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Anatomy

Branching patterns of the adrenal arteries in the degu (*Octodon degus*)

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ABSTRACT. The degu has drawn increasing attention for use as an experimental animal in stress response studies due to its physiological features, such as diurnality and seasonal breeding, which differ from conventional laboratory rodents. Stress response is elicited by steroid hormones secreted by the adrenal gland, whose functions are controlled by pituitary hormones reaching through the adrenal arteries. However, knowledge of the arterial anatomy of the degu adrenal gland remains insufficient. To address this issue, we observed adrenal arteries in 20 male degus injected with red-colored latex. Adrenal arterial branching patterns were classified into Types 1–4, which respectively have 1 to 4 parent arteries that give rise to the adrenal arteries. Based on the combination of the parent arteries, Types 2 and 3 were categorized into subtypes a to c, while Type 4 was categorized into subtypes a and b. On the left side, Type 2 (45%) and Type 3 (45%) were predominant, whereas Type 1 (5%) and Type 4 (5%) were infrequent. On the right side, Type 2 (50%) and Type 3 (45%) were predominant, whereas Type 4 (5%) was infrequent. Type 1 was not present. There were 0 to 4 cranial, 1 to 4 middle and 1 to 4 caudal adrenal arteries, with the total number varying from 2 to 9. The present observation provides knowledge of comparative anatomical features of the degu adrenal arteries, which can serve as an anatomical basis for comparative endocrinological studies.

KEY WORDS: adrenal artery, anatomical variation, angiology, degu, macroscopic anatomy

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The degu (*Octodon degus*; suborder Hystricomorpha; order Rodentia) is native to central Chile and lives at high altitudes up to 1,200 m [21]. Recently, the degu has drawn increased attention as an experimental animal that can be used in endocrinological studies of stress response [1, 5, 14]. The degu exhibits peculiar diurnal and seasonal rhythms in their stress hormone levels under wild conditions [1, 12]. Stress response is mediated by steroid hormones released from the adrenal gland under the control of pituitary hormones that flow into the adrenal gland through the adrenal arteries [16, 18]. In the rat, which is a conventional experimental animal used in the field of stress response, the arterial anatomy of the adrenal gland is well studied. A prior study in the rat demonstrates the parent arteries and number of the adrenal arteries with an explicit identification of the cranial, middle and caudal adrenal arteries [9]. Their study reports that the cranial and middle adrenal arteries emerge from the caudal phrenic artery in almost all cases, with the same incidence of caudal adrenal arteries arising from the caudal phrenic artery, the renal artery or the abdominal aorta. The total number of rat adrenal arteries has been shown to vary from 3 to 12 [9]. Such anatomical features of the adrenal arteries enable us to perform the experimental surgery for the adrenal gland and facilitate understanding of the function of this gland [8, 15, 20]. However, as compared to the knowledge base for the rat, there is only little information available on the arterial anatomy of the degu adrenal gland. In the degu, Ventura *et al*. [19] mentioned that the common trunk of the adrenal artery with either the caudal phrenic artery or the caudal phrenic and cranial abdominal arteries stemmed from the renal artery or abdominal aorta, but details of the origin, distribution and number of the degu adrenal arteries remains to be studied yet.

In order to provide an anatomical basis for studying the function of the degu adrenal gland, it is necessary to determine the definitive origin and number of cranial, middle and caudal adrenal arteries, including their individual variations in the degu. Therefore, the present study attempted to elucidate the detailed anatomy of the degu adrenal arteries.

MATERIALS AND METHODS

The animal experiments in the present study were approved by the Research Ethics Committee for Animal Experimentation of the Tokyo University of Agriculture and Technology (approval numbers: 30-43, R03-15).

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The present study examined 20 male degus (80–250 g), which were purchased from Tokyo Laboratory Animal Science Co. (Tokyo, Japan). Although the accurate ages of these degus were unknown, it was surmised that they were 6 weeks old or older, according to the study by Long and Ebensperger [11]. Food and water were supplied *ad libitum* before sacrifice. All the animals were euthanized by an intraperitoneal injection of sodium pentobarbital (over 75 mg/kg). After opening the thoracic cavity to expose the heart, the right auricle was incised and a disposable pipette tip whose pointed end had been cut sharply was inserted through the ventricular wall into the left ventricle. Then, we transcardially perfused the animal through the pipette tip connected to the tube with saline followed by 4% paraformaldehyde in 0.1 M phosphate buffer. In order to clearly observe the arteries, we injected 0.3 to 0.8 ml of a mixture of latex (LACSTAR DFP-800, DIC Corp., Tokyo, Japan) and water at a one to one ratio in conjunction with red acrylic paint coloring (Acryl Gouache, Turner Colour Works Ltd., Osaka, Japan) through a catheter inserted into the thoracic aorta. The cadavers were immersed in 10% formalin for more than 7 days before observation.

The adrenal arteries and related structures were observed under a surgical microscope (L-0950SDP, Inami & Co., Ltd., Tokyo, Japan) and photographed with a digital camera (Nikon D5500, Nikon Imaging Japan, Tokyo, Japan). The brightness, contrast and resolution of photographs were adjusted using Adobe Photoshop (Adobe, San Jose, CA, USA), with the schematic line drawings prepared using Adobe Illustrator (Adobe).

For adrenal artery identification, the arteries whose sites of penetration into the adrenal capsule were the cranial third, middle third and caudal third of the adrenal gland were, respectively, identified as the cranial, middle and caudal adrenal artery, in line with the results of our previous studies in rats [9] and rabbits [10]. In order to count the number of cranial, middle and caudal adrenal arteries, we only numbered the adrenal arterial roots that had just branched from the parent arteries. We did not count any of the twigs diverging distal to the root at the adrenal capsule. This counting method was performed due to the difficulty of accurately counting the twigs on the adrenal capsule.

Although the nomenclature used in the present study conformed to the Nomina Anatomica Veterinaria [13], we referred to the common trunk of the caudal phrenic and cranial abdominal arteries as the phrenicoabdominal trunk in accordance with Hermanson *et al*. [7].

RESULTS

The adrenal arteries arose with various combinations, from the caudal phrenic artery, cranial abdominal artery, renal artery and phrenicoabdominal trunk, although they were rarely observed from the abdominal aorta. From our observations, we categorized the adrenal arterial branching patterns into 4 major types, which, respectively, had 1 to 4 different parent arteries giving rise to the adrenal arteries (Fig. 1). Moreover, based on the combination of the parent arteries, we further classified Types 2 and 3 into subtypes a to c, while Type 4 was classified into subtypes a and b (Fig. 1).

Type 1

In Type 1 (Fig. 1a), the caudal phrenic artery was the only parent artery that gave rise to all of the adrenal arteries, which consisted of 2 cranial, 2 middle and 1 caudal adrenal arteries. This pattern was only observed in 1 of 20 left halves, thereby accounting for 5% of the left halves.

Type 2

In Type 2 (Figs. 1b-d and 2), the renal artery always gave rise to the adrenal arteries. The other parent artery was either the caudal phrenic artery in Type 2a (Fig. 1b), the cranial abdominal artery in Type 2b (Fig. 1c) or the phrenicoabdominal trunk in Type 2c (Fig. 1d). Table 1 summarizes the number of adrenal arteries in Types 2a, 2b and 2c.

Type 2a (Figs. 1b and 2) was present in 3 of 20 left halves (15%) and in 10 of 20 right halves (50%), and was the most common type on the right side. In this type, the most frequent branching pattern was that the cranial and middle adrenal arteries originated from the caudal phrenic artery, and the caudal adrenal arteries originated from the caudal phrenic and renal arteries (Figs. 1b and 2). This pattern was observed in 1 of 20 left halves and in 5 of 20 right halves (25%). In other halves in Type 2a (not illustrated), the cranial adrenal arteries always arose from the caudal phrenic artery, except in 1 right half where the cranial adrenal artery was not present. The middle adrenal arteries usually emerged from the caudal phrenic artery alone (1 left half and 4 right halves) or originated from both the caudal phrenic and renal arteries in 1 half in each side. The caudal adrenal arteries always arose from the renal artery alone (2 left halves and 5 right halves). In Type 2a, 0 to 3 cranial, 1 to 4 middle and 1 to 4 caudal adrenal arteries were present, and the total number varied from 2 to 8 (Table 1).

Type 2b (Fig. 1c) was observed in 3 of 20 left halves (15%). In this type, the cranial adrenal arteries always arose from the cranial abdominal artery (CrA in Fig. 1c), the middle adrenal arteries emerged from the cranial abdominal artery alone (1 half) or both the cranial abdominal and renal arteries (2 halves; MAs in Fig. 1c). The caudal adrenal artery arose from the renal artery alone (2 halves; CaA in Fig. 1c) or both the cranial abdominal and renal arteries (1 half). In Type 2b, we observed 1 cranial, 1, 2 or 4 middle and 1 to 3 caudal adrenal arteries, and the total number was 4 or 6 (Table 1).

Type 2c (Fig. 1d) was observed in 3 left halves (15%). In this type, the cranial adrenal arteries always arose from the phrenicoabdominal trunk (CrA in Fig. 1d), the middle adrenal arteries arose from the renal artery (1 half; MA in Fig. 1d) or phrenicoabdominal trunk (1 half), or both of these artery and trunk (1 half). The caudal adrenal arteries arose from the renal artery alone (2 halves; CaA in Fig. 1d) or both the renal artery and phrenicoabdominal trunk (1 half). In Type 2c, we observed 1 cranial, 1 to 3 middle and 1 to 3 caudal adrenal arteries, and the total number was 3 to 7 (Table 1).

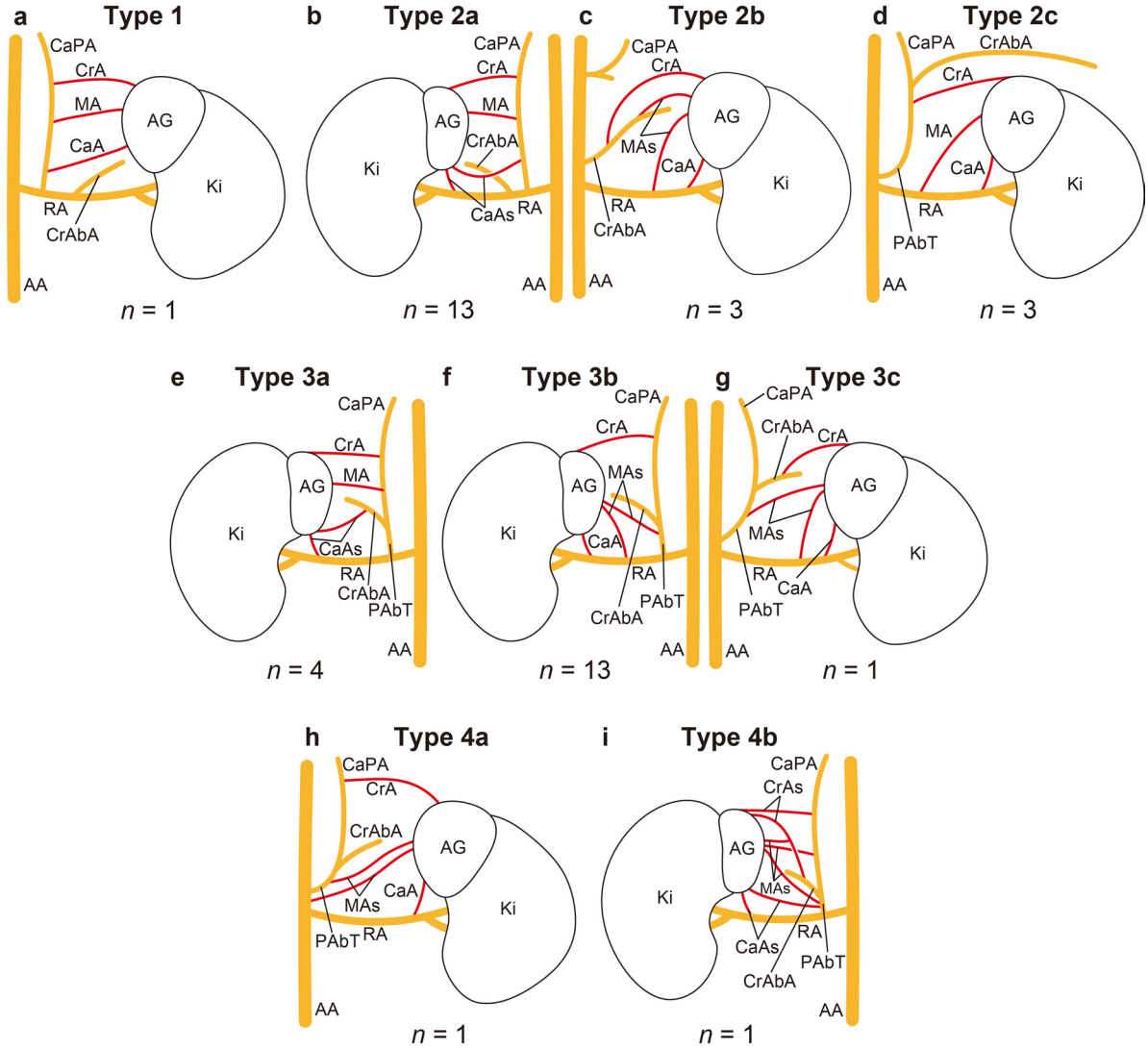

Fig. 1. Schematic drawings of the branching patterns of Types 1 (**a**), 2 (**b–d**), 3 (**e-g**) and 4 (**h, i**), in the ventral view. Adrenal arteries are colored in red, while other arteries are colored in orange. (a), (c), (d), (g) and (h) are present only on the left side, (i) is present only on the right side, and (b), (e) and (f) are present on both sides. The illustrations display only the origins and approximate courses and not the exact number of adrenal arteries. To clearly show the adrenal arteries in these figures, the adrenal gland is depicted more laterally and cranially, while the kidney is depicted more laterally than the original position. Abbreviations used in this figure and Figs. 2 and 3: AA, abdominal aorta; AG, adrenal gland; CaA, caudal adrenal artery; CaPA, caudal phrenic artery; CrA, cranial adrenal artery; CrAbA, cranial abdominal artery; Ki, kidney; MA, middle adrenal artery; PAbT, phrenicoabdominal trunk; and RA, renal artery.

Type 3

Type 3 (Figs. 1e–g and 3) had 3 parent arteries, one of which was always the renal artery. The remaining 2 parent arteries were the caudal phrenic and cranial abdominal arteries in Type 3a (Fig. 1e), the caudal phrenic artery and phrenicoabdominal trunk in Type 3b (Fig. 1f), and the cranial abdominal artery and phrenicoabdominal trunk in Type 3c (Fig. 1g). Table 2 summarizes the number of adrenal arteries in Types 3a, 3b and 3c.

Type 3a (Fig. 1e) was observed in 2 halves on each side. In this type, the cranial adrenal arteries usually emerged from the caudal phrenic artery alone (2 left halves and 1 right half; CrA in Fig. 1e), but in 1 right half, the cranial adrenal arteries had the additional origin of the cranial abdominal artery. The origins of the middle adrenal arteries differed in each half; the origins were the caudal phrenic artery alone (1 right half; MA in Fig. 1e), or both the caudal phrenic and cranial abdominal arteries (1 left half), or both the cranial abdominal and renal arteries (1 left half), or all of these three parent arteries (1 right half). The caudal adrenal arteries usually arose from the renal artery alone (2 left halves and 1 right half), but in 1 right half, they originated from both the cranial abdominal and renal arteries (CaAs in Fig. 1e). In Type 3a, there were 1, 3 or 4 cranial, 2 or 3 middle and 1 or 2 caudal adrenal arteries, with the total number varying from 5 to 7 (Table 2).

Type 3b (Figs. 1f and 3), which was observed in 6 left halves (30%) and in 7 right halves (35%), was the most common type observed on the left side. The cranial adrenal arteries originated usually from the caudal phrenic artery alone (5 left halves and 4

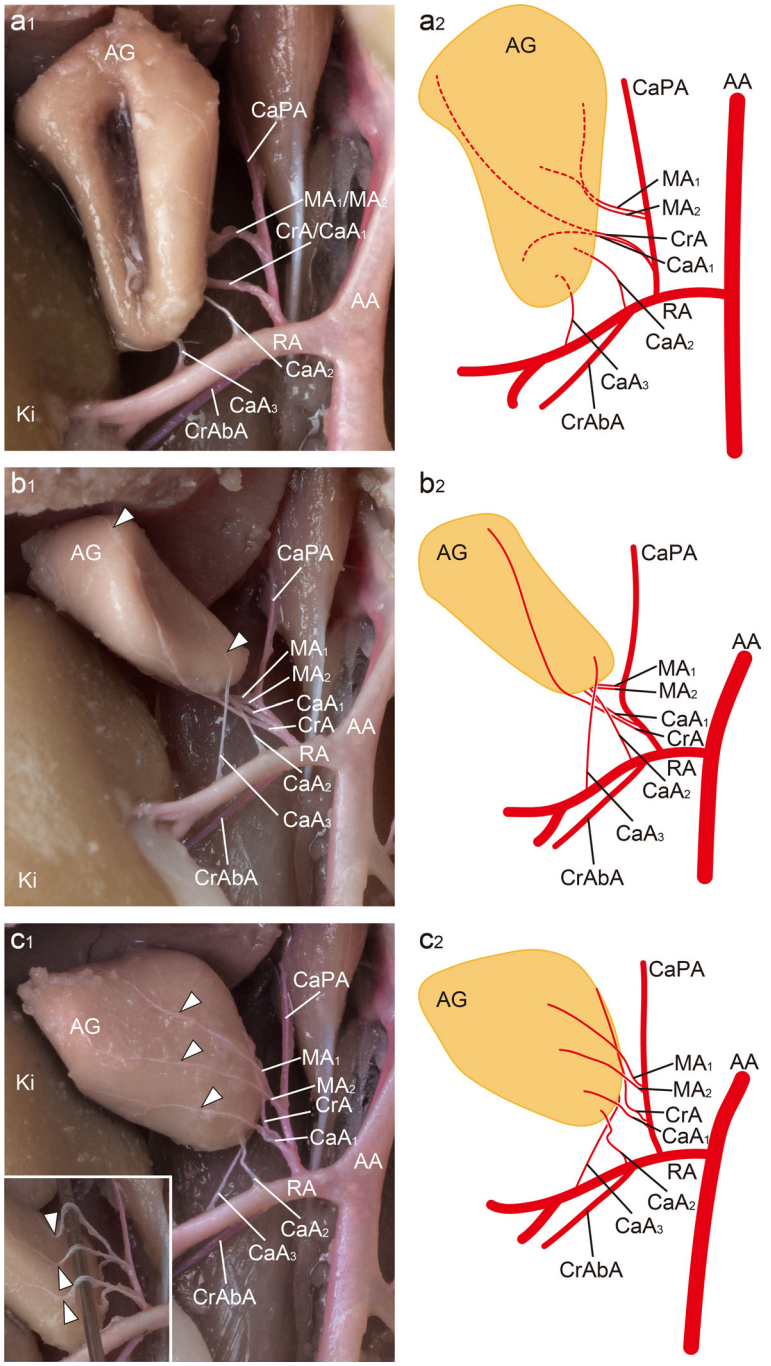

Fig. 2. Photographs and schematic drawings of a half with the most frequent branching pattern (Type 2a) of the adrenal arteries and related structures on the right side in the ventral view. One cranial (CrA), 2 middle ($MA_{1,2}$) and 3 caudal (CaA_{1-3}) adrenal arteries are identified. **(a_1)** The adrenal arteries can be clearly observed with the adrenal gland displaced cranially. As the adrenal arteries course on the dorsal and lateral aspects of the gland, the exact courses are not visible from this view. **(a_2)** Schematic drawing of a_1. Dotted lines represent the courses of the adrenal arteries on the dorsal and lateral surfaces of the adrenal gland. **(b_1)** The courses of the adrenal arteries on the lateral aspect of the same adrenal gland as shown in a_1, in a medially reflected position. Arrowheads indicate the penetration sites of the cranial adrenal and one of the caudal adrenal arteries (CaA_3). **(b_2)** Schematic drawing of b_1. **(c_1)** The courses of the adrenal arteries on the dorsal aspect of the same adrenal gland as shown in a_1 and b_1 in a laterally reflected position. Arrowheads indicate the penetration sites of the middle and caudal adrenal arteries (MA_1, MA_2 and CaA_1). These penetration sites are clearly shown in the inset where the arteries running on the surface of the adrenal gland are gently raised by a needle. **(c_2)** Schematic drawing of c_1.

Table 1. Number of adrenal arteries in Types 2a, 2b and 2c

Number of arteries				Number of halves in each type		
CrA	MA	CaA	Total	2a	2b	2c
0	1	1	2	1		
1	1	1	3			1
1	1	2	4		1	
1	2	1	4	1		
1	2	2	5			1
1	3	1	5	1		
1	2	3	6	1	1	
1	4	1	6		1	
2	1	3	6	1		
2	2	2	6	3		
1	2	4	7	1		
1	3	3	7			1
1	4	2	7	1		
2	3	2	7	1		
2	4	1	7	1		
3	2	3	8	1		

CaA, caudal adrenal artery; CrA, cranial adrenal artery; and MA, middle adrenal artery.

right halves; CrA in Figs. 1f and 3) or originated from both the caudal phrenic artery and the phrenicoabdominal trunk in fewer halves (1 left half and 3 right halves). The parent arteries of the middle adrenal arteries varied between each other. They were the phrenicoabdominal trunk alone (1 left half and 2 right halves), or both the caudal phrenic artery and phrenicoabdominal trunk (3 left halves and 1 right half), or both the renal artery and phrenicoabdominal trunk (2 left halves and 2 right halves; MAs in Figs. 1f and 3). Rare patterns were that the middle adrenal artery originated from the caudal phrenic artery alone (1 right half) or from the three parent arteries (1 right half). The caudal adrenal arteries usually emerged from the renal artery alone (5 left halves and 3 right halves; CaA in Figs. 1f and 3) or both the renal artery and the phrenicoabdominal trunk in fewer halves (1 left half and 4 right halves). In Type 3b, 1 to 3 cranial, 1 to 4 middle and 1 to 3 caudal adrenal arteries were observed, with the total number varying from 4 to 8 (Table 2).

Only 1 half was identified as Type 3c (Fig. 1g) on the left side alone. In this specimen, the cranial adrenal artery originated from the cranial abdominal artery, the middle adrenal arteries arose from both the renal artery and phrenicoabdominal trunk, and the caudal adrenal artery emerged from the renal artery. There was 1 cranial, 2 middle and 1 caudal adrenal arteries, totaling 4 arteries (Table 2).

Type 4

Type 4 (Fig. 1h and 1i) had 4 parent arteries, which included the caudal phrenic artery, phrenicoabdominal trunk and renal artery, and either the abdominal aorta in Type 4a (Fig. 1h) or cranial abdominal artery in Type 4b (Fig. 1i).

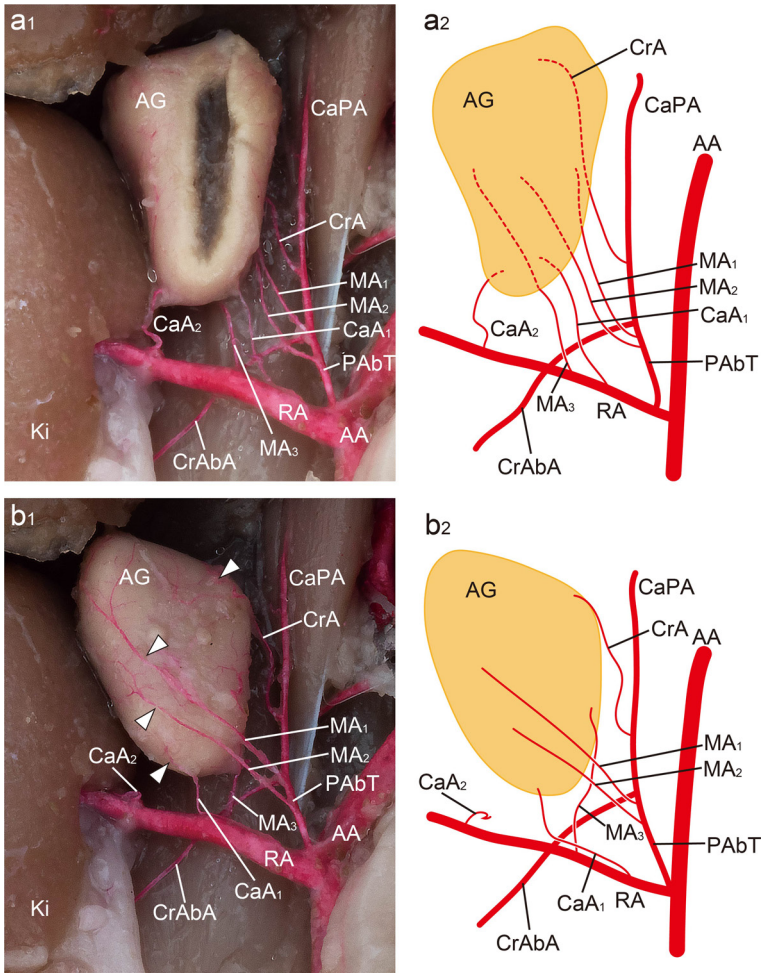

Fig. 3. Photographs and schematic drawings of a half categorized as Type 3b on the right side in the ventral view. One cranial (CrA), 3 middle ($MA_{1\text{-}3}$) and 2 caudal ($CaA_{1,2}$) adrenal arteries are identified. **(a_1)** The adrenal arteries are clearly observed with the adrenal gland displaced cranially. **(a_2)** Schematic drawing of a_1. Dotted lines represent the courses of the adrenal arteries on the dorsal surface of the adrenal gland. **(b_1)** The courses of the adrenal arteries on the dorsal aspect of the same adrenal gland as in a_1 in a laterally reflected position. Arrowheads indicate the site of penetration into the adrenal parenchyma. One caudal adrenal artery (CaA_2) is transected to show the other adrenal arteries for this reflected position. **(b_2)** Schematic drawing of b_1.

Table 2. Number of adrenal arteries in Types 3a, 3b and 3c

Number of arteries				Number of halves in each type		
CrA	MA	CaA	Total	3a	3b	3c
1	2	1	4			1
2	1	1	4		1	
1	2	2	5	1	1	
2	2	1	5		2	
1	3	2	6		1	
1	4	1	6		1	
2	2	2	6		1	
1	3	3	7		1	
2	3	2	7		2	
3	2	2	7		1	
3	3	1	7	2		
4	2	1	7	1		
2	4	2	8		1	
3	2	3	8		1	

CaA, caudal adrenal artery; CrA, cranial adrenal artery; and MA, middle adrenal artery.

Type 4a (Fig. 1h) was observed in 1 left half, where 1 cranial adrenal artery emerged from the caudal phrenic artery, 2 and 1 middle adrenal arteries, respectively, originated from the phrenicoabdominal trunk and abdominal aorta, and 1 caudal adrenal artery emerged from the renal artery. There were 1 cranial, 3 middle and 1 caudal adrenal arteries, totaling 5 arteries.

In Type 4b (Fig. 1i), which was observed in 1 right half, 2 and 1 cranial adrenal arteries, respectively, arose from the caudal phrenic and cranial abdominal arteries, 1 middle adrenal arteries arose from each of the caudal phrenic and cranial abdominal arteries, and the phrenicoabdominal trunk, and 2 and 1 caudal adrenal arteries, respectively, originated from the renal artery and phrenicoabdominal trunk. There were 3 cranial, 3 middle and 3 caudal adrenal arteries, for a total of 9 arteries.

Combination of right and left branching patterns in each specimen

Table 3 summarizes the combinations of the right and left branching patterns. Three specimens had the combination of Type 2a on the right side and Type 3b on the left side, and Type 3b on both sides. Two specimens had the combination of Type 2a on both sides, and Type 3b on the right side and Type 2b on the left side. All other combinations were only observed in 1 specimen each.

DISCUSSION

This is the first report to provide details on the origin, distribution and number of the adrenal arteries in the degu, extending prior findings by Ventura *et al*. [19] who demonstrated that the adrenal artery originated from the common trunk with either the caudal phrenic artery or caudal phrenic and cranial abdominal arteries. The present study demonstrated that the branching pattern of the degu adrenal artery was categorized into 4 major types based on the number of the parent arteries. Moreover, these major types were subcategorized based on the combination of the parent arteries. On the left side, Type 3b, which has the caudal phrenic and renal arteries and the phrenicoabdominal trunk as the parent artery, was the most frequent (35%). On the other hand, Type 2a, which has the caudal phrenic and renal arteries as the parent artery, was the typical pattern observed on the right side (50%). Moreover, the most frequent number of the cranial, middle and caudal adrenal arteries was, respectively, 1 (45%), 2 (45%) and 1 (40%).

Table 3. Combinations of the branching patterns on the right and left side in each specimen

		Left side							
		Type 1	Type 2a	Type 2b	Type 2c	Type 3a	Type 3b	Type 3c	Type 4a
Right side	Type 2a		2 (10%)	1 (5%)	1 (5%)	1 (5%)	3 (15%)	1 (5%)	1 (5%)
	Type 3a	1 (5%)			1 (5%)				
	Type 3b			2 (10%)	1 (5%)	1 (5%)	3 (15%)		
	Type 4b		1 (5%)						

Origin of the adrenal arteries

In the present study, the cranial adrenal arteries were observed to originate from 1 artery or several different arteries including the caudal phrenic artery, cranial abdominal artery and phrenicoabdominal trunk on both sides. In the majority of the cases (55% on the left side and 70% on the right side), the cranial adrenal artery emerged only from the caudal phrenic artery. Furthermore, our findings showed that the caudal phrenic artery was at least one of the parent arteries in 65% on the left side and in 95% on the right side. This occurrence rate was more than twice as high as that found for the cranial abdominal artery (20% on the left side and 10% on the right side) or phrenicoabdominal trunk (25% on the left side and 15% on the right side).

The caudal phrenic artery is also the main parent artery of the cranial adrenal artery in other mammals, such as guinea pigs [3], rats [4, 6, 9] and rabbits [10]. Additionally, the cranial abdominal artery that is present in the guinea pig and rabbit has also been shown to give rise to the cranial adrenal artery [3, 10], similar to that observed in the degu. However, unlike the degu, the cranial abdominal artery and the caudal phrenic artery do not form the phrenicoabdominal trunk in the rabbit [10]. Therefore, in the rabbit, the origin of the phrenicoabdominal trunk is not present. This may yield differences in the branching pattern for the middle and caudal adrenal arteries, as discussed below. Moreover, although there is a low incidence of the abdominal aorta giving rise to the cranial adrenal artery in rabbits [10], this was not observed in the present study in degus.

In the degu, there were 5 parent arteries that gave off the middle adrenal arteries: the caudal phrenic artery, cranial abdominal artery, renal artery, phrenicoabdominal trunk and abdominal aorta. On the left side, there were numerous combinations for the origination of the middle adrenal arteries from the caudal phrenic, cranial abdominal and renal arteries, and the phrenicoabdominal trunk. The most frequent pattern on the left side was the middle adrenal arteries emerging from both the renal artery and phrenicoabdominal trunk, which was observed in 20% of the left halves. In contrast, on the right side, the middle adrenal arteries emerged only from the caudal phrenic artery in 55% of the halves observed.

In rats, the middle adrenal artery emerges from the caudal phrenic artery on both sides [9]. The rabbit middle adrenal arteries can arise from the cranial abdominal artery and abdominal aorta on the left side, and from the caudal phrenic artery in addition to these 2 arteries on the right side [10]. As compared to other species, the degu middle adrenal artery emerged from the renal artery more often (45% on the left and 25% on the right), with it rarely originating from the abdominal aorta (only 5% of left halves in this study). These differences are considered to be features of the degu middle adrenal artery.

In the degu, the caudal adrenal artery emerged from the caudal phrenic, cranial abdominal and renal arteries, and the phrenicoabdominal trunk on both sides. Among these parent arteries, the caudal adrenal artery originated from the renal artery alone in 75% of the left halves and in 45% of the right halves. In addition, the incidence that at least 1 parent artery was the renal artery was 95% on the left side and 100% on the right side in this study.

In the guinea pig [3], the caudal adrenal artery arises from the renal artery on both sides, and this pattern is similar to that observed in the degus. In contrast, in the rat [9], the right caudal adrenal arteries primarily emerge from the caudal phrenic artery, while the left ones arise from either the caudal phrenic artery, the renal artery or the abdominal aorta in one-third of the cases. Moreover, in the rabbit [10], the parent arteries of the caudal adrenal arteries are the cranial abdominal artery, renal artery and abdominal aorta on both sides, and the caudal phrenic artery additionally on the right side. In contrast to the rat and rabbit [9, 10], the abdominal aorta did not provide the caudal adrenal artery in the degu.

Although both the rat and degu belong to the rodent, the incidence of the renal artery being the parent artery of the adrenal arteries in the degu was higher than that reported in the rat, whereas the incidence of the abdominal aorta being the parent artery in the degu was lower than that observed in the rat. This may be attributable to the interspecies differences in the positional relationship between the adrenal gland and the parent arteries. Since the adrenal gland in the degu is relatively large as compared to that found in other rodents of a similar size [2], we observed that its caudal end reached the renal artery on both sides (unpublished data; also, please note that in Figs. 1 to 3, the adrenal gland has been displaced cranially in order to demonstrate the adrenal arteries). Therefore, the renal artery can be the predominant parent artery that is distributed to the adrenal gland on both sides. In contrast, the caudal phrenic artery and phrenicoabdominal trunk in the degu travel between the abdominal aorta and the adrenal gland on both sides. This positional relationship makes it difficult for the abdominal aorta to give off the adrenal arteries, which must, if present, pass over the caudal phrenic artery and/or the phrenicoabdominal trunk in order to reach the adrenal gland. Therefore, these findings suggest that it is not usually possible that the abdominal aorta is the parent artery in the degu.

In the rat, the adrenal gland is relatively small and located at the cranial pole of the ipsilateral kidney, with the caudal margin of this gland at a much greater distance from the renal artery [6] than that found for the adrenal gland in the degu. Therefore, these findings may explain that the incidence of the adrenal arteries arising from the renal artery in the rat [9] is lower than that in the degu. Furthermore, although the positional relationship of the adrenal gland with the abdominal aorta and caudal phrenic artery on the right side is similar to that described above in the degu, there is no artery on the left side between the caudal portion of

the adrenal gland and the abdominal aorta [4, 9]. Therefore, these findings may explain that the incidence of the abdominal aorta giving rise to the left adrenal arteries in the rat [9] is higher than that observed in the degu.

Number of the adrenal arteries

In the present study, we counted the number of the roots of the adrenal arteries (adrenal arterial roots) that occurred just after branching from the parent artery. As described in the Materials and Methods, we did not count the slender branches diverging from the root at the surface of the adrenal capsule. When using this counting standard, our findings showed that the number of the cranial adrenal arteries varied from 0 to 4, while the middle adrenal arteries varied from 1 to 4, as did the caudal adrenal arteries. The total number of the degu adrenal arteries ranged from 2 to 9.

In prior studies in rats and rabbits where the number of the adrenal arteries were counted at the adrenal capsule distal to the root, the total number of the adrenal arteries was shown to vary from 3 to 12 in rats and 3 to 16 in rabbits [9, 10]. After taking into consideration the difference in the standard for the arterial counting between the present and these prior studies, our findings suggest that a similar or larger number of the adrenal arteries may be present in the degu as compared to that found for the rat and rabbit. Although the standard used for the arterial counting in the guinea pig was not indicated, Shively and Stump [17] found 2 to 5 adrenal arteries in total, which was less than the number that we found in the degu.

Surgical implications

The present study demonstrated that the adrenal arteries originated from the caudal phrenic artery, the cranial abdominal artery, the renal artery, the phrenicoabdominal trunk and the abdominal aorta with individual various combinations and numbers. Since these patterns of branching of the adrenal arteries from their parent arteries in the degu differ from those in the rat, the surgical approach to the rat adrenal gland is not simply applicable to that to the degu adrenal gland. Thus, it is always necessary to pay attention to the complexity of the degu adrenal arterial branching patterns for experimental surgery such as adrenal arterial ligation and adrenalectomy to study endocrinology of stress response.

CONFLICT OF INTEREST. The authors declare that they have no conflict of interest.

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