



# Intraspecific variation of the interparietal suture closure in Siberian roe deer *Capreolus pygargus* from Jeju Island

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**ABSTRACT.** The sequence of cranial suture closure among cervids is reported to be generally species-specific and highly conservative within species. On the other hand, it is known that intraspecific variation often exists to some extent in other mammalian taxa. Here we studied the cranial suture closures of *Capreolus pygargus* from Jeju Island and compared it with other cervid species. We found that the timing of the interparietal suture closure is highly variable within *C. pygargus*. *Capreolus capreolus* similarly shows intraspecific variation of the interparietal suture closure, whereas other cervid species studied to date do not show any intraspecific variation in the sequence of cranial suture closure. Such high intraspecific variation of the interparietal suture may be a derived character for *Capreolus*.

**KEY WORDS:** cervids, growth, Korea, roe deer, skull

Siberian roe deer (*Capreolus pygargus*) is a cervid species distributed in southern Ural Mountains, northern and eastern Kazakhstan, Kyrgyzstan, southern Siberia, northern and central China, northern Mongolia and Korea [6]. The genus *Capreolus* is a sister genus of the water deer (*Hydropotes*) [14]. While closely related, these two genera are morphologically very different; male *Capreolus* has antlers but canines are absent while male *Hydropotes* lacks antlers and has well developed canines. Male *Muntiacus* also possesses canines [14, 16], but molecular evidence supports that genus *Hydropotes* is closer to genus *Capreolus*, rather than *Muntiacus* [14, 16]. Two species are currently recognized for *Capreolus*. The congener *C. capreolus* is distributed in Europe, western Russia, Ukraine, Turkey, Caucasus region, northwestern Syria, northern Iraq and northern Iran [6, 18].

*C. pygargus* has been differentiated from *C. capreolus* by the color of its head and metatarsal gland [4, 18].

Cranial sutures are fibrous tissues at the junction of bony parts in the skull [10, 17]. Generally, cranial suture lines disappear when growth of surrounding bones is completed [10, 17], and the timing of suture closure within the individual is different among each cranial suture [21]. It is known that closure timing of cranial sutures are often different between taxonomic groups [2, 15]. Many evidences suggest that variations of suture closure patterns strongly reflect phylogenetic history [2, 3, 5, 15, 22, 23].

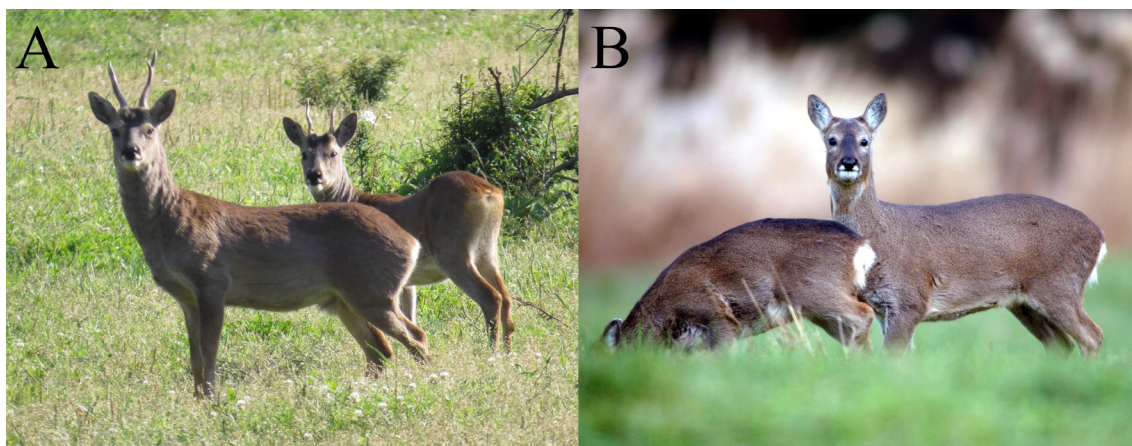
Here, we examined cranial suture closure pattern of Siberian roe deer from Jeju (Fig. 1) to describe its characteristics and difference from other cervid species. Siberian roe deer specimens studied here are all collected from Jeju island of Korea and stored at the College of Veterinary Medicine of Chonbuk National University (Iksan, South Korea), Department of Science Education of Jeju National University (Jeju, South Korea), Folklore and Natural History Museum (Jeju, South Korea), Halla Arboretum (Jeju, South Korea) and the Roe Deer Observation Center (Jeju, South Korea). Detailed information can be found in Appendix 1. Twenty-eight cranial sutures of 24 male and seven female Siberian roe deer skulls were observed. Observed cranial sutures are described in Table 1 and Fig. 2. Observed cranial sutures are comparable with our previous study on water deer [8] except for basisphenoid-parietal suture. This is because the basisphenoid and parietal bone do not contact in *C. pygargus*. Closure levels of each sutures were classified into five score categories; “0” for no closed suture, “1” for 1/4 closed suture, “2” for 1/2 closed suture, “3” for 3/4 closed suture, “4” for all closed suture [9]. Sutures which were impossible to evaluate the degree of closure due to fractures were marked as “-”. Then, ten males and five females whose all 28 cranial sutures were scorable were used to describe the suture closure sequence of this species. Scores “3” and “4” were considered as closed suture for this sequence description. The number of specimens with scores “3” or “4” was counted for each suture, and such numbers was used to determine the sequence of suture closure [15]. Furthermore, Pearson’s correlation coefficient between the sum of closure level scores and total cranial length [7] was computed by using SPSS version 24.0. The sum of closure level scores of each individual

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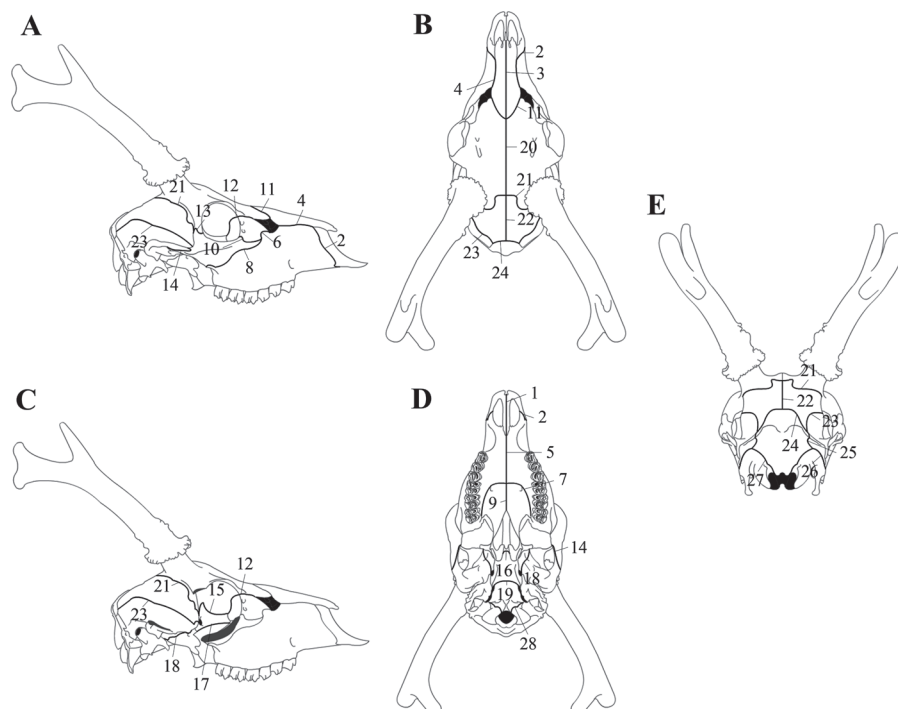
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**Fig. 1.** Siberian roe deer (*Capreolus pygargus*) males (A) and females (B) from Jeju island.

**Table 1.** List of cranial sutures of *Capreolus pygargus* used in this study

Number	Cranial Suture
1	Interincisive
2	Incisive-Maxillary
3	Internasal
4	Nasal-Maxillary
5	Intermaxillary
6	Maxillary-Lacrimal
7	Maxillary-Palatine
8	Maxillary-Zygomatic
9	Interpalatine
10	Lacrimal-Zygomatic
11	Nasal-Frontal
12	Lacrimal-Frontal
13	Zygomatic-Frontal
14	Zygomatic-Temporal
15	Presphenoid-Frontal
16	Presphenoid-Basisphenoid
17	Presphenoid-Palatine
18	Basisphenoid-Temporal
19	Basisphenoid-Basioccipital
20	Interfrontal
21	Frontal-Parietal
22	Interparietal
23	Parietal-Temporal
24	Parietal-Supraoccipital
25	Temporal-Supraoccipital
26	Temporal-Exoccipital
27	Supraoccipital-Exoccipital
28	Exoccipital-Basioccipital



**Fig. 2.** Cranial sutures of *Capreolus pygargus* used in this study. Names of each sutures are given in Table 1. Depiction of suture interdigitation is omitted in this figure (A: Lateral side of roe deer skull, B: Dorsal side of roe deer skull, C: Lateral side of roe deer skull without zygomatic arch, D: Ventral side of roe deer skull, E: Caudal side of roe deer skull).

was calculated as the total of all closure scores within the specimen. Twelve specimens whose cranial sutures and total cranial length were measurable were used for this analysis.

Kendall's tau-b statistic was calculated to assess the correspondence of suture closure pattern between two independent rankings [23]. SPSS version 24.0 was used for this analysis. This analysis was performed between males and females of *C. pygargus*. Suture closure data of *C. capreolus* acquired from Bärmann and Sánchez-Villagra [2] were also compared. Twenty-four cranial sutures common between this study and Bärmann and Sánchez-Villagra [2] were adopted. We also compared with *Hydropotes* which is the sister genus of *Capreolus*. The sequence of *H. inermis* was adopted from our previous study [9], but the basisphenoid-parietal suture was excluded from the analysis because it does not exist in *C. pygargus*. The basisphenoid-parietal suture did not show

**Table 2.** Cranial suture closure sequences of *Capreolus pygargus*, *Capreolus capreolus* and *Hydropotes inermis*

Order	<i>Capreolus pygargus</i>			<i>Capreolus capreolus</i>	<i>Hydropotes inermis</i>
	Male	Female	Overall		
1	Exoccipital-basioccipital	Exoccipital-basioccipital	Exoccipital-basioccipital	Interparietal	Exoccipital-basioccipital Interparietal
2	Supraoccipital-exoccipital Basisphenoid-basioccipital	Supraoccipital-exoccipital Basisphenoid-basioccipital Interparietal	Supraoccipital-exoccipital Basisphenoid-basioccipital	Exoccipital-basioccipital	Supraoccipital-exoccipital
3	Interparietal		Interparietal	Supraoccipital-exoccipital	Basisphenoid-basioccipital
4	Presphenoid-basisphenoid	Presphenoid-basisphenoid	Presphenoid-basisphenoid	Basisphenoid-basioccipital	Presphenoid-basisphenoid
5				Presphenoid-basisphenoid	Interfrontal

Sequences of *C. capreolus* and *H. inermis* are taken from previous reports [2, 9]. Other sutures not listed here remained open in all individuals.

closure in any *H. inermis*.

Acquired sequences of *C. pygargus* are given in Table 2. Generally, the exoccipital-basioccipital suture closes first, and then the supraoccipital-exoccipital and basisphenoid-basioccipital sutures close in both sexes. In males, next closure occurred in the interparietal suture. In females, the timing of supraoccipital-exoccipital, basisphenoid-basioccipital and interparietal suture closures were tied. The presphenoid-basisphenoid suture is the last to close in both sexes.

On the other hand, suture closures of some specimens did not follow the general patterns and showed variation to a certain extent. Maxillary-palatine, basisphenoid-temporal sutures showed partial closure in RDOC002 (Appendix 1). Lacrimal-zygomatic suture exhibited partial closure in RDOC009 (Appendix 1). These sutures were not closed in other specimens. In general, supraoccipital-exoccipital and basisphenoid-basioccipital sutures close earlier than the interparietal suture, but in two specimens (CNU-Jeju006 and CNU-Jeju003 in Appendix 1) the interparietal suture was closed without the supraoccipital-exoccipital and basisphenoid-basioccipital sutures being closed. JNU001, FNHM003, HA003 and HA004 (Appendix 1) showed closure of the interparietal suture without basisphenoid-basioccipital closure, and HA004 (Appendix 1) showed no closure of the exoccipital-basioccipital.

There was no significant correlation between degree of suture closure and skull size among adults ( $r=-0.05$ ,  $P=0.87$ ). Minimum and maximum total cranial length of 12 specimens used in this analysis is 178.23 and 193.81, all of which were adults with fully-erupted dentition [11].

Kendall tau b between male and female *C. pygargus* was 0.99 ( $P<0.001$ ). Suture closure sequences appear to be highly similar between both sexes in *C. pygargus*. Kendall tau b between *C. pygargus* and *C. capreolus* was 0.94 ( $P<0.001$ ). The interparietal suture was the first suture to close in *C. capreolus*. Kendall tau b between *H. inermis* and *C. pygargus* was 0.88 ( $P<0.001$ ), suggesting that the overall suture closure sequences of the two species are highly comparable. While the interfrontal suture closes in mature *H. inermis*, we did not observe such closure in any studied *C. pygargus*. Closure of the interparietal suture occurs relatively later in *C. pygargus* whereas it is one of the first sutures to close in *H. inermis*.

Among other cervid species (*Alces alces*, *Axis axis*, *C. capreolus*, *Cervus elaphus*, *Dama dama*, *H. inermis*, *Mazama gouazoubira*, *Muntiacus muntjak* and *Rangifer tarandus*), the interparietal suture is one of the first sutures to close [2, 15]. Therefore, the late closure of the interparietal suture in *C. pygargus* could be a derived trait among cervid species, which is not even found in the closely related *C. capreolus*. However, it must be noted that late closure of the interparietal suture was not applicable to all individuals. In *C. pygargus* the closures of the interparietal suture in most of studied specimens occur after the exoccipital-basioccipital, supraoccipital-exoccipital and basisphenoid-basioccipital sutures are closed. Nevertheless, two specimens showed closure of the interparietal suture while the supraoccipital-exoccipital and basisphenoid-basioccipital sutures were still open, a pattern which rather resembles the sequence of other cervid species [2, 15]. In four individuals with closed interparietal suture, the supraoccipital-exoccipital suture was closed but the basisphenoid-basioccipital suture was not closed.

The suture closure sequence shown by Rager *et al.* [15] was not compared in our statistical analysis because only 18 sutures were studied, and the alternative dataset of *C. capreolus* from Bärman and Sánchez-Villagra [2] which studied 24 sutures was adopted for this study. However, Rager *et al.* [15] which included more specimens than Bärman and Sánchez-Villagra [2] found that *C. capreolus* show sequence variation of the interparietal suture closure, a result similar to our findings. In their study, one specimen showed no closure of the interparietal suture while the exoccipital-basioccipital suture was closed. Quite strikingly, this exceptional sequence in one individual of *C. capreolus* is similar to the general sequence of *C. pygargus* reported here. Other two cervid species (*M. muntjak* and *R. tarandus*) studied by Rager *et al.* [15] do not show any other variation in cranial suture closure patterns. Variation of suture closure pattern was also found in *H. inermis* in our previous study [9], but only one specimen showed the exception; the supraoccipital-exoccipital suture was open while the basisphenoid-basioccipital suture was closed. However, the timing of the interparietal suture closures was not variable and always early in this species [9].

In mammals, the amount of intraspecific variation is pointed out to characterize phylogenetic relationships of certain groups. For example, it is reported that considerably higher intraspecific variation in thoracolumbar vertebral count characterizes atlantogenatan mammals [1]. It is known that the degree of intraspecific variation of suture closure sequence differs among mammalian clades. The variation is high in xenarthrans whereas it is relatively low in afrotherians [15]. Laurasiatherians show moderate variation.



Among Laurasiatherians, only two species showed no intraspecific variation, and both of them were cervids (*M. muntjak* and *R. tarandus*) [15]. Given these, we postulate that the high intraspecific variation of cranial suture closures may be a derived character of *Capreolus*.

In conclusion, *Capreolus* as a whole appears to show high variation of the interparietal suture closure pattern which is not found in other cervid groups. However, since our study was limited to the specimens from Jeju island of Korea, further study on *C. pygargus* from other populations is needed to clarify the phylogenetic trend of intraspecific variation of suture closure pattern of *Capreolus*. To date, considerable morphological and genetic variation among populations of *C. pygargus* has been recognized [19, 20, 24]. Especially, the population of Jeju Island, which is isolated from the Korean peninsula, is for sure genetically and morphologically distinct from other populations [8, 11–13].

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## Appendix Table

ID	Sex	Exoccipital-Basioccipital	Supraoccipital-Exoccipital	Basisphenoid-Basioccipital	Interparietal	Presphenoid-Basisphenoid	Interincisive	Incisive-Maxillary	Internasal	Nasal-Maxillary	Internasal	Maxillary-Lacrimal	Maxillary-Palatine	Maxillary-Zygomatic	Interpalatine	Lacrimal-Zygomatic	Nasal-Frontal	Lacrimal-Frontal	Zygomatic-Frontal	Zygomatic-Temporal	Presphenoid-Frontal	Presphenoid-Palatine	Basisphenoid-Temporal	Frontal-Parietal	Parietal-Temporal	Supraoccipital	Temporo-Exoccipital	Total cranial length (mm)	Collection
JNU001	F	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	181.84	JNU
JNU002	F	4	4	4	4	4	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	JNU
CNU-Jeju007	F	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	178.23	CNU
RDOC001	F	4	4	4	4	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	RDOC
CNU-Jeju008	F	4	3	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	CNU
080802	F	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	180.94	JNU
CNU-Jeju006	F	4	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	CNU
RDOC004	M	4	4	3	4	4	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	185.45	RDOC
FNHM002	M	4	4	4	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	192.24	FNHM
CNU-Jeju004	M	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	186.26	CNU
CNU-Jeju012	M	4	4	4	4	0	-	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	CNU
JNU003	M	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	190.12	JNU
JNU004	M	4	4	4	4	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	JNU
FNHM001	M	4	4	4	4	0	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	FNHM
RDOC002	M	4	4	4	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	185.64	RDOC
RDOC007	M	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	185.78	RDOC
RDOC008	M	4	4	4	4	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	RDOC
RDOC009	M	4	4	4	4	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	187.65	RDOC
CNU-Jeju005	M	4	3	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	183.44	CNU
FNHM004	M	4	4	4	3	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	-	FNHM
FNHM003	M	4	4	1	4	0	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	FNHM
CNU-Jeju001	M	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	193.81	CNU
HA002	M	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	187.20	HA
RDOC003	M	4	4	4	0	0	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	RDOC
HA001	M	4	4	3	0	0	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	HA
JNU005	M	4	4	0	4	0	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	JNU
HA003	M	4	4	0	4	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	HA
RDOC005	M	4	4	0	0	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	RDOC
RDOC006	M	4	4	0	0	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	RDOC
CNU-Jeju003	M	4	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	CNU
HA004	M	2	3	0	4	0	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	HA

“-” indicates missing data due to fracture of specimens. Abbreviations: JNU, Department of Science Education, Jeju National University (Jeju, South Korea); CNU, College of Veterinary Medicine, Chonbuk National University (Iksan, South Korea); RDOC, Roe Deer Observation Center (Jeju, South Korea); FNHM, Folklore and Natural History Museum (Jeju, South Korea); HA, Halla Arboretum (Jeju, South Korea).