The Journal of Veterinary Medical Science

NOTE

Anatomy

Various branching patterns of the aortic arch in the Siberian roe deer (*Capreolus pygargus*, Pallas, 1771) on Jeju Island

Jeoung-Ha SIM[1], Sangyun SHIN[2], Won Kyu KIM[3], Hong-Shik OH[4], In-Shik KIM[2] and Dongchoon AHN[2]*

[1]Department of Nursing, College of Medical Science, Jeonju University, 303 Cheonjam-ro, Wansan-gu, Jeonju-si, Jeollabuk-do 55069, Republic of Korea
[2]Bio-safety Research Institute and College of Veterinary Medicine, Chonbuk National University, 79 Gobong-ro, Iksan-si, Jeollabuk-do 54596, Republic of Korea
[3]Department of Anatomy and Cell Biology, College of Medicine, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, Republic of Korea
[4]Department of Science Education, College of Education, Jeju National University, 102 Jejudaehak-ro, Jeju-si, Jeju Special Self-Governing Province 63243, Republic of Korea

J. Vet. Med. Sci.
81(2): 160–164, 2019
doi: 10.1292/jvms.18-0520

Received: 29 August 2018
Accepted: 10 December 2018
Published online in J-STAGE: 19 December 2018

ABSTRACT. This study examined and compared the branching pattern of the aortic arch (AA) and its major branches in the Siberian roe deer (*Capreolus pygargus*) on Jeju Island (Jeju roe deer [JRD]) with those in the roe deer of the Korean peninsula (mainland roe deer [MRD]). Seven of the nine expected types was observed in the arterial silicone casts of 29 deer (10 males, 19 females). The JRD was identical to the MRD in that absence of the typical pattern; however, the main three pattern types differed between the two. This difference resulted from differences in the branching patterns of the right subclavian artery and costocervical trunk. In conclusion, the JRD has different type of AA from the MRD.

KEY WORDS: aortic arch, branching pattern, Jeju Island, Siberian roe deer

The aortic arch (AA) arises from the heart, curves left, and continues as the thoracic aorta. Each mammalian species has the typical branching pattern of the AA and its major arteries [11, 12, 22, 28]. The word *normal* or *typical* in anatomy can be applied with regard to the most frequent structure when a structure is present more than 50% from statistical standpoint [6]. In ruminants, the typical pattern shows that only the brachiocephalic trunk (BCT) branches from the AA. BCT branches off the three arteries; i.e., the left subclavian artery (LSB), bicarotid trunk (BC) and right subclavian artery (RSB) [7, 17, 22, 28]. *Cervidae* species may have a typical pattern, except for the Siberian roe deer. The AA of the pampas deer (*Ozotoceros bezoarticus*), the Korean water deer (*Hydropotes inermis argyropus*), the brown brocket deer (*Mazama gouazoubira*), and the axis deer (*Axis axis*) branches off the BCT only, similar to other ruminants [1, 2, 23]. The pattern of the BCT in pampas deer is the same as that in small domestic ruminants; i.e., the SB on both sides of the pampas deer branches off the costocervical trunk (CCT), the internal thoracic artery (IT), and the superficial cervical artery (SC) in order. The BC divides into the left and right common carotid arteries (CCs). However, the BC is absent in the axis deer, the brown brocket deer, and the Korean water deer. In addition, the CCT arises before, simultaneously with, or from the SB in these three deer species. Recently, we reported that the Siberian roe deer (*Capreolus pygargus*, Pallas, 1771) on the Korean peninsula has no typical AA pattern, unlike the above-mentioned deer [26].

The Siberian roe deer ranges from the eastern regions of Europe, including the Volga area and the Ural Mountains, to the Far East [5, 8, 9]. In the Republic of Korea, the Siberian roe deer lives on the Korean peninsula and Jeju Island, and is considered a subspecies of Siberian roe deer, *Capreolus pygargus tianschanicus* Satunin, 1906 [5] or *Capreolus pygargus bedifordi* Thomas, 1908 [9]. However, several recent genetic and morphological studies have suggested that the roe deer on Jeju Island (Jeju roe deer [JRD]) is different from the roe deer on the Korean peninsula (mainland roe deer [MRD]) [13, 15, 16, 19–21]. The JRD has a smaller body and skull than the MRD [19–21] and is genetically more similar to populations in western Siberia than those in the Far East [13, 15, 16]. Therefore, the possibility that the JRD belongs to the subspecies *Capreolus pygargus ochracean*, not *C. p. tianschanicus*, has been suggested [13]. Moreover, the JRD has been proposed as a new subspecies [19, 21]. However, this opinion has not been accepted officially so far, likely due to insufficient morphometric data on structures other than the skull in JRD, and because the classification of deer subspecies has not been officially certified.

*Correspondence to: Ahn, D.: ahndc@jbnu.ac.kr

Table 1. Abbreviations of artery names

Artery	Abbreviation
Aortic arch	AA
Axillary artery	AX
Bicarotid trunk	BC
Brachiocephalic trunk	BCT
Common carotid artery	CC
Costocervical trunk	CCT
Deep cervical artery	DC
Dorsal scapular artery	DS
Highest intercostal artery	HI
Internal thoracic artery	IT
Left costocervical trunk	LCCT
Left subclavian artery	LSB
Right costocervical trunk	RCCT
Right subclavian artery	RSB
Subclavian artery	SB
Superficial cervical artery	SC
Vertebral artery	VT

Table 2. Frequencies (%) of branching patterns in the JRD

Subtype	I	II	III	Subtotal
A	–	13.8	6.9	20.7
B	3.5	20.7	24.1	48.3
C	–	3.4	27.6	31.0
Subtotal	3.5	37.9	58.6	100.0

This study, therefore, examined the branching patterns of the AA and its major branches in the JRD and compared them with those of the MRD and other ruminants.

Carcasses of 10 males and 19 females, stored at the Department of Science Education, College of Education, Jeju National University, with body weights ranging from 14.14 to 27.28 kg were dissected to take arterial casts. The ages of deer were estimated from the delivery season, the sequence of tooth eruption, and the abrasion state of premolar and molar teeth in the mandible [3, 5]. No approval is required from the Institutional Animal Care and Use Committee of Chonbuk National University for the use of dead deer.

Arterial casts and branching-pattern diagrams were produced as described previously [1, 2, 26]. Briefly, casts of arterial branches were created by retrograde infusion of commercial silicone (Lucky-Silicon, Wacker Chemical Korea Co., Ltd., Jincheon-Gun, Chungcheongbuk-do, Republic of Korea) into the abdominal aorta. As in a previous study on MRD [26], if one artery originated with another vessel at the same site or at a neighboring site not greater than its lumen diameter, we regarded them as being at the same level or branching site. If the length of the common lumen of two arteries formed over the diameter of one vessel, then it was considered a common trunk. Diagrams of branching patterns were prepared for comparison with those of the MRD and other ruminants. The abbreviations of artery names are listed in Table 1.

Similar to the MRD and other ruminants, only the BCT branched from the AA in all individuals. The branching site or level of the CCT varied: The CCT branched from the BCT directly before the SB, or from the SB, or at the same level or site as the SB on both sides. The classification of AA branching types was conducted as in a prior study of Siberian roe deer [26]. Briefly, classification as subtype A, B, or C was based on the branching site of the left costocervical trunk (LCCT), and that as subtype I, II, or III was based on the site of the right costocervical trunk (RCCT). In subtypes A and I, both CCTs arose from the BCT proximal to each SB. In subtypes B and II, the CCT and SB branched from the BCT at the same level or site. In subtypes C and III, the CCT branched from the SB. The types are thus described as combinations of these two kinds of subtypes. Of the nine types expected from a combination of the above criteria, a total of seven was observed, with some minor variations (Fig. 1, Table 2).

No type was detected in more than 50% of cases. Types CIII, BIII, and BII were the most frequently detected (27.6, 24.1, and 20.7%, respectively; Table 2).

Type CIII, which is similar to that in domestic ruminants, bovine and ovine, had a BCT from which first branched out the LSB, then ramified into the RSB and BC. The CCT, the IT and the SC were the first, second, and third branches, respectively, from the SB. The highest intercostal artery (HI), the dorsal scapular artery (DS), and the deep cervical artery (DC) branch out, in that order, from both CCTs. Then both CCTs continued as the vertebral artery (VT). Eight of twenty-nine (seven females, one male) deer were classified as this type. One variation on this type, a male, had a common trunk of the left HI and DS (Fig. 1).

Type BIII, which was not observed in the MRD, was similar to CIII except that the branching site or level of the LCCT ramifies at the same site or level as the LSB. Seven deer (four males, three females) were classified as this type. Two variations, both in males, had a common trunk of the HI and DS on both sides, and no BC and a double DC on the left side (Fig. 1).

Type BII is similar to BIII except that the branching site or level of the RCCT ramifies at the same site or level as the RSB. Six deer (five females, one male) were grouped into type BIII, with one variation in which a common trunk of the HI and DS was observed on both sides (Fig. 1).

Types AII and CIII were observed in four (13.8%) and two (6.9%) deer, respectively. Types BI and CII were each observed in one deer. However, the deer classified as type BI was a variation with no BC. Types AI and CI were not observed (Fig. 1, Table 2). Interestingly, variations in each type were observed in only male deer.

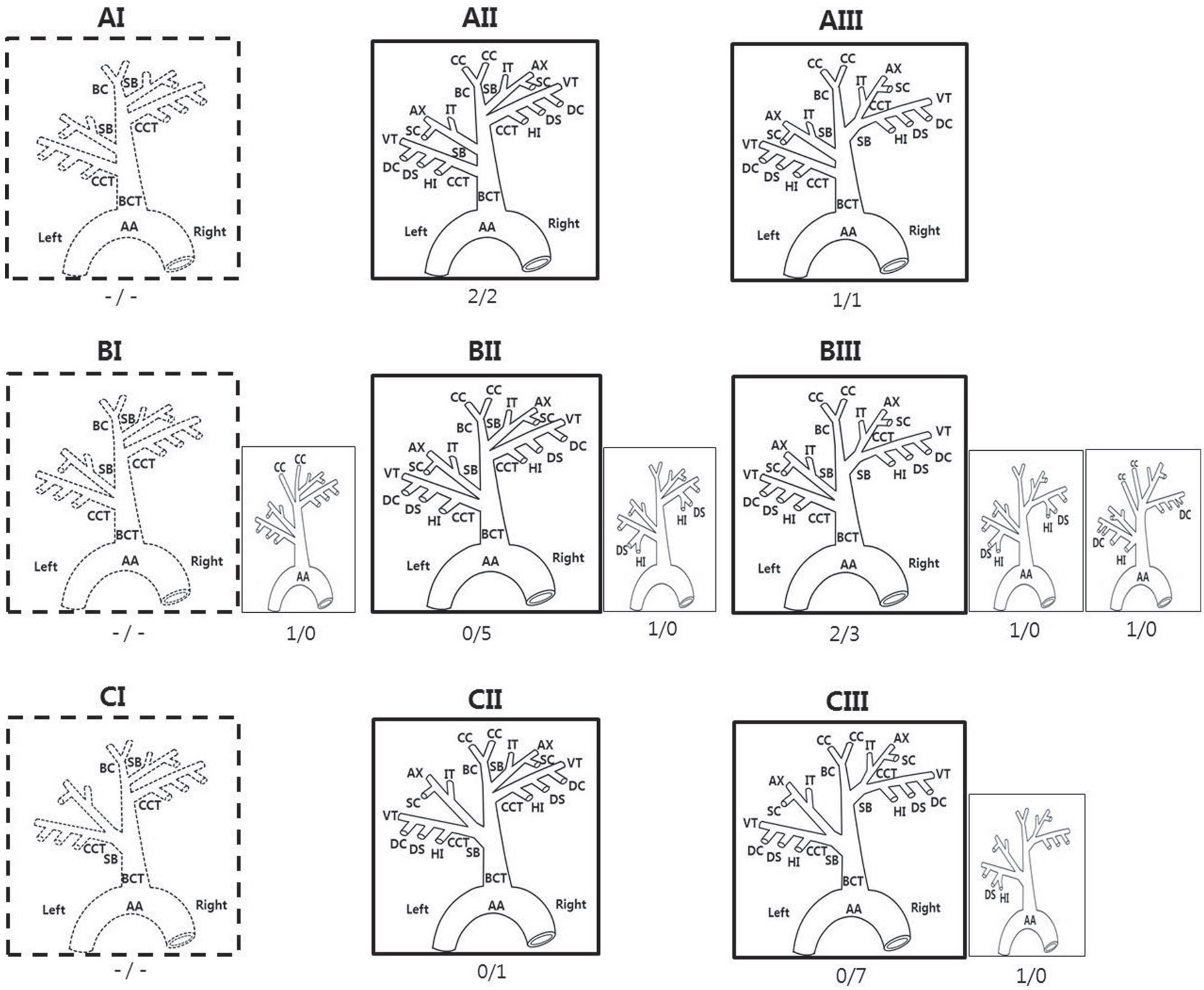

Fig. 1. Diagrams of branching patterns of the aortic arch of the JRD. Subtypes A, B, and C, and I, II, and III are based on the branching sites of the left and right costocervical trunks, respectively. Types are written as combinations of these subtypes. Larger diagrams enclosed in the thick lined boxes represent each type, and smaller ones in the thin lined boxes are its variants. Types AI, CI, and BI except for one variant, in the broken-lined box, were not observed. The numbers of males/females exhibiting each pattern are shown. Abbreviations are as indicated in Table 1.

Generally, in ruminants such as cattle [7], buffalo [4, 27], ovine [7], caprine [7, 14], and deer [1, 2, 23, 26], only the BCT originates from the AA. Common features of the branching patterns of the AA and its major arteries in ruminants are that the LSB and the RSB branch from the BCT as the first and last branches, respectively; and the HI, DS, and DC arise from the CCT in that order and the trunk continues as the VT. The differences are the presence or absence of the BC, the originating site of both CCTs from the BCT or SB, and the branching order of the IT and SC. The branching patterns of cattle [7], ovine and caprine [7, 14], pampas deer [23], and Siberian roe deer [26] have the BC adjacent to the LSB. Korean water deer [1, 2], buffalo [4, 27], brown brocket deer, and axis deer [23] lack a BC. Furthermore, the first branch of the BCT is the LCCT in the axis deer [23], and frequently in Siberian roe deer [26]. The BCT of axis deer bifurcates into the LSB and RSB adjacent to the LCCT, and four and five arteries branch from the left and right SB, respectively [23].

Most ruminants have the typical pattern with only minor variations. However, in this study, seven of the nine expected types were observed in the JRD, subtypes CIII, BIII, and BII were the most frequently detected (27.6, 24.1, and 20.7%), followed by AII (13.8%) and AIII (6.9%). The MRD showed a similar frequency in distribution of branching patterns and, also, various AA branching patterns due to differences in the originating site or level of the LCCT [26]. In anatomy, any structure or pattern that occurs at a frequency of >50% is termed normal or typical [6]; therefore, the Siberian roe deer has no typical branching pattern of the AA and its major arteries.

Unlike the MRD, the major types in the JRD were the CIII, BIII, and BII. In other words, the JRD and the MRD differed in terms of the frequencies of subtypes I, II, and III. The frequencies of subtypes A, B, and C in the JRD and MRD were 20.7 and 37.1%, 48.3 and 37.1%, and 31.0 and 25.8%, respectively [26]. In contrast, the frequencies of subtypes I and III in the JRD and MRD were 3.5 and 74.3%, and 58.6 and 5.8%, respectively [26]. Subtypes I, II, and III are classified according to the branching pattern of the RCCT and RSB, so that the difference between the JRD and MRD likely resulted from differences in the branching pattern of the right rather than left arteries.

Morphological differences in the body configuration and skull of the JRD and MRD have been reported. The body weight, total length, height at shoulder, body girth, front and hind foot length, ear length and width, and neck length of the JRD are smaller than those of the MRD [21]. A craniometric study similarly showed that the JRD has a smaller skull than the MRD. Moreover, compared with three other subspecies of Siberian roe deer, the JRD clustered with *Capreolus pygargus melanotis*, whereas the MRD was ranked third in skull size and grouped with *Capreolus pygargus tianschanicus* [19]. Genetic differences have revealed that the JRD differs from the MRD in the sequence of mitochondrial cytochrome *b* and the mitochondrial DNA control region, and is similar to northwestern and northern populations of the Siberian roe deer, *Capreolus pygargus pygargus* [13, 15, 20]. Furthermore, JRD clustered as a new isolated population [13, 15, 16, 20], for which a new subspecies name, *Capreolus pygargus jejuensis*, has been proposed [19, 21]. In this context, differences in anatomical structure between the two populations are feasible. This is to our knowledge the first report that the morphology of blood vessels differs between the JRD and the MRD.

There is considerable morphological and genetic diversity among Siberian roe deer populations. Unlike other deer, it shows marked variation of the interparietal suture closure pattern [18], craniometrics parameters [9, 10, 25], B-chromosome number [5], the genetic characteristics of microsatellite loci [16], and the sequences of cytochrome *b* and mitochondrial DNA [13, 15, 20, 24, 29]. Indeed, this species shows mosaicism in that different numbers of B-chromosomes may occur in a single animal or in different animals from a single population, particularly in Far Eastern populations [5]. Intra-population diversity of blood-vessel patterns in Siberian roe deer has been reported previously [26].

Interestingly, 17.2% of the JRD (five males) and 20.0% of the MRD (three males and four females) were minor variants. Most of the minor variants in the JRD were in the branching pattern of three arteries from the CCT, and one in which the BC was absent. Also, types CIII and BII were found only in females. Therefore, the JRD, unlike the MRD, might show sexual dimorphism in the AA branching pattern. These deer show sexual dimorphism in body length; in the JRD, females are bigger than males, and *vice versa* in the MRD [21]. Therefore, sexual dimorphism in the AA branching pattern is feasible. However, larger-scale studies are required to confirm this.

Our results suggest that the JRD, like the MRD, has various BCT branching patterns that are different from those of domestic ruminants and other deer species. Moreover, the main AA branching patterns of the JRD were different from those of the MRD, supporting the view that these two groups of deer should be regarded as separate populations.

ACKNOWLEDGMENTS. This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science, and Technology (NRF-2013028138), Republic of Korea.

REFERENCES

1. Ahn, D. C., Kim, H. C., Tae, H. J., Kang, H. S., Kim, N. S., Park, S. Y. and Kim, I. S. 2008. Branching pattern of aortic arch in the Korean water deer. *J. Vet. Med. Sci.* **70**: 1051–1055. [Medline] [CrossRef]
2. Ahn, D. C., Tae, H. J., Park, B. Y., Sim, J. H., Kim, J. T. and Kim, I. S. 2011. Incomplete brachiocephalic trunk in a Korean water deer. *J. Vet. Clin.* **28**: 526–529.
3. Aitken, R. J. 1975. Cementum layers and tooth wear as criteria for ageing Roe deer (*Capreolus capreolus*). *J. Zool.* **175**: 15–28. [CrossRef]
4. Cortellini, L. M. F., Machado, M. R. F., de Oliveira, F. S., Miglino, M. A. and Artoni, S. M. B. 2000. Branches of the aortic arch of buffaloes. *Cienc. Rural* **30**: 445–448. [CrossRef]
5. Danilkin, A. 1996. Behavioural Ecology of Siberian and European Roe Deer, 1st ed., Chapman & Hall, London.
6. DiDio, L. J. A. 1975. Anatomical variation. pp. 15–18. *In*: Sisson and Grossman's The Anatomy of the Domestic Animals, 5th ed. (Getty, R. eds), W.B. Saunders Company, Philadelphia.
7. Ghoshal, N. G. 1975. Ruminant heart and arteries. pp. 960–1023. *In*: Sisson and Grossman's the Anatomy of the Domestic Animals, 5th ed. (Getty, R. eds), W.B. Saunders Company, Philadelphia.
8. Geist, V. 1998. Deer of the World. Their Evolution, Behavior, and Ecology, 1st ed., Stackpole Books, Mechanicsburg.
9. Groves, C. P. and Grubb, P. 1987. Relationships of living deer. pp. 21–59. *In*: Research Symposia of the National Zoological Park; Biology and Management of the Cervidae (Wemmer, C.M. eds), Smithsonian Institution, Washington, D.C.
10. Groves, C. P. and Grubb, P. 2011. Ungulate Taxonomy, 1st ed., The John Hopkins University Press, Baltimore.
11. Kardong, K. V. 2006. Vertebrates: Comparative Anatomy, Function, Evolution. 4th ed., McGraw Hill, New York.
12. Kent, G. C. and Carr, R. K. 2001. Comparative Anatomy of the Vertebrates, 9th ed., McGraw Hill, New York.
13. Koh, H. S. and Randi, E. 2001. Genetic distinction of roe deer (*Capreolus pygargus* Pallas) sampled in Korea. *Mamm. Biol.* **66**: 371–375.
14. Lee, H. S. and Lee, J. S. 1984. Anatomical studies on patterns of branches of aortic arch in Korean native goat. *Korean J. Vet. Res.* **24**: 1–7.
15. Lee, Y. S., Markov, N., Argunov, A., Voloshina, I., Bayarlkhagva, D., Kim, B. J., Min, M. S., Lee, H. and Kim, K. S. 2016. Genetic diversity and phylogeography of Siberian roe deer, *Caproulus pygargus*, in central and peripheral populations. *Ecol. Evol.* **6**: 7286–7297. [Medline] [CrossRef]
16. Lee, Y. S., Markov, N., Voloshina, I., Argunov, A., Bayarlkhagva, D., Oh, J. G., Park, Y. S., Min, M. S., Lee, H. and Kim, K. S. 2015. Genetic diversity and genetic structure of the Siberian roe deer (*Capreolus pygargus*) populations from Asia. *BMC Genet.* **16**: 100 [CrossRef]. [Medline]
17. McGeady, T. A., Quinn, P. J., FitzPatrick, E. S., Ryan, M. T. and Cahalan, S. 2006. Veterinary Embryology, 1st ed., Blackwell Publishing, Oxford.
18. Oh, J., Oh, H. S., Kimura, J. and Koyabu, D. 2017. Intraspecific variation of the interparietal suture closure in Siberian roe deer *Capreolus pygargus* from Jeju Island. *J. Vet. Med. Sci.* **79**: 2052–2056. [Medline] [CrossRef]

19. Park, Y. S., Cha, J. Y. and Kim, N. S. 2016. Taxonomic revision of variation in skull morphology of Siberian roe deer (*Capreolus pygargus*, Pallas, 1771) in South Korea. *Korean J. Environ. Ecol* **30**: 39–47. [CrossRef]
20. Park, Y. S., Kim, B. J., Lee, W. S., Kim, J. T., Kim, T. W. and Oh, H. S. 2014. Molecular phylogenetic status of Siberian roe deer (*Capreolus pygargus*) based on mitochondrial cytochrome *b* from Jeju Island in Korea. *Chin. Sci. Bull.* **59**: 4283–4288. [CrossRef]
21. Park, Y. S., Lee, W. S., Kim, J. T. and Oh, H. S. 2011. Morphological examination of the Siberian roe deer *Capreolus pygargus* in South Korea. *J. Anim. Vet. Adv.* **10**: 2874–2878.
22. Parsons, F. G. 1902. On the arrangement of the branches of the mammalian aortic arch. *J. Anat. Physiol.* **36**: 389–399. [Medline]
23. Pérez, W. and Erdoğan, S. 2014. Arterial thoracic vascularization in some deer species: pampas deer (*Ozotoceros bezoarticus*), brown brocket deer (*Mazama gouazoubira*) and axis deer (*Axis axis*). *Anat. Histol. Embryol.* **43**: 490–494. [Medline] [CrossRef]
24. Randi, E., Pierpaoli, M. and Danilkin, A. 1998. Mitochondrial DNA polymorphism in populations of Siberian and European roe deer (*Capreolus pygargus* and *C. capreolus*). *Heredity (Edinb)* **80**: 429–437. [Medline] [CrossRef]
25. Sheremetyeva, I. N. and Sheremetyev, I. S. 2008. Skull variation in the Siberian roe deer *Capreolus pygargus* from the Far East: A revision of the distribution of the subspecies. *Eur. J. Wildl. Res.* **54**: 557–569. [CrossRef]
26. Shin, S., Sim, J. H., Kim, J. T., Oh, H. S., Tae, H. J., Park, B. Y., Kim, I. S. and Ahn, D. 2018. Branching patterns of the aortic arch in the Siberian roe deer (*Capreolus pygargus* Pallas, 1771). *J. Vet. Med. Sci.* **80**: 128–132. [Medline] [CrossRef]
27. Singh, H., Saigal, R. P. and Roy, K. S. 1985. Comparative anatomical study on the truncus brachiocephalicus in buffalo and cattle. *Indian J. Anim. Sci.* **55**: 547–548.
28. Yoon, S. B. 1984. Anatomy of the Domestic Animals, 1st ed., Moon Woon Dang, Seoul (in Korean).
29. Zvychainaya, E. Y., Danilkin, A. A., Kholodova, M. V., Sipko, T. P. and Berber, A. P. 2011. Analysis of the variability of the control region and cytochrome *b* gene of mtDNA of *Capreolus pygargus* Pall. *Biol. Bull.* **38**: 434–439. [CrossRef]