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NOTE

Anatomy

Branching patterns of the aortic arch in the Siberian roe deer (*Capreolus pygargus* Pallas, 1771)

Sangyun SHIN[1)], Jeong-Ha SIM[2)], Jong-Teak KIM[3], Hong-Shik OH[4)], Hyun-Jin TAE[1)], Byung-Yong PARK[1)], In-Shik KIM[1)] and Dongchoon AHN[1)]*

[1)]Bio-safety Research Institute and College of Veterinary Medicine, Chonbuk National University, 79 Gobong-ro, Iksan-si, Jeollabuk-do 54596, Republic of Korea
[2)]Department of Nursing, College of Medical Science, Jeonju University, 303 Cheonjam-ro, Wansan-gu, Jeonju-si, Jeollabuk-do 55069, Republic of Korea
[3)]College of Veterinary Medicine, Kangwon National University, 1 Kangwondaehak-gil, Chuncheon-si, Gangwon-do 24341, Republic of Korea
[4)]Department of Science Education, College of Education, Jeju National University, 102 Jejudaehakno, Jeju-si, Jeju-do 63243, Republic of Korea

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ABSTRACT. This study examined the branching pattern of the aortic arch (AA) and its major branches in the Siberian roe deer (*Capreolus pygargus* Pallas, 1771) from South Korea. A total of eight of the nine expected types, based on the branching site and bilateral levels of the costocervical trunk (CCT) and subclavian artery (SB), were observed in the arterial silicone casts of 35 deer (16 males, 19 females). This deer has no typical type. The three most common types were present in 28.6, 25.7 and 20.0% of cases and resulted from different branching patterns of the left CCT and left SB. These results suggest that the Siberian roe deer in the Korean peninsula has various AA branching patterns, which differs from other ruminants.

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

One or more major arteries branch from the aortic arch (AA) with patterns that differ among mammal species [16, 17, 20, 24]. Most mammalian species have a typical AA branching pattern found in the majority of individuals and some typical variation in the minority [17, 20, 24]. In domestic ruminants, only the brachiocephalic trunk (BCT) generally originates from the AA [9, 24]. In these animals, the BCT branches off the left subclavian artery (LSB) and ends with the bicarotid trunk (BC), which is a common trunk of the left common carotid artery (LCC) and right common carotid artery (RCC), and the right subclavian artery (RSB). Bilaterally, the axillary artery (AX) continues from the subclavian artery (SB). However, buffalo [5, 23] and some domestic ruminants [9, 18] have no BC, and the BCT ends with the RCC and RSB after branching off the LCC.

To date, four reports have examined patterns of AA branching and its variation in deer [1, 2, 15, 21]. There is a general pattern in deer with certain variations by species. The pampas deer (*Ozotoceros bezoarticus*) has a pattern similar to that of domestic ruminants, such as bovines, ovines, and caprines, in that the BCT branches off three arteries (LSB, BC and RSB) and the costocervical trunk (CCT) branches off of the bilateral SB. However, the BC is absent in the Korean water deer (*Hydropotes inermis argyropus*), brown brocket deer (*Mazama gouazoubira*), and axis deer (*Axis axis*). The first distinctive branch of the BCT is the left costocervical trunk (LCCT) in axis deer; therefore, the number of arteries from the SB differs between the left and right sides.

There are two species of living roe deer: the Siberian roe deer (*Capreolus pygargus*, Pallas, 1771) and the European roe deer (*Capreolus capreolus*, Linnaeus, 1758) [6, 10, 11]. The roe deer found on the Korean peninsula is classified as the Siberian roe deer (*Capreolus pygargus* Pallas, 1771) [6, 10, 11]. There are no reports on the branching patterns of the AA in roe deer species. This study examined the branching patterns of the AA and its major branches in Siberian roe deer and compared them with those of other domestic ruminants and deer.

A total of 35 carcasses (16 males and 19 females) with body weights of 11.65–26.35 kg were donated over 13 years (2004–2016) by the "Wildlife Rescue Centers" in Jeonbuk and Kangwon-Do and the Kangwon Veterinary Service Laboratory. The ages of all deer were estimated from the delivery season, tooth eruption sequence, and number of premolar and molar teeth in the mandible [3, 6]. No approval is required from the Institutional Animal Care and Use Committee of Chonbuk National University to use the dead deer. Casts were made after dissection of the thoracic cage and retrograde infusion of commercial silicone

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

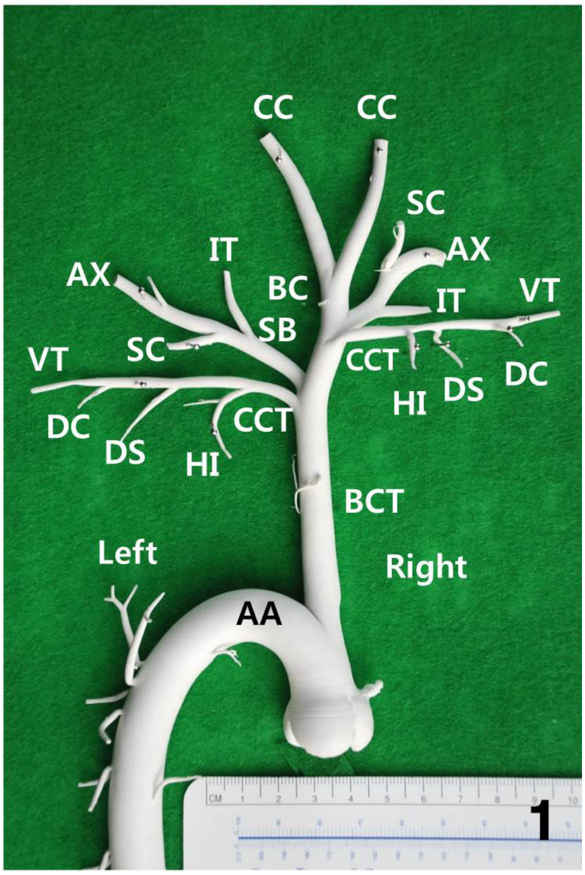

Fig. 1. A silicon cast showing the aortic arch and its major branches in the Siberian roe deer (*Capreolus pygargus*). Some arteries are fixed by pins. The costocervical trunk does not originate from the subclavian artery. AA, aortic arch; BCT, brachiocephalic trunk; SB, subclavian artery; BC, bicarotid trunk; CC, common carotid artery; CCT, costocervical trunk; IT, internal thoracic artery; SC, superficial cervical artery; AX, axillary artery; HI, highest intercostal artery; DS, dorsal scapular artery; DC, deep cervical artery; VT, vertebral artery. Dorsal view.

(Lucky-Silicon; Wacker Chemical Korea Co., Ltd., Jincheon-Gun, Chungcheongbuk-do, South Korea) into the abdominal aorta as described in a previous report [1] (Fig. 1). After observations of their anatomical characteristics, branching patterns were classified into different types and diagrams were prepared for comparison with other ruminants [1, 9, 18, 21]. If one artery originated with another vessel at the same site or a neighboring site not greater than its lumen diameter, we considered 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.

Only the BCT branched from the AA in all individuals. We found that the CCT branching site or level varied: The CCT branched from the BCT directly before the SB, from the SB, or at the same level or site as the SB bilaterally. This variation in branching order was based on a classification of AA branching types. If the LCCT branched first from the BCT, from the same site and/or level as the LSB, or from the LSB, it was classified as subtype A, B or C, respectively. If the right costocervical trunk (RCCT) branched from the BCT before the RSB, from the area shared with it, or as a branch of the RSB, it was classified as subtype I, II or III, respectively. Of the nine types expected from a combination of the above criteria, eight were observed with some minor variation (Fig. 2 and Table 2). The types were written as the left and right subtypes combined.

The combination type AI has a BCT from which the LCCT, LSB, and RCCT branch in that order. It then ramifies into the RSB and BC. The internal thoracic artery (IT) and superficial cervical artery (SC) are the first and second branches, respectively, from the SB. The highest intercostal artery (HI), dorsal scapular artery (DS), and deep cervical artery (DC) branch out in that order from the bilateral CCT. The bilateral CCT continue as the vertebral artery (VT). Nine (25.7%) of 35 deer were classified as this type. Three variations on this type are the branching sites of the HI and IT and the common trunk of the DS and DC (Fig. 2 and Table 2).

Type BI has a pattern similar to that of AI except that the branching site or level of LCCT ramifies at the same site or level as the LSB. Ten (28.6%) deer were classified as this type. Three variations were observed: branching of the IT only, branching of the IT and a common trunk of the HI and DS, and no BC (Fig. 2 and Table 2).

Type CI is similar to AI and BI except that the LCCT branches from the LSB. Seven (20.0%) deer were grouped into type CI with one variation in which the left HI directly branched from the BCT (Fig. 2 and Table 2).

Types AII and BII were each observed in three deer. Types CII, AIII, and CIII were each observed in one deer. Type BIII was not

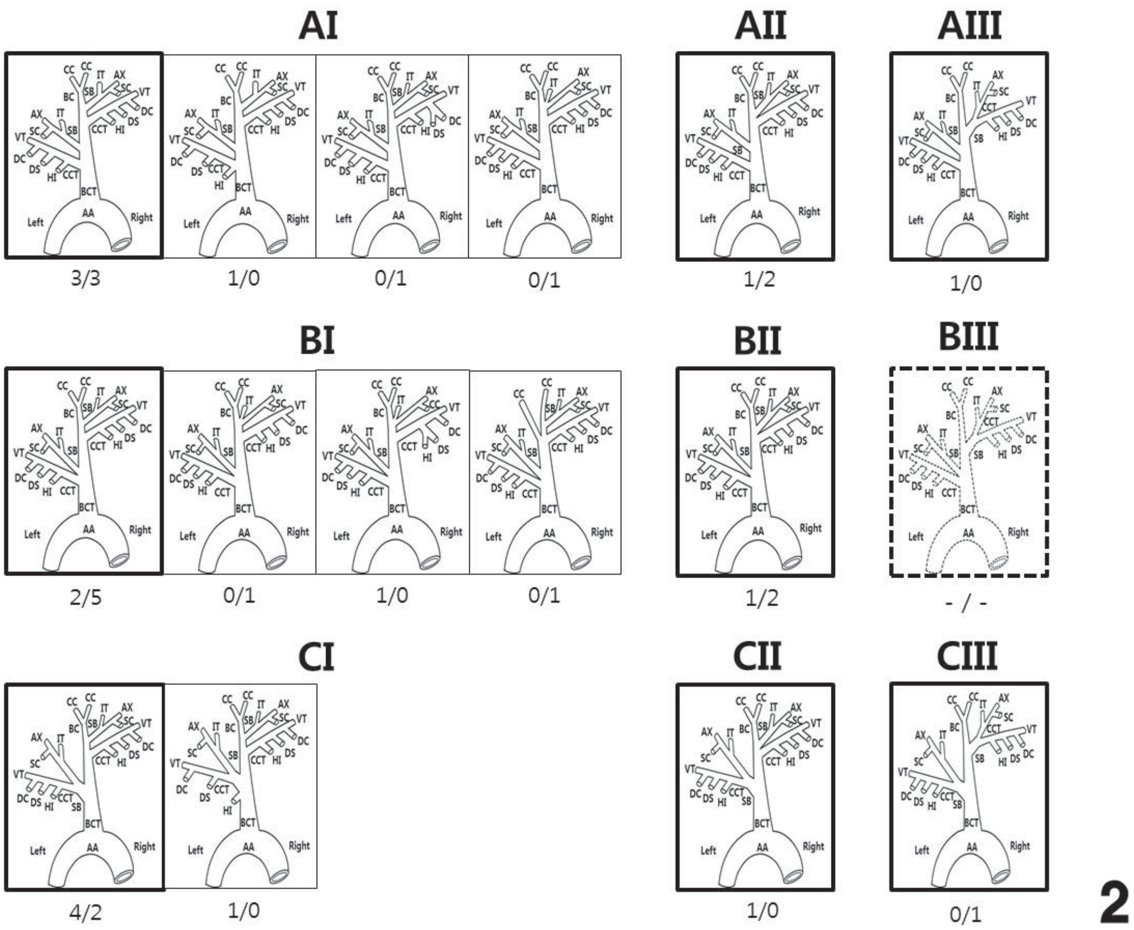

Fig. 2. Diagrams of branching patterns of the aortic arch of Siberian roe deer from the Korean peninsula. Subtypes A, B, and C, and I, II, and III are based on the branching sites of the left and right costocervical trunks, respectively. Types are written as combinations of these subtypes. Diagrams enclosed in the thick-lined boxes represent each type, while those in the thin-lined boxes are its variants. Type BIII, in the broken-lined box, was not observed. The numbers of males/females exhibiting each pattern are shown. Abbreviations are the same as indicated in Table 1.

Table 1. List of arteries and their abbreviations

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

Table 2. Aortic branching pattern types and appearance ratios (%) in Siberian roe deer

Subtype	I	II	III	Subtotal
A	25.7	8.5	2.9	37.1
B	28.6	8.5	-	37.1
C	20	2.9	2.9	25.8
Subtotal	74.3	19.9	5.8	100

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observed.

Typical AA branching patterns are observed in several mammalian species [9, 17, 20, 24], although there is variation within species and among individuals [17]. In ruminants, such as cattle [9, 19], sheep [9], goats [9] and pampas deer [21], generally only the BCT originates from the AA, giving off the LSB as the first branch and ramifying into the RSB and BC. The SB in type CIII in this study also branches off the CCT, IT, and SC in that order and the pattern is symmetrical on the left and right [9]. The AA and BC branching patterns and order of the IT and SC of the Siberian roe deer in this study are similar to those of other ruminants, but the BC differs from those of the buffalo [5, 23], Korean water deer [1], brown brocket deer [21] and axis deer [21], which do not have that artery. Siberian roe deer differ from the Korean native goat [18] in that the SC branches from the SB before the IT. The Siberian roe deer are similar to other ruminants in that the HI, DS and DC arise from the CCT and the trunk continues as the VT, although a few variations were observed.

The most striking difference in aortic arch branching patterns in Siberian roe deer compared to other ruminants is the variable branching sites and asymmetry of the CCT. No typical pattern was observed. The CCT branched off from the BCT as the first branch in 37.1% (subtype A), with the SB at the same site or level in 37.1% (subtype B), and ramified from the SB in 25.8% (subtype C) of cases. The word *normal* (typical) can be applied to anatomical structure when it is present >50% of the time [7]. We could not designate a typical pattern from the above results. On the right side, the CCT branching sites showed a typical pattern by branching directly from the BCT before the RSB in 74.3% of cases (subtype I). In 19.9 and 5.8% of cases, it branched at the same site or level from the BCT (subtype II) or as a branch of the SB (subtype III), respectively.

The number of expected types (combination of the six subtypes) was nine, but only eight types were found in this study. Instead of a typical type, there were three main types including BI (28.6%), AI (25.7%) and CI (20.0%), followed by AII (8.6%) and BII (8.6%). Because a typical subtype was present on the right but not left side, the diversity was due not to the RCCT but to the LCCT branching sites. SB branch asymmetry was observed in 71.4% of cases, whereas symmetry was only seen in 28.6%, which differs from domestic ruminants [9] and the brown brocket deer [21]. Patterns such as subtype I could be unique to Siberian roe deer since other studies on deer [1, 21] and domestic ruminants [9, 18] have not reported this pattern. We could not ascertain differences between males and females because the appearance ratios by sex in each type were too small. However, there tended to be more numbers of types BI and CI depending on sex. The appearance ratio of type BI including variations in female roe deer was almost twice that of males, while the male ratio of type CI was almost three times that of females.

In axis deer [21], the LCCT is the first branch of the BCT and does not come from the LSB, which is similar to the results of this study. The BCT terminates with a trifurcation into the RCCT, BC, and RSB in the Korean native goat [18] and Korean water deer [1], i.e., the RCCT does not branch from the SB. The Siberian roe deer may possess a different CCT branching site.

Modification of the embryonic aortic arches, ventral aorta, and dorsal aorta results in species-specific branching patterns of the AA. The BCT develops from remodeling of the aortic sac and its fusion with a portion of the left and right third and fourth aortic arch arteries. This trunk arises from the AA in definitive form. The LSB and RSB in mammals have different origins: The RSB originates from the fourth aortic arch proximally and the right dorsal aorta and right seventh dorsal intersegmental artery distally, whereas the LSB is formed from the left seventh dorsal intersegmental artery, which is fused into the aortic arch and migrates cranially during embryonic aortic arch artery remodeling [4, 13, 19]. The degree of LSB migration varies among species; in ruminants and horses, the LSB reaches the BCT and branches from it [14, 19]. In addition, the VT is formed from the longitudinal anastomoses of the first six dorsal intersegmental arteries in the cervical region and continues from the SB. In the thoracic region, the anastomoses after the seventh dorsal intersegmental artery form the IT, a branch of the SB [4, 13, 19]. The CCT is the artery that generally arises from the SB before the IT and ultimately continues as the VT in ruminants [1, 2, 9, 18, 24]. The proximal portion of the seventh dorsal intersegmental artery also contributes to CCT formation [4]. Because arterial migration occurs during the embryonic period, varying degrees of fusion could be the cause of the variation seen in this study. It could also be postulated that the CCT origination sites vary. Further studies should be performed to determine the genetic, physiological, and morphological factors involved in such variation.

Variations in the morphologic data of roe deer have been mainly reported in terms of skull size and shape and observed among subspecies or different populations that are far apart geographically. The Siberian roe deer inhabit a vast area, and several subspecies have been proposed by various researchers [6, 10–12, 22]. Skulls from the Ural-Ante-Baikal populations (*Capreolus pygargus pygargus*) are largest and those from central China (*Capreolus pygargus melanotis*) are smallest [6, 10]. Such differences have also been observed in European roe deer populations. These single-species populations showing different mandible and neurocranium sizes live in habitats at least 300 km apart [6, 8, 11]. However, in this study of aortic arch branching patterns, several morphological variants without typical patterns were observed in single populations on the Korean peninsula. The chromosome number among the roe deer also shows such variation. Unlike the European roe deer, whose populations all have the same chromosome number (2n=70), Siberian roe deer have a B chromosome numbering of 1–14 in addition to the normal chromosome set (2n=70 + 1–14) [6]. This accessory chromosome number appears to increase toward the eastern part of the range. There is mosaicism in that different numbers of B chromosomes that may occur in a single animal or in different animals from a single population, particularly in Far Eastern populations [6]. We cannot exclude the possibility that the diversity of the chromosome structure may have some influence on the aortic branching pattern. However, this study was limited to the Korean peninsula, so other studies should be performed to determine whether there is a geographic connection.

These results of our study suggest that Siberian roe deer have varied BCT branching patterns compared to domestic ruminants and other deer species.

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