



Anatomical variations of the arterial branches from the rat iliac arteries

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ABSTRACT. Animal disease models contribute to a better understanding of the pathogenic mechanisms of human and animal diseases and help develop treatments for them. Ligation of the rat iliac arteries is performed to reproduce erectile dysfunction and peripheral arterial disease. Although knowledge of the ramification of branches from the rat iliac artery is important to perform such surgery, descriptions in previous studies are insufficient. Therefore, 17 male and 18 female Wistar rats were observed to elucidate the detailed ramification patterns of branches from the iliac arteries with the latex injection method. The iliac arteries branched off the umbilical, cranial gluteal, lateral and medial circumflex femoral, external pudendal, and caudal epigastric arteries, and the common trunk of the caudal gluteal and internal pudendal arteries. The branching pattern of the umbilical, cranial and caudal gluteal, and internal pudendal arteries varied greatly and was categorized as Types 1 to 3 based on the number of branching levels along the proximodistal axis of the iliac arteries. Based on the same criteria, the ramification patterns of the lateral and medial circumflex femoral arteries were also divided into Groups 1 and 2. The external pudendal and caudal epigastric arteries originated from the external iliac artery mainly as a common trunk or less frequently as independent arteries in this order. The detailed branching patterns of the rat iliac arteries elucidated in the present study are beneficial for the refinement of surgical procedures.

KEY WORDS: anatomical variation, angiology, iliac artery, macroscopic anatomy, rat

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Animal disease models are widely used to understand the pathogenic mechanisms of human and animal diseases and to establish more effective approaches to their treatment. One of the common animal models of disease is an “induced” model, where a pathological condition is experimentally reproduced with surgical treatment, such as ligation of an artery [8]. The rat is commonly used to create an induced disease model. For instance, models of erectile dysfunction [10, 15], peripheral arterial disease [14], and femoral neuropathy [13] are reproduced with ligation of the iliac arteries. To ligate the target artery precisely, knowledge of the branching patterns of the rat iliac arteries is one of the most important prerequisites. The rat iliac arteries mainly branch off the umbilical, cranial and caudal gluteal, external and internal pudendal, lateral and medial circumflex femoral, and caudal epigastric arteries, with frequent individual variations in the origin and order of branching [7, 9]. However, in prior studies, the description of the variations in the origin of each artery was not detailed and was inconsistent [7, 9]. For instance, the umbilical artery is reported to emerge from the common, external, or internal iliac artery [7] or arise only from the common iliac artery [9]. The origin of the cranial gluteal artery is described as the common or internal iliac artery [7], or only from the common iliac artery [9]. For the remaining branches, such as the lateral and medial circumflex femoral, external pudendal, and caudal epigastric arteries, there are only a few descriptions of the individual variations in the branching patterns [7, 9]. Thus, the description of the individual variations of the branching patterns of the rat iliac arteries is insufficient. Moreover, the combination of each variation in each individual has not yet been studied in the rat [7, 9] or in other mammals.

Therefore, the aim of this study was to observe and document the detailed anatomical variations in the ramification patterns of arterial branching from the rat iliac arteries.

MATERIALS AND METHODS

All experimental procedures were approved by the Research Ethics Committee for Animal Experimentation of the Tokyo

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University of Agriculture and Technology (No. 27-17).

The iliac arteries and their branches were dissected out and observed in 17 male and 18 female Wistar rats (180–300 g, purchased from Tokyo Laboratory Animals Science, Tokyo, Japan), all of which were also used in our previous study [11]. In brief, all rats were euthanized by intraperitoneal injection of sodium pentobarbital (60 mg/kg) and perfused transcardially with saline followed by 10% formalin. For better visualization of the iliac arteries, 1 ml of latex (Neoprene latex 601A or 842A, Showa Denko, Kawasaki, Japan) colored with red acrylic paint (Acryl Gouache, Turner Colour Works Ltd., Osaka, Japan) was injected through a catheter inserted into the thoracic aorta. Before observation, all rats were fixed for more than 7 days with 10% formalin and dissected under the surgical microscope (L-0950SDP, Inami & Co., Ltd., Tokyo, Japan). Photographs of the dissected arteries were taken with a digital camera (Nikon D5500, Nikon Corp., Tokyo, Japan). The contrast and resolution of the images captured were adjusted with Adobe Photoshop (Adobe Systems, San Jose, CA, U.S.A.), and schematic drawings were prepared with Adobe Illustrator (Adobe Systems).

RESULTS

In all rats examined, the common iliac artery arose as the bifurcation of the abdominal aorta and divided into the external and internal iliac arteries. The rat iliac arteries branched off the umbilical, cranial gluteal, lateral and medial circumflex femoral, external pudendal, caudal epigastric arteries, and the common trunk of the caudal gluteal/internal pudendal arteries (Fig. 1). The origin of these arteries varied frequently in each specimen, and the branching patterns of these arteries that issued from the iliac arteries were remarkably complicated. Therefore, first, the branching patterns were categorized into 3 major types based on the origin of the umbilical and cranial gluteal arteries, and the common trunk of the caudal gluteal/internal pudendal arteries. Then, the ramification patterns of the lateral and medial circumflex femoral, and, finally, the patterns of the external pudendal and caudal epigastric arteries were described. In the present study, there was no obvious sex difference in the ramification patterns of these arteries. Therefore, the categorization was conducted regardless of sex.

Patterns of iliac arterial branching to the umbilical artery, cranial and caudal gluteal arteries, and the internal pudendal artery

The branching patterns of the umbilical, cranial and caudal gluteal, and internal pudendal arteries were categorized into 3 major types based on the number of their branching levels along the proximodistal axis of the common, external, and internal iliac arteries (Fig. 1). Types 1, 2, and 3 had 1, 2, and 3 branching levels, respectively (Fig. 1).

Type 1

Type 1 included 2 of 35 halves on the right (6%) and 1 of 35 halves on the left (3%), and consisted of 2 further branching patterns (Figs. 1A_{1,2} and 2). In 1 case each on the right and left sides (3%), the umbilical artery arose independently, and the cranial gluteal artery and caudal gluteal/internal pudendal arteries emerged as a common trunk (Fig. 2A). The umbilical artery, cranial gluteal artery, and the common trunk of the caudal gluteal/internal pudendal arteries arose separately from the same branching level in the remaining 1 case on the right side (3%) (Fig. 2B).

Type 2

Type 2 included 16 of 35 halves on the right (46%) and 6 of 35 halves on the left (17%) (Figs. 1B_{1,2} and 3), and it was subdivided into Types 2a to 2e based on the order of branching (Fig. 3A, 3B_{1,2}, 3C₁₋₃, 3D, and 3E_{1,2}). Types 2a to 2e were categorized according to the extent of the distribution area of the artery that arose at the most proximal branching level from the iliac arteries. For instance, in Types 2a and 2b, the most proximal branch is the cranial gluteal artery, which has the narrowest distribution area (Fig. 3A and 3B_{1,2}), whereas in Type 2e, such a branch is the common trunk of the cranial gluteal artery and caudal gluteal/internal pudendal arteries, which has the broadest distribution area (Fig. 3E_{1,2}). Type 2a was distinguished from Type 2b by the absence of the umbilical artery.

In Type 2a, which was observed in 1 exceptionally rare case on the right side (3%) (Fig. 3A), the umbilical artery was lacking. The cranial gluteal artery arose from the common iliac artery, and the common trunk of the caudal gluteal/internal pudendal arteries emerged from the internal iliac artery.

Type 2b included 12 cases on the right (34%) and 1 case on the left (3%), and there were 2 further branching patterns of the umbilical and cranial gluteal arteries and the common trunk of the caudal gluteal/internal pudendal arteries. In 1 case on the left side (3%) (Fig. 3B₁), the cranial gluteal artery arose from the common iliac artery, and the umbilical artery and common trunk of the caudal gluteal/internal pudendal arteries originated from the internal iliac artery at the same branching level. In 12 cases on the right side (34%) (Fig. 3B₂), the cranial gluteal artery arose from the common iliac artery, and the umbilical artery and common trunk of the caudal gluteal/internal pudendal arteries arose from the distal end of the common iliac artery. This branching pattern (Fig. 3B₂) was the most frequent on the right side in the present study.

In Type 2c, which was seen in 3 halves (9%) only on the left side, there were 3 further branching patterns (Fig. 3C₁₋₃). In 1 case (3%) (Fig. 3C₁), the umbilical artery emerged from the distal end of the common iliac artery, and the cranial gluteal artery and common trunk of the caudal gluteal/internal pudendal arteries arose from the internal iliac artery at the same branching level. In 1 case (3%) (Fig. 3C₂), the umbilical artery arose from the common iliac artery, and the cranial gluteal artery and common trunk of the caudal gluteal/internal pudendal arteries arose from the distal end of the common iliac artery. The umbilical artery arose from

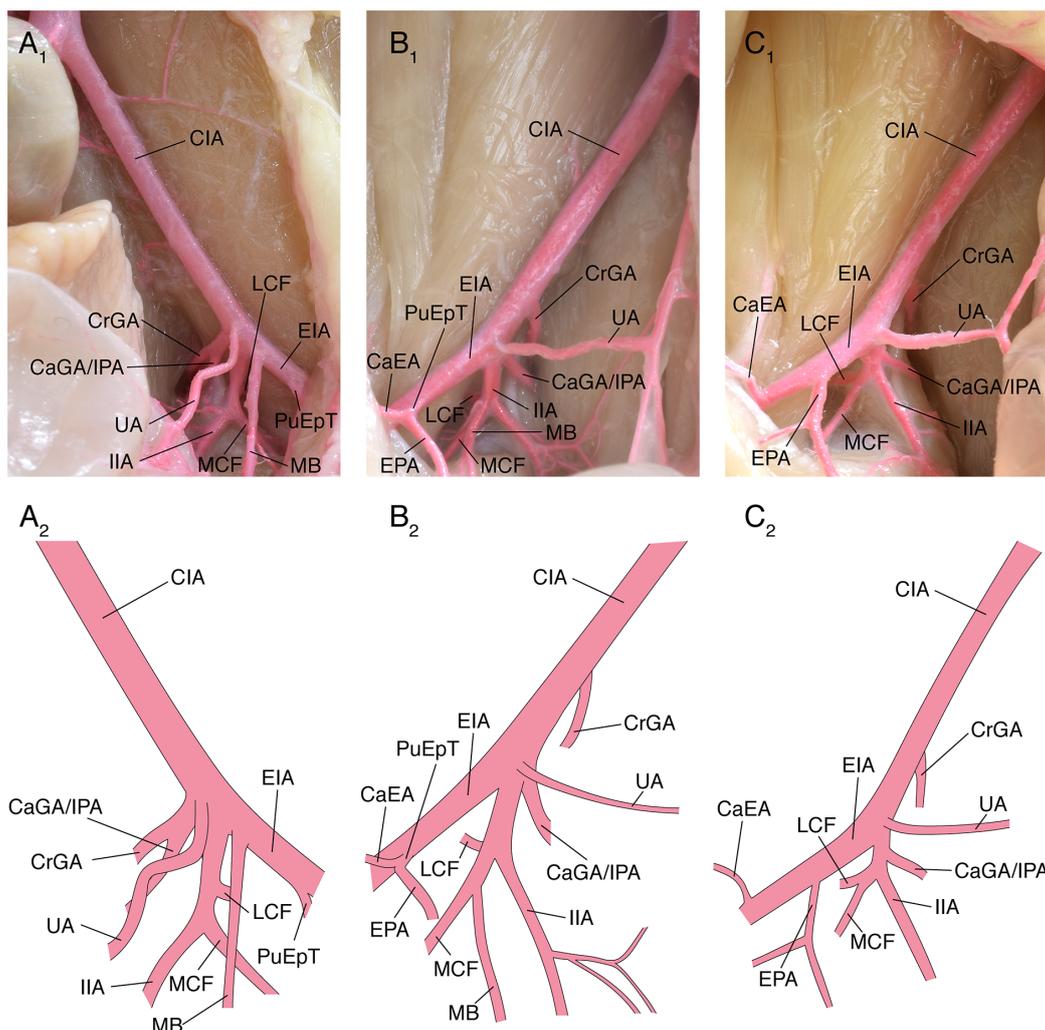


Fig. 1. Photographs and schematic drawings showing the patterns of arterial branching from the rat iliac arteries in the ventral view. A, B, and C show Types 1, 2, and 3, respectively, for the branching patterns of the umbilical, cranial and caudal gluteal, and internal pudendal arteries. A₁: The umbilical artery and the common trunk of the cranial and caudal gluteal and internal pudendal arteries arise from the common iliac artery at the same branching level. The photograph also shows that the lateral and medial circumflex femoral arteries emerge from the internal iliac artery in this order, and the pudendoepigastric trunk arises from the external iliac artery. A₂: Schematic drawing of A₁. B₁: Type 2 where the cranial gluteal artery emerges from the common iliac artery, and the umbilical artery and the common trunk of the caudal gluteal and internal pudendal arteries originate from the distal end of the common iliac artery. The photograph also shows that the lateral and medial circumflex femoral arteries originate from the internal iliac artery at the same branching level, and the pudendoepigastric trunk arises from the external iliac artery. B₂: Schematic drawing of B₁. C₁: Type 3 where the cranial gluteal artery arises from the common iliac artery, the umbilical artery emerges from the distal end of the common iliac artery, and the common trunk of the caudal gluteal and internal pudendal arteries originates from the internal iliac artery. The photograph also shows that the common trunk of the lateral and medial circumflex femoral arteries arises from the internal iliac artery, and the external pudendal and caudal epigastric arteries emerge independently from the external iliac artery in this order. Abbreviations used in this figure and Figs. 2–6: CaEA, caudal epigastric artery; CaGA/IPA, common trunk of the caudal gluteal/internal pudendal arteries; CIA, common iliac artery; CrGA, cranial gluteal artery; EIA, external iliac artery; EPA, external pudendal artery; IIA, internal iliac artery; LCF, lateral circumflex femoral artery; MB, muscular branch that distributes to the rectus abdominis muscle; MCF, medial circumflex femoral artery; PuEpT, pudendoepigastric trunk; and UA, umbilical artery.

the common iliac artery, and a common trunk of the cranial gluteal artery and the caudal gluteal/internal pudendal arteries arose from the distal end of the common iliac artery in the remaining 1 case (3%) (Fig. 3C₃).

Type 2d included 1 case on the left side (3%) (Fig. 3D), where the umbilical and cranial gluteal arteries arose from the distal end of the common iliac artery, and the common trunk of the caudal gluteal/internal pudendal arteries emerged from the internal iliac artery.

Type 2e included 3 cases on the right (9%) and 1 case on the left (3%), and 2 further branching patterns were observed. In 3 cases on the right (9%), the common trunk of the cranial gluteal artery and caudal gluteal/internal pudendal arteries arose from the common iliac artery, and the umbilical artery emerged from the distal end of the common iliac artery (Fig. 3E₁). In 1 case on the

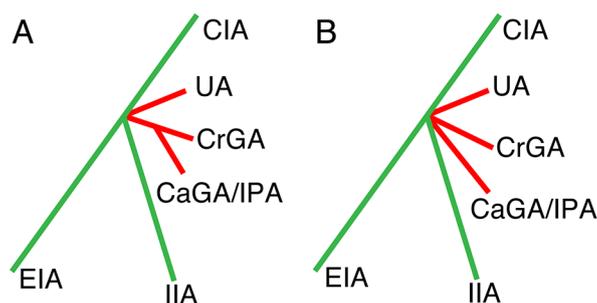


Fig. 2. Schematic drawings of the branching patterns of the umbilical, gluteal, and internal pudendal arteries that are categorized as Type 1 in the ventral view. A is present on both sides. B is only on the right side. In this figure and Figs. 3–6, the drawings depicted on the right side are the branching patterns observed on the right side only or both sides, and those depicted on the left side are the patterns observed only on the left side. The lateral and medial circumflex femoral, external pudendal, and caudal epigastric arteries are not illustrated in this figure and Figs. 3 and 4. In this figure and Figs. 3 and 4, the common, external, and internal iliac arteries are depicted in green, and the umbilical, gluteal, and internal pudendal arteries are depicted in red.

left (3%) (Fig. 3E₂), the branching pattern was the same as the former case (Fig. 3E₁), except that the origin of the umbilical artery was displaced to a more proximal level of the common iliac artery.

Type 3

Type 3 included 17 of 35 halves on the right (49%) and 28 of 35 halves on the left (80%) (Figs. 1C_{1,2} and 4) and was subdivided into Types 3a to 3c based on the same criteria as in Type 2 (Fig. 4A–C). The most proximal branch was the cranial gluteal artery in Type 3a (Fig. 4A). In Type 3c (Fig. 4C), the origin of the umbilical artery is closer to the bifurcation of the internal/external iliac artery than that of the cranial gluteal artery; therefore, the umbilical artery was regarded as the most proximal branch in this type.

Type 3a included 15 halves on the right (43%) and 23 halves on the left (66%), and there were 4 further branching patterns. In 11 cases on the right (31%) and 13 cases on the left (37%) (Fig. 4A₁), the cranial gluteal artery arose from the common iliac artery, and the umbilical artery emerged from the distal end of the common iliac artery. The common trunk of the caudal gluteal/internal pudendal arteries originated from the internal iliac artery. This branching pattern (Fig. 4A₁) was the most frequent on the left side in the present study. In 1 case on the right (3%) and 9 cases on the left (26%) (Fig. 4A₂), the branching pattern was the same as the former case (Fig. 4A₁), except that the umbilical artery originated at a more proximal level of the common iliac artery distal to the origin of the cranial gluteal artery (Fig. 4A₂). In 1 case each on the right and left sides (3%) (Fig. 4A₃), the origin of the common trunk of the caudal gluteal/internal pudendal arteries was displaced to the distal end of the common iliac artery. In the remaining 2 cases on the right side (6%) (Fig. 4A₄), the cranial gluteal artery and common trunk of the caudal gluteal/internal pudendal arteries arose from the common iliac artery in this order, and, finally, the umbilical artery emerged from the distal end of the common iliac artery.

Type 3b included 1 case on the right (3%) and 5 cases on the left (14%), and contained 3 further branching patterns. In 1 case on the right side (3%) (Fig. 4B₁), the umbilical artery arose from the distal end of the common iliac artery, and the cranial gluteal artery and common trunk of the caudal gluteal/internal pudendal arteries arose from the internal iliac artery in this order. In 4 cases on the left side (11%) (Fig. 4B₂), the branching pattern was the same as the former case (Fig. 4B₁), except that the umbilical artery originated at a more proximal level of the common iliac artery (Fig. 4B₂). In the remaining 1 case on the left side (3%) (Fig. 4B₃), the umbilical and cranial gluteal arteries emerged from the common iliac artery in this order, and the common trunk of the caudal gluteal/internal pudendal arteries emerged from the internal iliac artery.

Type 3c was an exceptionally rare case on the right side (3%). The umbilical artery emerged from the external iliac artery, and the cranial gluteal artery and common trunk of the caudal gluteal/internal pudendal arteries arose from the internal iliac artery in this order (Fig. 4C).

Combination in each individual of the branching pattern of the umbilical artery, cranial and caudal gluteal arteries, and internal pudendal artery

The combinations of the branching patterns on the right and left sides are summarized in Table 1. In 9 of 35 specimens (26%), the branching pattern was Type 2b on the right and Type 3a on the left (Table 1), and in 8 cases (23%), the branching pattern was Type 3a on both sides, and in 3 cases (9%), Type 3a on the right and Type 2c on the left. In 2 cases each (6%), Type 2b on the right side and Type 3b on the left side, and Type 2e on the right side and Type 3a on the left side, respectively. In other cases, the combination of the branching pattern was different in each specimen (Table 1).

Patterns of iliac arterial branching to the lateral and medial circumflex femoral arteries

To distinguish the categorization of the branching pattern of the lateral and medial circumflex femoral arteries from that of the umbilical, gluteal, and internal pudendal arteries, the term “group” was used to categorize the branching pattern of the lateral and medial circumflex femoral arteries. The ramification pattern of the lateral and medial circumflex femoral arteries was divided into

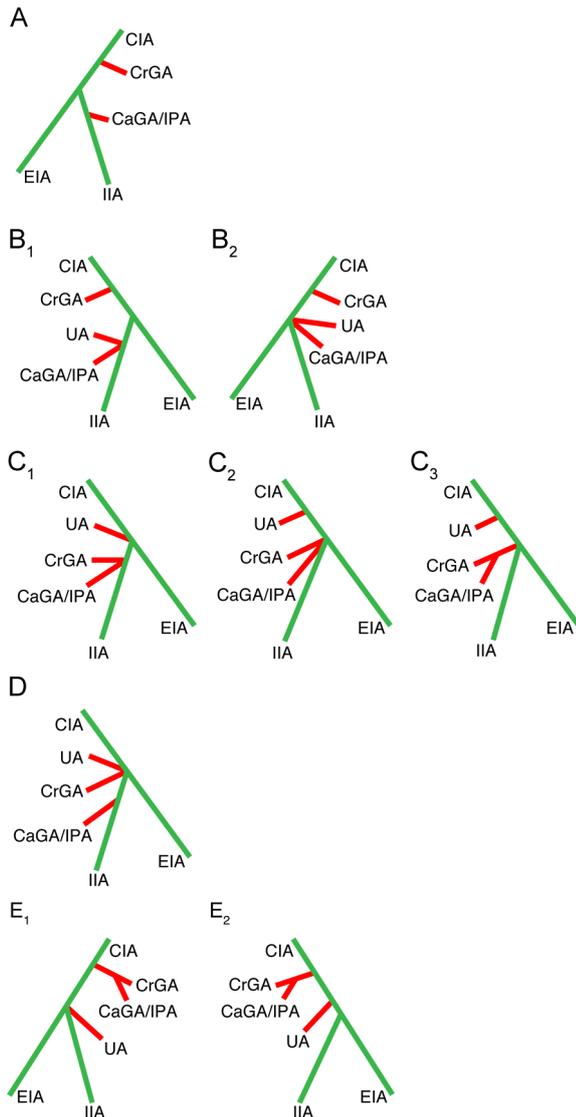


Fig. 3. Schematic drawings of the branching patterns of the umbilical, gluteal, and internal pudendal arteries that are categorized as Types 2a to 2e in the ventral view. A: Type 2a. B₁ and B₂: Type 2b. C₁–C₃: Type 2c. D: Type 2d. E₁ and E₂: Type 2e. A, B₂, and E₁ are present only on the right side, and B₁, C₁–C₃, D, and E₂ are only on the left side.

2 major groups based on the number of branching levels, the same as in the categorization of the branching pattern of the umbilical, gluteal, and internal pudendal arteries. Groups 1 and 2 had 1 and 2 branching levels, respectively.

Group 1

Group 1 included 21 halves on the right (60%) and 12 halves on the left (34%) and consisted of 2 further branching patterns (Fig. 5A and 5B). The common trunk of the lateral and medial circumflex femoral arteries emerged from the internal iliac artery in 1 case on the right (3%) and 2 cases on the left (6%) (Figs. 1C_{1,2} and 5A). In 20 halves on the right (57%) and 10 halves on the left (29%) (Figs. 1B_{1,2} and 5B), the lateral and medial circumflex femoral arteries arose from the internal iliac artery at the same branching level. This branching pattern (Fig. 5B) was the most frequent on the right side in the present study.

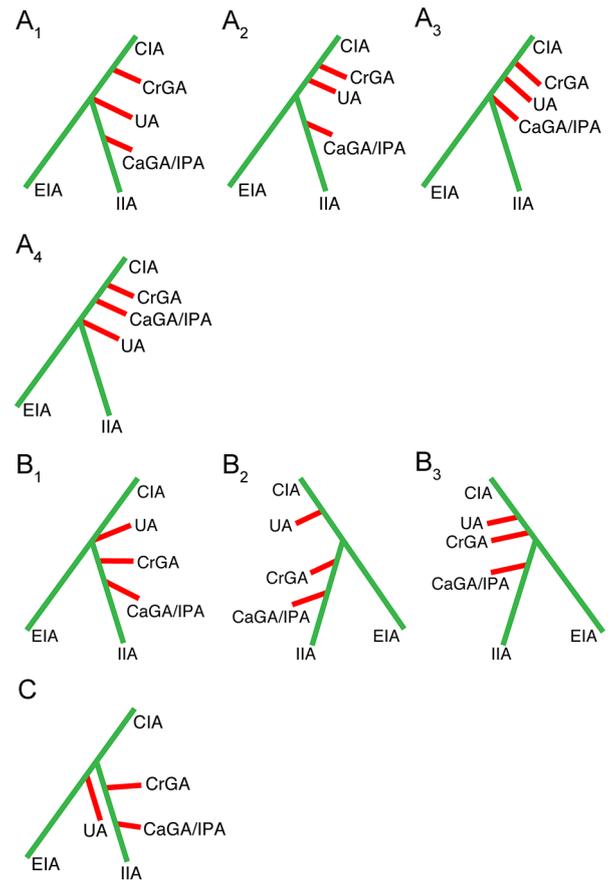


Fig. 4. Schematic drawings of the ventral view of the branching patterns of the umbilical, gluteal, and internal pudendal arteries that are categorized as Types 3a to 3c. A₁–A₄: Type 3a. B₁–B₃: Type 3b. C: Type 3c. A₄, B₁, and C are present only on the right side, B₂ and B₃ are only on the left side, and A₁–A₃ are present on both sides.

Table 1. Combinations of types of branching patterns between the right and left side

Type		Number of cases (%)
Right	Left	
2b	3a	9 (26)
3a	3a	8 (23)
3a	2c	3 (9)
2b	3b	2 (6)
2e	3a	2 (6)
1	3a	1 (3)
1	3b	1 (3)
2a	3a	1 (3)
2b	1	1 (3)
2e	3b	1 (3)
3a	2b	1 (3)
3a	2d	1 (3)
3a	2e	1 (3)
3a	3b	1 (3)
3b	3a	1 (3)
3c	3a	1 (3)

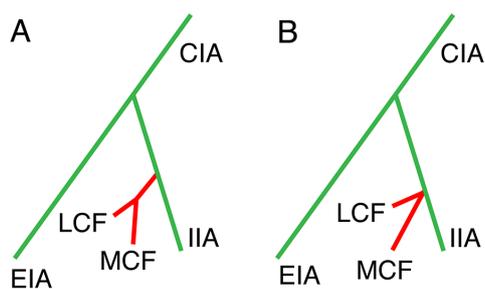


Fig. 5. Schematic drawings showing the branching pattern of the lateral and medial circumflex femoral arteries that are categorized as Group 1 in the ventral view. A and B are present on both sides. In this figure and Fig. 6, schemas illustrate the branching patterns of the common, external, and internal iliac arteries (depicted as green line), lateral and medial circumflex femoral arteries, and pudendoepigastric trunk (depicted as red line) only.

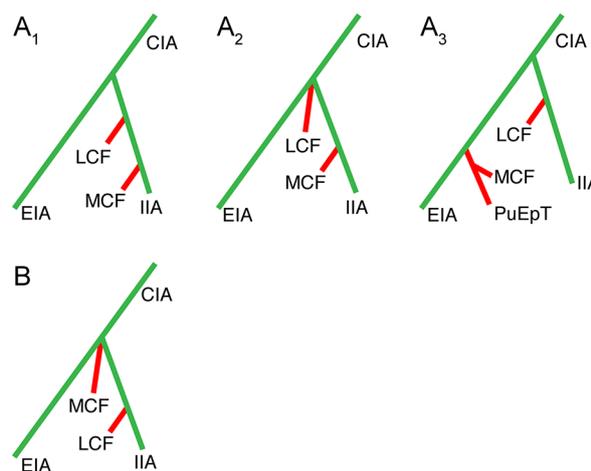


Fig. 6. Schematic drawings showing the ventral view of the branching pattern of the lateral and medial circumflex femoral arteries that are categorized as Group 2. A₁, A₂, and A₃: Group 2a. B: Group 2b. A₁, A₂ and B are present on both sides, and A₃ is present only on the right side.

Group 2

Group 2 included 14 halves on the right (40%) and 23 halves on the left (66%) and contained 4 further branching patterns (Fig. 6A_{1,2,3} and 6B). Group 2 was subdivided into Groups 2a and 2b based on the order of branching. For the subcategorization of Type 2 as described above, the extent of the distribution area of the most proximal branch from the iliac arteries was used as the criterion for subcategorization. However, for Group 2, the lateral and medial circumflex femoral arteries had a similar range of the distribution area. Therefore, we set the first criterion based on the first branching of the lateral circumflex femoral artery and the second one based on the first branching of the medial circumflex femoral artery.

Group 2a, where the 1st branch was the lateral circumflex femoral artery, included 13 halves on the right side (37%) and 22 halves on the left (63%) and contained 3 further branching patterns. In 11 cases on the right (31%) and 21 cases on the left (60%) (Figs. 1A_{1,2} and 6A₁), the lateral and medial circumflex femoral arteries arose from the internal iliac artery in this order. On the left side, this branching pattern (Fig. 6A₁) was the most frequent in the present study. In 1 case each on the right and left sides (3%), the lateral circumflex femoral artery emerged from the distal end of the common iliac artery, and the medial circumflex femoral artery originated from the internal iliac artery (Fig. 6A₂). In 1 exceptionally rare case on the right side (3%), the lateral circumflex femoral artery emerged from the internal iliac artery, and the medial circumflex femoral artery originated as a common trunk with the pudendoepigastric trunk (Fig. 6A₃).

In Group 2b (Fig. 6B), which was seen in 1 case each on the right and left sides (3%), the medial circumflex femoral artery arose from the distal end of the common iliac artery, and the lateral circumflex femoral artery emerged from the internal iliac artery. Table 2 summarizes the correlations of the ramification patterns between the lateral/medial circumflex femoral arteries and Types 1 to 3, which were the branching patterns of the umbilical, gluteal, and internal pudendal arteries. The most frequent combination was Group 1 and Type 3 on the right (12 of 35 halves, 34%) and Group 2a and Type 3 on the left (17 of 35 halves, 49%) (Table 2).

Patterns of iliac arterial branching to the external pudendal and caudal epigastric arteries

These 2 arteries arose from the external iliac artery as the pudendoepigastric trunk in 20 halves on the right (57%) and 31 halves on the left (89%) (Fig. 1A_{1,2} and 1B_{1,2}), and in 15 cases on the right (43%) and 4 cases on the left (11%), the external pudendal and caudal epigastric arteries arose independently from the external iliac artery in this order (Fig. 1C_{1,2}). These 2 arteries tended to originate separately from the external iliac artery in this order more on the right side than on the left side. Table 3 summarizes the correlations of the branching patterns between the external pudendal/caudal epigastric arteries and the branching type of the umbilical, gluteal, and internal pudendal arteries. In all types, the external pudendal and caudal epigastric arteries originated from the external iliac artery mainly as the pudendoepigastric trunk.

DISCUSSION

This is the first report to show the remarkable individual variations and their incidences in the ramification patterns of the arteries that issue from the iliac arteries in the rat. In prior studies [7, 9], the descriptions of such variations were not detailed. The individual variation in the branching pattern of the arteries from the rat iliac arteries was described separately, one by one, and there was no indication of the relationship between the individual variation in each branching pattern in each individual. In the

Table 2. Correlation between the number of cases of each group of iliac branching to the lateral and medial circumflex femoral arteries and each type*

		Groups		
		1	2a	2b
Type 1*	Right	0	2	0
	Left	0	1	0
Type 2*	Right	9	6	1
	Left	2	4	0
Type 3*	Right	12	5	0
	Left	10	17	1
Total		33 (47%)	35 (50%)	2 (3%)

Asterisks show the types of branching patterns of the umbilical, gluteal, and internal pudendal arteries.

Table 3. Correlation between the number of cases of each pattern of iliac branching to the external pudendal and caudal epigastric arteries and each type*

		Pudendoepigastric trunk	Independent external pudendal and caudal epigastric arteries
		Type 1*	Right
	Left	1	0
Type 2*	Right	8	8
	Left	4	2
Type 3*	Right	10	7
	Left	26	2
Total		51 (73%)	19 (27%)

Asterisks show the types of branching patterns of the umbilical, gluteal, and internal pudendal arteries.

present study, the pattern of rat iliac branching to the umbilical artery, cranial gluteal artery, and the common trunk of the caudal gluteal/internal pudendal arteries was categorized into 3 major types. In humans, the ramification pattern of the branches from the internal iliac artery is categorized based on the origin of the umbilical, cranial (=superior) and caudal (=inferior) gluteal, and internal pudendal arteries [1], all of which are thought to be the principal branches of the internal iliac artery in humans [1, 18]. In other species including rats, the origin of the umbilical, cranial and caudal gluteal, and internal pudendal arteries differs between species.

In the present study, the umbilical artery originated from the common iliac (97%), external iliac (1%), or internal iliac arteries (1%), and was absent in 1 case (1%). In prior studies in the rat [7, 9], this artery arose from the common, external, or internal iliac arteries [7], or only from the common iliac artery [9]. In other rodents, the branching pattern of the umbilical artery differs between species. For instance, in the guinea pig [16] and Persian squirrel [2], the umbilical artery arises from the internal iliac artery. In the ground squirrel [5], the umbilical artery emerges from the internal pudendal artery that arises from the external iliac artery. Moreover, in the rabbit, which is phylogenetically closely related to rodents, the umbilical artery emerges from the internal iliac artery [4]. In humans, it is considered that the umbilical artery is the terminal branch [1] or one of the branches of the internal iliac artery in all cases [18].

In the present study, the cranial gluteal artery emerged independently from the common iliac artery (80%) or internal iliac artery (10%), or alternatively from the common iliac artery as a common trunk with the caudal gluteal/internal pudendal arteries in 7 of 70 halves (10%). In the rat, Greene [7] reported that the cranial gluteal artery emerged from the common or internal iliac arteries, while Hebel and Stromberg [9] reported that the cranial gluteal artery arose only from the common iliac artery, and occasionally arose as a common trunk with the caudal gluteal/internal pudendal arteries. In other rodent species, the branching pattern is different from that in rats. For example, the cranial gluteal artery emerges independently from the common iliac artery in mice [12], and it arises from the internal iliac artery in ground and Persian squirrels [2, 5]. However, in the guinea pig [6, 16], the artery that distributes to the gluteal muscles is referred to as the gluteal artery and originates from the internal iliac artery [6], or the internal pudendal artery, which is a branch from the internal iliac artery [16]. In the rabbit [3], the cranial gluteal artery arises from the internal iliac artery. Moreover, in humans, the cranial (=superior) gluteal arteries emerge independently from the internal iliac artery in 69.4% [1] or 80.8% [18] of cases, arise as a common trunk with the caudal (=inferior) gluteal artery in 23.1% [1] or 13.6% [18], arise as a common trunk with the caudal (=inferior) gluteal and internal pudendal arteries in 4.1% [1] or 5.4% [18], or originate as a common trunk with the internal pudendal artery in 0.8% [1] or 0.2% [18].

The caudal gluteal and internal pudendal arteries always arise as a common trunk in all rats examined. This common trunk arises from the common iliac artery in 36% of cases, and it originates from the internal iliac artery in 64% of cases. In prior studies [7, 9], the caudal gluteal artery was described as the branch from the internal pudendal artery, which emerges from the internal iliac artery, so that the cases with the internal pudendal artery arising from the common iliac artery have not been reported. In other rodents, the branching pattern is different from the rat. For instance, in mice [12], the caudal gluteal artery arises from the common or internal iliac arteries, and the internal pudendal artery is one of the terminal branches of the caudal gluteal artery. In ground and Persian squirrels [2, 5], the caudal gluteal and internal pudendal arteries arise independently from the internal iliac artery. In humans, the common trunk of the caudal (=inferior) gluteal and internal pudendal arteries emerges from the internal iliac artery in 51.2% [1] or 58% [18]. In 19% [1] and 23% [18], the caudal (=inferior) gluteal artery originates independently from the internal iliac artery, and the internal pudendal artery emerges separately from the internal iliac artery in 41.3% [1] or 36.4% [18].

In the present study, the most frequent branching pattern was Type 2b on the right side (12 of 35 halves, 34%) and Type 3a on the left side (13 of 35 halves, 37%). This may be attributable to the right and left difference in the embryological development of the umbilical artery, which plays an important role in determining the branching pattern of the internal iliac artery [1]. In the rat, the left umbilical artery begins to regress earlier than the right one, and only one persistent umbilical artery plays a prominent role in the placental circulation at the end stage of the development [9]. This may affect the difference between the branching pattern on the right and left sides.

The rat iliac arteries also branch off the lateral and medial circumflex femoral, caudal epigastric, and external pudendal arteries. The descriptions of the individual variations in the branching patterns of these arteries were insufficient in prior studies in the rat [7, 9], so this is the first study that elucidated the frequent individual variation and its incidence in these arteries in the rat.

There were 6 branching patterns of the lateral and medial circumflex femoral arteries observed in the present study, and they were divided into 2 major groups based on the number of branching levels. In prior studies in the rat, the lateral and medial circumflex femoral arteries emerged from the internal iliac artery in this order [7, 9] or arose as a common trunk [7]. In many species, such as the mouse [12], guinea pig [6, 16], ground squirrel [5], and rabbit [4, 17], it has been reported that the origin of the lateral circumflex femoral artery was the femoral artery. Therefore, it is considered that the origin of the lateral circumflex femoral artery from the internal or external iliac artery is exceptional, as observed in the present rat and previous Persian squirrel studies [2]. The origin of the medial circumflex femoral artery is the femoral artery in the Persian squirrel [2] and the femoral [17] or internal iliac artery in the rabbit [4].

The external pudendal and caudal epigastric arteries originated from the external iliac artery as the pudendoepigastric trunk (80%) or separately (20%) in the present study. Greene [7] reported the same variation in the branching pattern of these arteries. However, Hebel and Stromberg [9] reported that these arteries always arose as the pudendoepigastric trunk. In other rodents, such as the guinea pig [6, 16], mouse [12], and squirrel [2, 5], the pudendoepigastric trunk arises from the external iliac artery in all cases.

In the present study, the arteries that issued from the rat iliac arteries and their branches were dissected out in 70 halves belonging to 35 rats, and many variations that have not been reported in prior studies were observed [7, 9]. It has been reported in the rat that individual variation in the ramification pattern of the arteries branched from the iliac arteries occurs at a very high frequency [7, 9], and Greene [7] also reported that the 12 specimens that she had observed were not enough to discuss the average of such wide variation. Therefore, the difference between the present and prior studies may be explained by the insufficient number of samples in the prior studies.

In the present study, the branching pattern of the umbilical, cranial gluteal, caudal gluteal, and internal pudendal arteries were categorized into 3 major types based on the number of the branching level along the proximo-distal axis of the iliac arteries, and Types 2 and 3 were divided further into subtypes based on the extent of the supplying area of the most proximal branch. These categorizations are useful for adequate and selective arterial ligation to reproduce a particular disease model, such as erectile dysfunction [10, 15], peripheral arterial disease [14], and femoral neuropathy [13]. The findings of the present study greatly contribute to better understanding of the pathogenic mechanism of these diseases.

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