Anatomical variations of the arterial supply to the adrenal gland in the rat

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ABSTRACT. The adrenal gland is an essential endocrine organ for the stress response. The functions of this organ may be studied by ligation of the adrenal artery or adrenalectomy. However, in prior studies, descriptions of the anatomical variations of the adrenal artery were insufficient and inconsistent. Therefore, anatomical variations of the arterial supply to the adrenal gland were studied in 18 male and 18 female Wistar rats by colored latex injection into the arteries. The vascularization pattern was categorized into 4 types based on the origin of each adrenal artery. The cranial and middle adrenal arteries arose from the caudal phrenic artery in Types 1–3, but the caudal adrenal artery emerged from the caudal phrenic artery in Type 1, from the renal artery in Type 2 and from the abdominal aorta in Type 3. In Type 4, the cranial and middle adrenal arteries stemmed from the cranial phrenic artery, and the caudal adrenal artery arose from the caudal phrenic artery. The number of adrenal arteries varied from 3 to 11 on the left side and from 4 to 12 on the right side, and the total varied from 9 to 20 (predominantly 14) in each individual. There was no sex difference in the vascularization pattern. The results show that more individual variations occur in the adrenal arteries of rats than was previously reported. Such variations should always be considered when experimental treatments of the rat adrenal gland are performed.

KEY WORDS: adrenal artery, angiology, macroscopic anatomy, rat

The adrenal gland plays a pivotal role in the stress response mechanism. To study the functional role of the adrenal gland, ligation of the adrenal artery and adrenalectomy are commonly performed [7]. Detailed knowledge of the origin, courses and numbers of the adrenal arteries is an essential prerequisite to performing such experiments.

The adrenal gland receives its arterial supply via the cranial (=superior), middle and caudal (=inferior) adrenal arteries, based on the terminology used in human studies [9, 10]. These arteries supply the cranial third, middle third and caudal third of the adrenal gland, respectively. In the rat, it was found that the cranial adrenal artery can arise from the caudal phrenic artery or directly from the abdominal aorta [5], or only from the caudal phrenic artery [2, 4, 8]. In addition, the middle adrenal artery can stem from the caudal phrenic artery or directly from the abdominal aorta [8]. Other studies have shown that the middle adrenal artery emerges only from the abdominal aorta [4] or may be lacking [2, 5]. The caudal adrenal artery has been reported to arise from the renal or caudal phrenic artery [2, 8], but Harrison [4] and Hebel and Stromberg [5] have reported that the caudal adrenal artery arises only from the renal artery. Thus, the descriptions of the origins of the adrenal arteries are inconsistent and insufficient.

In other mammals, the vascularization of the adrenal gland has not been studied in detail. However, in humans [9, 10], the individual variations in the origin, number and left and right sides of each adrenal artery have been described in greater detail. Manso and DiDio [9] reported that the cranial (=superior) adrenal arteries that were 3 to 6 on the right and 3 to 8 on the left arose from the caudal (=inferior) phrenic artery; the middle adrenal arteries that were 1 to 2 on the right and 1 to 3 on the left emerged from the abdominal aorta or the caudal phrenic artery; and the caudal adrenal arteries that were 1 to 4 on the right and 1 to 3 on the left stemmed from the renal artery or directly from the adrenal aorta. However, there have been no reports describing such variations in the origin and number of adrenal arteries in rats.

Therefore, the present study aimed to elucidate the individual anatomical variations of the arterial supply to the rat adrenal gland macroscopically.

MATERIALS AND METHODS

The present study was approved by the Research Ethics Committee for Animal Experimentation of the Tokyo University of Agriculture and Technology. All rats were sacrificed by decapitation.

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In this study, 18 male and 18 female Wistar rats (weight, 180–300 g), purchased from Tokyo Laboratory Animal Science Co. (Tokyo, Japan) were used. All animals were euthanized by intraperitoneal administration of sodium pentobarbital (60 mg/kg) and perfused with saline followed by 10% formalin. A catheter was then inserted into the thoracic aorta to inject 1 ml of latex (Neoprene latex 601A or 842A, Showa Denko, Kawasaki, Japan) colored with red acrylic paint (Acryl Gouache, Turner Colour Works Ltd., Tokyo, Japan).

After further fixation for more than 7 days in 10% formalin, the specimens were dissected to observe the adrenal arteries and related structures under a surgical microscope (L-0950SDP, Inami & Co., Ltd., Tokyo, Japan). When the number of branches of each adrenal artery was identified, the numbers of all branches, which issued from each artery and entered the adrenal parenchyma through its capsule, were counted.

Images of the dissected arteries were taken with a digital camera (Nikon D5500, Nikon Corporation, Tokyo, Japan), and their contrast and resolution were adjusted with Adobe Photoshop (Adobe Systems, San Jose, CA, U.S.A.). Assembly of the adjusted images and drawing of schematics were performed using Adobe Illustrator (Adobe Systems).

RESULTS

The adrenal arteries arose mainly from the caudal phrenic and renal arteries and the abdominal aorta, and rarely from the cranial phrenic artery. No other arteries contributed to the adrenal arterial supply. The adrenal arteries reached the adrenal gland with various vascularization patterns, which had no sex difference. The patterns were categorized into 4 types based on the origin of each adrenal artery (Fig. 1). In Type 1, the cranial, middle and caudal adrenal arteries arose from the caudal phrenic artery, and they ran laterally toward the adrenal gland (Figs. 1A, 2A and 2A’). Type 1 was observed in 12 of 36 cases (33%) on the left side and 33 of 36 cases (91%) on the right side. This type was the most frequently observed pattern on the right side. In Type 1, 1 to 4 cranial, 1 to 5 middle and 1 to 3 caudal adrenal arteries were present on both sides (Table 1). The most common total numbers were 6 and 7 on the left side (3 of 12 cases each, 25%) and 6 on the right side (10 of 33 cases, 30%) (Table 1).

In Type 2, the cranial and middle adrenal arteries arose from the caudal phrenic artery and ran laterally, but the caudal adrenal artery stemmed from the renal artery and ran craniolaterally (Figs. 1B, 2B and 2B’). On the left side, 13 of 36 cases (36%) were categorized as Type 2, whereas on the right side, 2 of 36 specimens (6%) were classified as Type 2. This type was the most frequent branching pattern on the left side. In Type 2, 1 to 5 cranial, 1 to 5 middle and 1 to 2 caudal adrenal arteries were present on both sides (Table 1). The most common total numbers were 6 and 7 on the left side (3 of 12 cases each, 25%) and 6 on the right side (10 of 33 cases, 30%) (Table 1).

In Type 3, the cranial and middle adrenal arteries ran laterally after arising from the caudal phrenic artery, but the caudal adrenal artery stemmed directly from the abdominal aorta and ran craniolaterally (Fig. 1C). Type 3 was observed in 11 of 36 cases (31%)
on the left side only. This type had 1 to 5 cranial, 1 to 3 middle and 1 to 2 caudal adrenal arteries (Table 3). The most common total
number was 5 in 4 of 11 specimens (36%) (Table 3).

Type 4 was seen in 1 exceptionally rare case (3%) on the right side only, where the cranial and middle adrenal arteries originated
from the cranial phrenic artery. In this case, the cranial phrenic artery arose caudally from the thoracic aorta, pierced the diaphragm
through an independent opening and entered the abdominal cavity to provide the cranial and middle adrenal arteries. The caudal
adrenal artery arose from the caudal phrenic artery and ran craniolaterally (Fig. 1D). In this type, 5 cranial, 3 middle and 4 caudal
adrenal arteries were present, totaling 12 adrenal arteries (Table 4). This was the maximum number of arteries observed on one side
in any type in the present study.

The combinations of the branching patterns of the left and right sides in each specimen are shown in Table 5. The most common
combination was Type 2 on the left side and Type 1 on the right side (13 of 36 cases, 36%). The second most common was Type
3 on the left side, Type 1 on the right side (28%) and Type 1 on both sides (28%). The remaining combinations observed were:
Type 1 on the left and Type 2 on the right (3%); Type 1 on the left and Type 4 on the right (3%); and Type 3 on the left and Type 2
on the right (3%).

The total number of adrenal arteries varied from 3 to 11 on the left side and from 4 to 12 on the right side (Tables 1–4). The total
number on both sides in one individual varied from 9 to 20 (predominantly 14).
### Table 1. Number of arteries in Type 1

| Artery Type | Left Side | Right Side |
|-------------|-----------|------------|
|             | Number of arteries | Number of cases | Number of arteries | Number of cases |
| Cr Mid Ca Total | | | Cr Mid Ca Total | |
| 1 1 1 3 1 | 1 | 1 2 1 4 4 | |
| 1 2 1 6 1 | 2 | 1 1 2 4 1 | |
| 2 3 1 6 1 | 1 | 2 2 1 5 3 | |
| 3 1 2 6 1 | 1 | 1 2 2 5 1 | |
| 2 3 2 7 1 | 1 | 3 1 1 5 1 | |
| 2 2 3 7 1 | 1 | 2 2 2 6 4 | |
| 3 3 1 7 1 | 1 | 3 2 3 6 3 | |
| 4 2 2 8 2 | 1 | 3 1 2 6 2 | |
| 3 4 2 9 1 | 1 | 3 2 1 6 1 | |
| 2 5 2 9 1 | 1 | 2 3 2 7 3 | |

### Table 2. Number of arteries in Type 2

| Artery Type | Left Side | Right Side |
|-------------|-----------|------------|
|             | Number of arteries | Number of cases | Number of arteries | Number of cases |
| Cr Mid Ca Total | | | Cr Mid Ca Total | |
| 2 2 1 5 1 | 1 | 2 1 2 5 1 | 1 |
| 2 1 2 5 1 | 2 | 2 4 2 8 1 | 1 |
| 2 3 2 7 2 | 2 | 4 1 2 7 1 | 1 |
| 3 2 2 7 2 | 1 | 2 2 3 7 1 | 1 |
| 1 4 2 7 1 | 1 | 4 1 2 7 1 | 1 |
| 3 3 1 7 1 | 1 | 2 4 2 8 1 | 1 |
| 2 4 2 8 1 | 1 | 2 5 1 8 1 | 1 |
| 3 3 2 8 1 | 1 | 4 3 2 9 1 | 1 |
| 4 3 1 8 1 | 1 | 4 3 2 9 1 | 1 |

### Table 3. Number of adrenal arteries in Type 3

| Artery Type | Number of case |
|-------------|----------------|
| Cr Mid Ca Total | | |
| 2 1 1 4 1 | 1 |
| 1 2 2 5 2 | |
| 2 1 2 5 1 | |
| 3 1 1 5 1 | |
| 2 2 2 6 2 | |
| 3 1 2 6 1 | |
| 4 1 2 7 1 | |
| 4 3 2 9 1 | |
| 5 2 2 9 1 | |

### Table 4. Number of adrenal arteries in Type 4

| Artery Type | Number of case |
|-------------|----------------|
| Cr Mid Ca Total | | |
| 5 3 4 12 1 | 1 |

This type is observed only on the right side.

This type is observed only on the left side.
Moreover, in sheep [3], cranial adrenal artery arose from the lumbar artery on both sides in all cases observed by Suzuki et al. and 83.3% on the right side. However, in other species, the origin differs and sometimes varies more. For example, in the pig, the predominant origin of the cranial (=superior) adrenal artery is the caudal (=inferior) phrenic artery in 80.0% of cases on the left arteries arose from the cranial phrenic artery, which was not reported in prior studies. In humans [9], similar to the rat, the caudal adrenal artery demonstrated by the present investigation are highly informative for experimental treatment of the adrenal gland in rats.

The origin of the cranial adrenal artery from the caudal phrenic artery agrees with the previous descriptions for rats [2, 4, 8]. However, Hebel and Stromberg [5] reported that the cranial adrenal artery arose directly from the abdominal aorta. Such a branching pattern was not observed in the present study. Instead, in one exceptional case of our specimens, the cranial adrenal arteries arose from the cranial phrenic artery, which was not reported in prior studies. In humans [9], similar to the rat, the predominant origin of the cranial (=superior) adrenal artery is the caudal (=inferior) phrenic artery in 80.0% of cases on the left and 83.3% on the right side. However, in other species, the origin differs and sometimes varies more. For example, in the pig, the cranial adrenal artery arose from the lumbar artery on both sides in all cases observed by Suzuki et al. [11]. Moreover, in sheep [3], the cranial adrenal artery arose only from the lumbar artery in 48% of cases on the left and 92% on the right or from the lumbar artery as well as the celiac artery, or cranial mesenteric artery, or their common trunk in 52% of cases on the left side and 8% on the right side. In the ferret [6], the cranial adrenal artery arose only from the abdominal aorta in 80% of cases on the left and 40% on the right or from the abdominal aorta and cranial adrenal artery (=their adreno-lumbar artery) in 20% on the left and 60% on the right.

The origin of the middle adrenal artery is described inconsistently in the results of previous rat studies, where this artery arose only from the abdominal aorta [4], or either from the caudal phrenic artery or abdominal aorta [8]. Other studies did not provide any description of the middle adrenal artery [2, 5]. In contrast, in the present study, the middle adrenal artery always arose from the caudal phrenic artery, except for one rare case where it originated from the cranial phrenic artery, as mentioned above. In humans [9], the incidence of the origin of the middle adrenal artery from the caudal phrenic artery is low, at 26.7% on both sides. Rather, this artery originates directly from the abdominal aorta at 46.7% on the left and 53.0% on the right.

The caudal adrenal artery emerged from the caudal phrenic artery or the renal artery or the abdominal aorta each in one-third of the cases studied. An origin in the caudal phrenic or renal artery has been reported in rats, but not in the abdominal aorta [2, 4, 5, 8]. In other species, the origin and its incidence of the caudal adrenal artery remarkably varied. In humans [9], the caudal (=inferior) adrenal artery arose from the renal artery (50.0%) or abdominal aorta (36.7%) on the left, and the renal artery (70.0%) and abdominal aorta (26.7%) on the right. The origin from the caudal (=inferior) phrenic artery was not described. In contrast, in the pig [11], the caudal adrenal artery emerged directly from the abdominal aorta in 56% on the left and 89% on the right, and the next predominant origin was the cranial adrenal artery (=their dorsal abdominal artery) at 44% on the left and 11% on the right. The origin from the renal artery was not reported in the pig.

In prior reports [2, 4, 5, 8], the description of individual variation was incomplete and inconsistent, but from the present study, it can be seen that many individual differences occur in the origin of each adrenal artery in rats. Since these prior reports did not specify the strain, and the numbers of their observed samples were too small (4 cases [4] and 5 cases [8]) or not described [2, 5], the difference in the findings between the present study and prior studies may be due to a strain difference and/or a bias caused by insufficient numbers of specimens.

On the left side, each of Types 1, 2 and 3 occupied about one-third of the total number of all the cases, whereas on the right side, most of the cases were Type 1. In rats, the left adrenal gland is located more caudally than the right one [2], yet the left caudal phrenic artery arises from the abdominal aorta more cranially than the right one [5, our unpublished data]. Therefore, the caudal adrenal artery may seek as its origin a nearby artery, such as the renal or abdominal aorta, rather than the caudal phrenic artery that is far on the left side from the caudal part of the adrenal gland. This may explain the occurrence of more frequent variations in the pattern of the adrenal arteries on the left side than on the right side.

In the present study, the total number of adrenal arteries varied from 3 to 12 on each side, but such variation has not been reported previously in rats [2, 4, 5, 8]. In cats [12] and dogs [1], the total number of adrenal arteries on each side is 15 and 20 to 30, respectively. Therefore, it is considered that there is a species difference in the number of adrenal arteries.

The anatomical variations, such as the differences in origin and number, and those between the left and right sides, of the adrenal artery demonstrated by the present investigation are highly informative for experimental treatment of the adrenal gland in rats.

**DISCUSSION**

The pattern of arteries supplying the adrenal gland was categorized into 4 types in the present study. Across all of these types, the cranial and middle adrenal arteries arose from the caudal phrenic artery on the left side and 35 of 36 cases (97%) on the right side.

The anatomical variations, such as the differences in origin and number, and those between the left and right sides, of the adrenal artery may seek as its origin a nearby artery, such as the renal or abdominal aorta, rather than the caudal phrenic artery that is far on the left side from the caudal part of the adrenal gland. This may explain the occurrence of more frequent variations in the pattern of the adrenal arteries on the left side than on the right side.

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