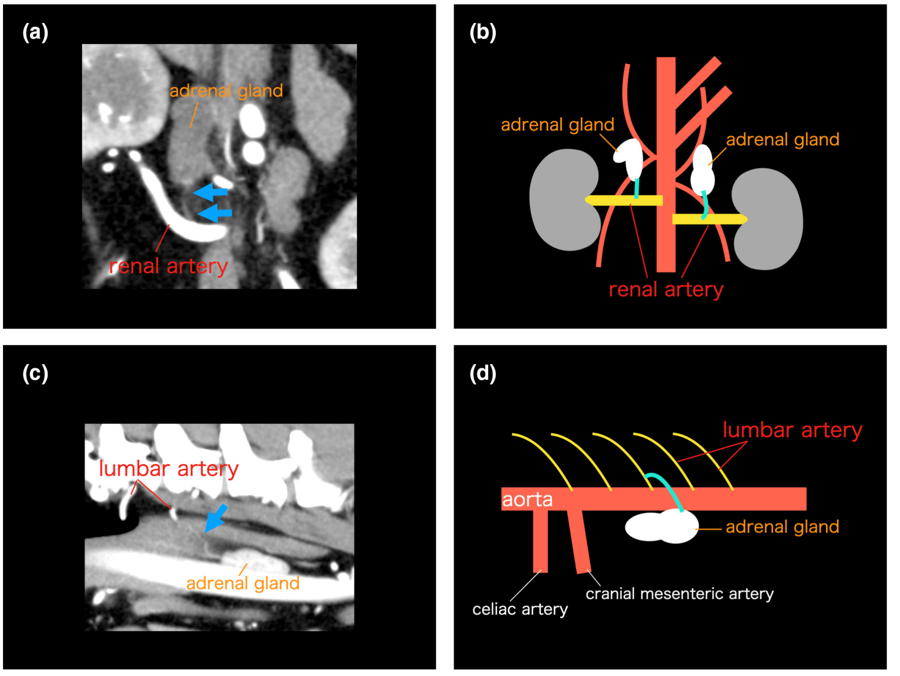

FIGURE 4 The caudal adrenal branches. In this study, we classified the adrenal arteries from the renal and lumbar arteries as the caudal adrenal branches. (a) A contrast computed tomography image of the caudal adrenal branches from the renal artery. Arrow: the adrenal artery. (b) Schematic representation of the artery from the renal artery in the ventral view. Light blue line: the adrenal artery; yellow line: cranial abdominal artery. (c) A contrast computed tomography image of the caudal adrenal branches from the lumbar artery. Arrow: the adrenal artery. (d) Schematic representation of the artery from the lumbar artery in the lateral view. Light blue line: the adrenal artery; yellow line: lumbar artery

TABLE 3 Number of adrenal veins

	Total	Right	Left
Cranial abdominal vein	93	46	47
Renal vein	17	4	13
Total	110	50	60

Note: In all adrenal veins, the phrenicoabdominal vein runs through the centre of the adrenal gland. We confirmed that the adrenal vein ran to the left and right renal veins. Fewer veins poured into the renal veins of the right adrenal gland than those in the left adrenal gland.

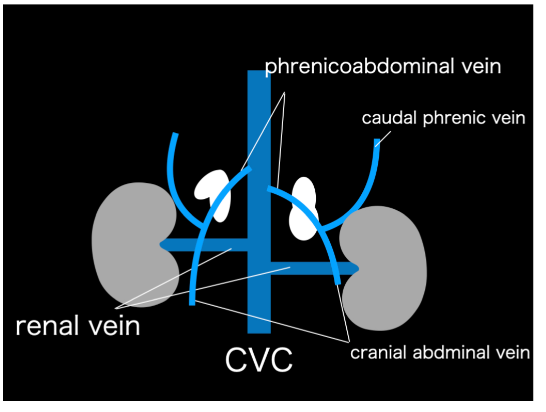

FIGURE 5 Schematic representation of the venous system around the adrenal glands in ventral view

Among the cases in which abdominal contrast CTs were performed, we excluded five dogs whose adrenal blood vessels could not be confirmed. One of the five patients had ascites retention, and two underwent abdominal CT contrast examination after gastric distension. Adrenal arteries and veins may be difficult to observe whether ascites retention or gastric distension is present. Therefore, it is necessary to remove ascites before contrast-enhanced CT examination, and if gastric gas retention is severe, it is necessary to remove gastric gas before performing a CT scan.

There are 20–30 or more small arteries per adrenal gland (Bezuidenhout, 2013a). The number of adrenal blood vessels confirmed in this study was between 1–6, and it was difficult to confirm all arteries, including small blood vessels, by contrast-enhanced CT. However, we believe that significant adrenal arteries essential for adrenalectomy have been visualized. In addition, since we examined normal adrenal blood vessels, there may be a difference in the vascular passage in dogs with adrenal tumours who underwent adrenalectomy. It is necessary to investigate whether there are variations in the adrenal arteries and veins in adrenal tumour cases. Further, we could not evaluate the adrenal blood vessels in small dogs weighing 2–3 kg. Although it may be challenging to depict the adrenal blood vessels in ultrasmall dogs (less than 3 kg), further studies are needed because the number of cases of ultrasmall dogs is small in this study. In humans, adrenal arteries have also been reported to branch from gonadal, splenic and intercostal arteries (Priya et al., 2022.). However, no branching from these arteries was reported in dogs before. It is possible that the sample size of 47 cases in our study was insufficient to detect rare vessels. Adrenal cortexes originate from mesenchymal cells of the celomic mesoderm, and the initial mass of these cells proliferates near the genital ridge (Hullinger, 2013). Therefore, we speculate that arterial branches from the gonadal artery, in humans, may also be present in dogs.

In conclusion, because there are previously unknown lateral and individual differences in the adrenal arteries and veins of dogs, it is recommended to perform a contrast CT scan to evaluate the blood vessels before adrenalectomy. Adrenal blood vessels are visualized when breath-holding, and CT imaging is performed under general

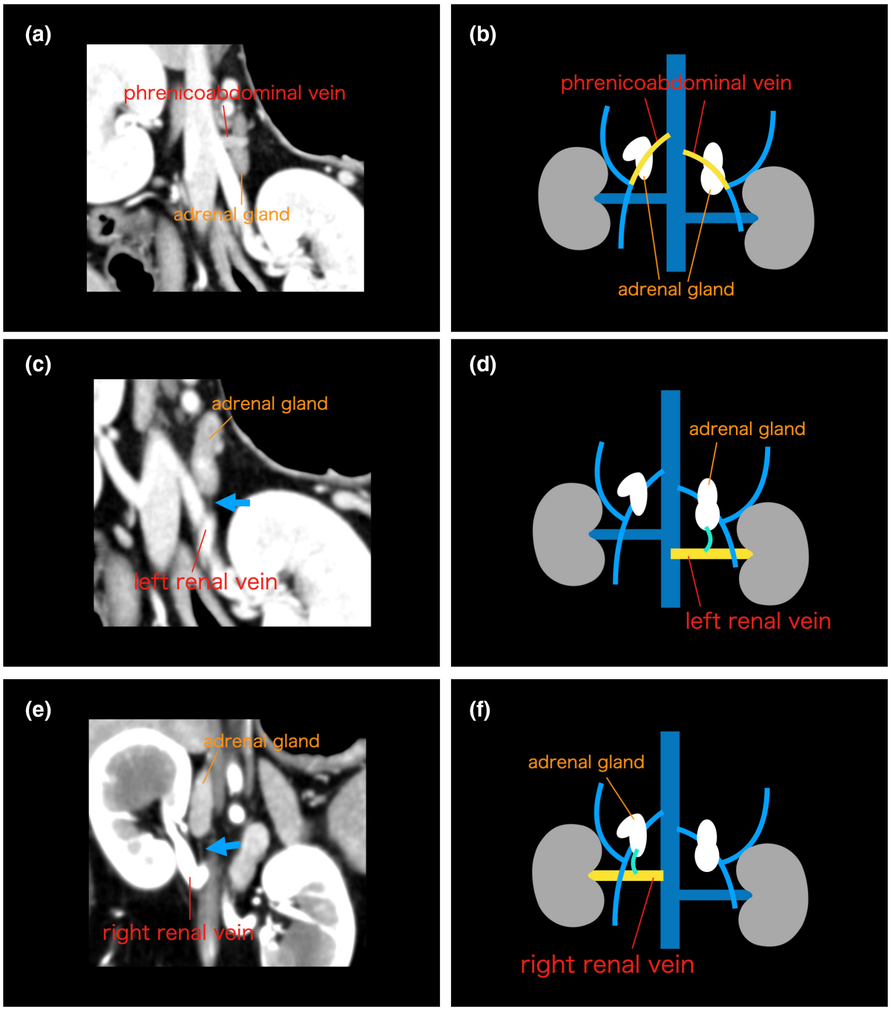

FIGURE 6 The adrenal veins. (a) A contrast computed tomography image shows the phrenicoabdominal vein passes ventral to the adrenal gland and the adrenal veins drain into this phrenicoabdominal vein. (b) Schematic representation of the vein to phrenicoabdominal vein in the ventral view. Yellow line: phrenicoabdominal vein. (c) A contrast computed tomography image shows the adrenal vein flowing into the left renal vein. Arrow: the adrenal vein. (d) Schematic representation of the vein to left renal vein in the ventral view. Light blue line: the adrenal vein; yellow line: left renal vein. (e) A contrast computed tomography image shows the adrenal vein flowing into the right renal vein. Arrow: the adrenal vein. (f) Schematic representation of the vein to right renal vein in the ventral view. Light blue line: the adrenal vein; yellow line: right renal vein

TABLE 4 Distribution of the number of blood vessels in each adrenal gland

Number of blood vessels	Number of adrenal glands
Artery	
1	15
2	30
3	24
4	10
5	10
6	3
Not evaluated	2
Vein	
1	77
2	15
3	1
Not evaluated	1

Note: 94 adrenal glands of 47 dogs were evaluated. This table shows the number of blood vessels running through one adrenal gland. Multiple arteries have various combinations of running arteries. There were three vein patterns: one to three. Most cases had one adrenal vein, and in a few cases, the adrenal vein branches into the renal veins.

anaesthesia using MDCT. By obtaining images with a thin slice thickness, it is possible to evaluate adrenal blood vessels using MPR. In the future, it will be necessary to investigate whether the variation in blood vessels in adrenal tumour cases is different from that in healthy dogs.

ACKNOWLEDGEMENTS

We would like to thank the veterinary nurses who assisted with the CT scans and the dog owners who permitted the study.

FUNDING INFORMATION

We did not receive any financial or material support for this study.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Nami Watanabe https://orcid.org/0000-0002-4319-0268
Shin Ono https://orcid.org/0000-0002-4675-5703

REFERENCES

Barrera, J. S., Bernard, F., Ehrhart, E. J., Withrow, S. J., & Monnet, E. (2013). Evaluation of risk factors for outcome associated with adrenal gland tumors with or without invasion of the caudal vena cava and treated via adrenalectomy in dogs: 86 cases (1993-2009). *Journal of the American Veterinary Medical Association*, *242*, 1715–1721. https://doi.org/10.2460/javma.242.12.1715

Bezuidenhout, A. J. (2013a). The heart and arteries. In H. E. Evans & A. De Lahunta (Eds.), *Miller's anatomy of the dog* (4th ed., pp. 428–504). Elsevier Saunders.

Bezuidenhout, A. J. (2013b). Veins. In H. E. Evans & A. De Lahunta (Eds.), *Miller's anatomy of the dog* (4th ed., pp. 505–534). Elsevier Saunders.

Chiti, L. E., Mayhew, P. D., & Massari, F. (2021). Renal venotomy for thrombectomy and kidney preservation in dogs with adrenal tumors and renal vein invasion. *Veterinary Surgery*, *50*, 872–879. https://doi.org/10.1111/vsu.13593

Hullinger, R. L. (2013). The endocrine system. In H. E. Evans & A. De Lahunta (Eds.), *Miller's anatomy of the dog* (4th ed., pp. 406–427). Elsevier Saunders.

Pey, P., Specchi, S., Rosshi, E., Diana, A., Drudi, I., Zwingenberger, L. A., Mayhew, D. P., Pisone, L., Mari, D., Massari, F., Dalpozzo, B., Fracassi, F., & Nicoli, S. (2022). Prediction of vascular invasion using a 7-point scale computed tomography grading system in adrenal tumors in dogs. *Journal of Veterinary Internal Medicine*, *36*, 713–725. https://doi.org/10.1111/jvim.16371

Priya, A., Narayan, R. K., & Ghosh, S. K. (2022). Prevalence and clinical relevance of the anatomical variations of suprarenal arteries: A review. *Anatomy and Cell Biology*, *55*, 28–39. https://doi.org/10.5115/acb.21.211

Singh, B. (2018). The endocrine glands. In *Textbook of veterinary anatomy* (5th ed., pp. 350–362). Elsevier Saunders.

Zini, E., Nolli, S., Ferri, F., Massari, F., Gerardi, G., Nicoli, S., Romanelli, G., Montinaro, V., Trez, D., Cavicchioli, L., & Ferro, S. (2019). Pheochromocytoma in dogs undergoing adrenalectomy. *Veterinary Pathology*, *56*, 358–368. https://doi.org/10.1177/0300985818819174

How to cite this article: Watanabe, N., & Ono, S. (2022). Anatomical variations of the canine adrenal vessels. *Anatomia, Histologia, Embryologia*, *51*, 802–809. https://doi.org/10.1111/ahe.12858