NOTE *Anatomy*

Morphological Examination of the Obturator Notch and Canal in Cervidae

Hyun-Jin TAE[1)], Byung-Yong PARK[2)], In-Shik KIM[2)] and Dongchoon AHN[2)]*

[1)]*Department of Biomedical Science and Research Institute for Bioscience and Biotechnology, Hallym University, 1 Hallymdaehak-gil, Chuncheon-si, Gangwon-do 200–702, Republic of Korea*
[2)]*Bio-Safety Research Institute, College of Veterinary Medicine, Chonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju-si, Jeollabuk-do 561–756, Republic of Korea*

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ABSTRACT. The purpose of this study was to investigate gross findings of the obturator notch (ON) and obturator canal (OC) in Cervidae. A total of 183 pelvic girdles from 26 species of deer were examined, and the obturator canal (OC) was classified into 4 types based on the degree of separation from the obturator foramen (OF). The deep ON was observed primarily in the subfamily Capreolinae (telemetacarpal deer). The small bony OC was frequently observed in *Hydropotes inermis*, *Mazama gouazoubira* and *Ozotoceros bezoarticus*. A canal without a tubercle or bony bridge structure was mainly observed in the subfamily Cervinae (plesiometacarpal deer). These results suggest that the deep ONs or the OCs separated by bony structures are more common in telemetacarpal rather than plesiometacarpal deer.

KEY WORDS: deer, obturator canal, obturator foramen, obturator notch.

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Deer are frequently the subject of research, because they constitute the second most species family of artiodactyls and live in a wide range of habitat with indigenous representatives around world, except for Australia and Antarctica. The subdivision of the Cervidae family into 2 subfamilies, Cervinae and Capreolinae, is generally agreed upon by taxonomists; however, the nomenclatures of its several genera and species of the subfamilies were recently revised in accordance with accumulating genetic, morphologic and phylogenic data [7, 9, 16]. Feral Cervinae are found only in Eurasia. They possess only the proximal end of the second and the fifth metacarpal bone and are thus considered Old World (plesiometacarpal) deer. In contrast, with the exception of 4 species, Capreolinae are found primarily in North and South America. This subfamily has the distal end of the second and fifth metacarpal bones, and its members are considered New World (telemetacarpal) deer [3, 7, 9].

In the mammal hip bone, the obturator canal (OC) is an opening in the obturator foramen (OF) through which the obturator vessels and nerve pass. The OC is formed by the bony border of the OF in the cranial aspect (superior in humans) and by the obturator membrane, a delicate sheath of connective tissue that closes the OF in humans inferiorly and domestic mammals caudally [5, 13, 18]. The cranial end of the obturator membrane attaches to the obturator tubercles (OTs), which protrude from the ischium, medially, and from the pubis, caudally (in humans) or laterally (in animals) [5, 13]. The anterior and posterior OTs are present in humans; however, they are generally absent, or too rudimentary to detect, in domestic and wild animals [13]. Although a notch on the OF cranial border has been observed in the goat [1, 10, 12], it was not believed to be of value for discriminating between humans and other mammals. Moreover, OTs are not mentioned in veterinary textbooks [6, 19] or the *Nomina Anatomica Veterinaria* [11]. These facts may explain why the relationship between the OC and OF in domestic and wild animals including ruminants has received little attention.

The notch on the cranial border of the OF has been observed in several living and 2 extinct deer species [2, 4, 10, 12, 14]. However, it is absent or less well developed in the Eurasia elk (*Alces alces*) [2]. Recently, an independent, small OC located between the acetabulum and OF has been identified in the hip bone of the antlerless deer, *Hydropotes inermis* [14].

Thus, we hypothesized that the structure of the OC in deer has evolved through several stages. We tested this hypothesis by first determining whether the notch structure is present in most deer or if it is restricted to specific species or subfamilies. We then established whether individual differences existed among subfamilies and species.

After meticulous inspection to exclude skeletons with congenital defects, the pelvic girdles of 183 skeletons (366 hip bones) from 26 species of deer were given gross examinations, and the OF was photographed when necessary. Most samples were stored in the Smithsonian Institution (Washington, DC, U.S.A.), except for 41 pelvic girdles of 3 *Cervus nippon*, 13 *Capreolus pygargus* and 25 *H. inermis* which were kept in the Laboratory of Veterinary Anatomy, Chonbuk National University, Republic of Korea. The number of samples examined for each species is shown in Table 1. We examined at least 1 species in each of the 9 Cervinae and 10 Capreolinae genera with the exception of the genera

*CORRESPONDENCE TO: AHN, D., Bio-Safety Research Institute, College of Veterinary Medicine, Chonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju-si, Jeollabuk-do 561–756, Republic of Korea. e-mail: ahndc@jbnu.ac.kr

Table 1. Obturator canal types observed in the Cervidae family

Subfamily*	Species	Common name	Obturator canal type in the hip bone				
			I	II	III	IV	Total
Cervinae	*Axis axis*	Chital or Axis deer	4	4			8
	Axis porcinus	Hog deer	2				2
	Rucervus duvauceli	Swamp deer (Barasigha)	2	2			4
	Cervus eldii	Eld's deer (Thamin)	16	4			20
	Elaphurus davidianus	Père David's deer	6				6
	Cervus elaphus	Red deer	10	8			18
	Cervus mariannus	Philippine sambar deer	6				6
	Cervus nippon	Sika deer	20	8			28
	Cervus timorensis	Rusa deer	2	2			4
	Cervus unicolor	Sambar deer	6				6
	Dama dama	Fallow deer	2				2
	Elaphodus cephalophus†	Tufted deer	8	1	1		10
	Muntiacus muntjak	Red muntjac	6				6
	Muntiacus reevesi	Reeves's muntjac	20				20
	Subtotal		110	29	1		140
Capreoliane	*Alces alces*	Moose		12			12
	Capreolus pygargus	Siberian roe deer		14	12		26
	Hydropotes inermis†	Chinese water deer		12	23	21	56
	Blastocerus dichotomus	Marsh deer			4		4
	Mazama gouazoubira	Brown brocket	2	2	2	4	10
	Mazama americana	Red brocket		2	2		4
	Odocoileus virginianus	White-tailed deer	6	28	14		48
	Odocoileus hemionus†	Black-tailed (Mule) deer	6	16	7	1	30
	Ozotoceros bezoarcticus†	Pampas deer		1	3	2	6
	Pudu mephistophiles†	Northern pudu		1	1		2
	Pudu puda	Southern pudu		12	2		14
	Rangifer tarandus	Caribou		14			14
	Subtotal		14	114	70	28	226
Total			124	143	71	28	366

*Deer were classified according to the Gilbert *et al.* [7]. †One pelvic girdle in each species had a different type of OC on the left and right sides.

Przewalskium and *Hippocamelus*, respectively. A total of 98 pelvic girdles (41 in Cervinae and 57 in Capreolinae) were from male specimens and 80 (26 and 54 in Cervinae and Capreolinae, respectively) were from females. We were unable to identify the sex of 1 specimen of the species *Cervus eldii*, 2 *Cervus elaphus* and 2 *A. alces*. The 2 hip bones were joined by ossification at the pelvic symphysis or the joint was almost occupied, and the symphysial crest was formed from a secondary ossification center, indicating that the specimens were at least older than 1 year. Carcasses of 25 *H. inermis*, 13 *C. pygargus* and 1 *C. nippon* were dissected to confirm that the obturator vessels and nerve passed through the OC prior to preparing the skeleton.

The OC was classified into 1 of 4 progressive categories based on the relationship with the OF: Type I comprised the craniolateral portion of the OF with no obturator tubercle (OT) or notch as found in domestic animals (Fig. 1A); Type II had a small notch that bulged cranially from the expected arc of the OF causing the OT to spontaneously form at the junction (Fig. 1B). This notch was considered the obturator notch (ON). The opening between the ON and the OF was more than a quarter of the OC. Type III was virtually closed by the bony spine of the OT; thus, the opening between the ON and the OF was less than a quarter of the OC (Fig. 1C). We believe this category signified the most progressive stage in the separation of the OC. In Type IV, a small canal was entirely separated by a bony bridge (Fig. 1D).

We found a marked difference in OC–OF categories between the subfamilies with some differences among deer species; Type I was frequently observed in Cervinae, whereas Types II, III and IV were primarily found in Capreolinae. Of the 14 Cervinae species examined, 7 were classified as Type II, appearing in only several specimens examined. Type II was found in all species of Capreolinae with the exception of *Blastocerus dichotomus*, in which all specimens were classified as Type III, which was characterized by bony spines of the OT and thought as advanced type to be bony OC. Type III was observed in all Capreolinae species with the exception of the 2 largest species, *A. ales* and *Rangifer tarandus*. Type IV was observed in 4 Capreolinae species, *H. inermis*, *M. gouazoubira*, *O. bezoarcticus* and *Odocoileus hemionus* (Table 1). The OC was classified as Type IV in 40.0% of *H. inermis* and *M. gouazoubira* and in one-third of *O. hemionus* specimens.

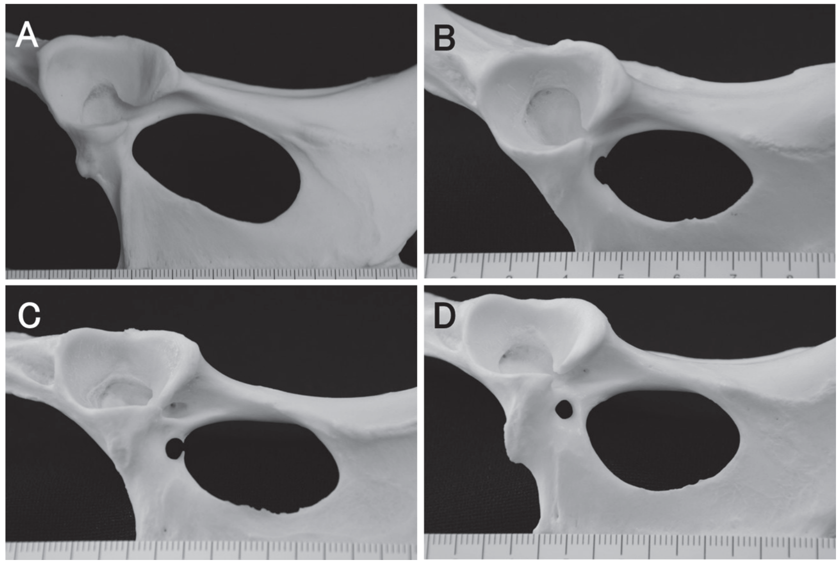

Fig. 1. Classification of obturator canal type in the left hip bone of deer (ventral view). Type I was formed without an obturator tubercle or bony bridge (A). Type II was notched, forming a small bulge in the foramen from the obturator foramen (OF) (B). Type III was virtually closed by the spiny tubercle of the OF (C). Type IV was a small canal that was separated from the OF by a bony bridge (D). A, *Cervus nippon*. B, C and D *Hydropotes inermis*.

More than 2 types of OC were observed in 16 of the 26 species; *Elaphodus cephalophus*, *H. inermis*, *Odocoileus virginianus* and *O. bezoarcticus* had 3 types, and all 4 types of OC were observed in *M. gouazoubira* and *O. hemionus*. One type was found in the remaining 10 species.

The type of OC differed between the right and left hip bones in 5 of 183 deer (2.7%). OC type did not differ between male and female specimens. The anatomical dissection performed on the cadavers of *C. nippon*, *C. pygargus* and *H. inermis* confirmed that the obturator vessels and nerve passed through the OC (Fig. 2). The obturator nerve appeared internal surface of body of ilium, ran caudoventrally and then passed through the OC. The nerve divided into the cranial and caudal branches, which were also divided into several muscular branches innervating the pectineus muscle, the external obturator muscle, adductor muscle and gracilis muscle. The obturator artery (OA) arose as a slender vessel from the internal iliac artery dorsal to obturator nerve. The OA ran along the body of the ilium with the obturator nerve. The artery was ventrolaterally positioned along the nerve. The artery gave off a nutrient branch to the ilium en route and then became more slender to reach the OC. Another vessel passing the OC, the obturator branch (OB) of the medial circumflex femoral artery, arose between the iliacus muscle and the pectineus muscle. The OB was larger than the OA and ran in a dorsal direction through the OC to anastomose with the OA (Fig. 2). The OB also ramified several small branches en route that supplied the hip joint capsule, the pectineus muscle and the external obturator muscle. A branch of the OB to vascularize the intrapelvic part of external obturator muscle was separated from the main stem inside the cranial part of the external obturator muscle. This branch passed through the OF, not the OC, and was enclosed in muscle fascia. The branch ran caudal to the OT and the fibrous band, or bony bridge of the OC, and ran along the lateral margin of the intrapelvic part of the muscle. A third vessel passing the OC was the branch of a vein than ran with the OB and was confluent with the medial circumflex femoral vein.

Among the 25 of *H. inermis* dissected, the Types II, III and IV of OC were observed in 3, 11.5 and 7.5 deer, respectively. That was 1 *H. inermis* which had different types in both hip bone. In 13 *C. pyargus*, Types II and III were observed in 7 and 6 deer. Type I of OC was revealed in 1 *C. nippon* dissected. In case of Types I, II and III, the fibrous band completed the OC border, which was continuous with the fascia of the external obturator muscle.

In contrast to the 9 genera of the subfamily Capreolinae, classification of the Cervinae genera is controversial. For example, Groves and Grubb [8, 9] designated the genus *Przewalskium* as a clade of Cervinae; however, in other reports [7, 15, 17], the genus is classified as a species of the genus *Cervus*. Groves and Grubb [8] classified *Axis porcinus* as a species of the genus *Hyelaphus*. Furthermore, *C. mariannus*, *C. timorensis* and *C. unicolor* have been placed under the genus *Rusa* [9].

To avoid confusion, we classified the 26 species we examined according to the new taxonomy proposed by Gilbert *et al*. [7] following a phylogenetic analysis using genetic and morphological data. We examined more than 1 specimen in each of the 7 of 8 Cervinae genera and in each of the 9 of 10 genera in Capreolinae.

The ON has been mentioned in previous studies of *P.*

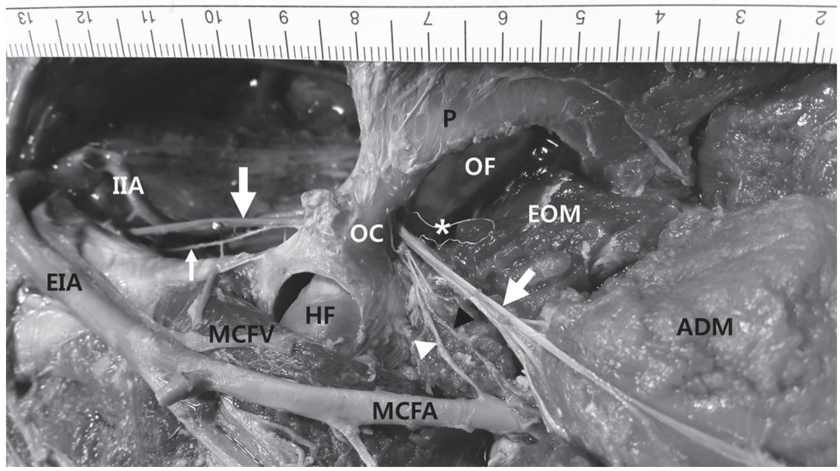

Fig. 2. A Type II obturator canal (OC) in a female *Hydropotes inermis*(right ventrolateral view). The nerve and vessels passing the OC are shown. Arteries were infused with red latex before dissection. The obturator nerve (large white arrows) and the obturator artery (small white arrow) were lifted with pins for the demonstration. The obturator artery arose from the internal iliac artery (IIA) dorsal to the nerve and ran ventrolateral to it. The obturator branch (white arrowhead) of the medial circumflex femoral artery (MCFA) and a branch of the medial circumflex femoral vein (MCFV) (black arrowhead) ran in a dorsal direction through the OC. The obturator branch anastomosed with the OF as verified by the latex casting (white asterisk). The pelvic viscera and abdominal wall were removed, and the portion of the MCFV covering the MCFA, pectineus muscle, gracilis muscle, adductor muscle (ADM) and external obturator muscle (EOM) was cut and reflected or partially removed. EIA, external iliac artery; HF, head of femur; OF, obturator foramen; P, pubic bone.

pudu [4], *O. hemionus* [10], *Capreolus capreolus* [12] and *H. inermis* [14], which belong to the subfamily Capreolinae. Moreover, it has previously been observed in 2 extinct species: *Megaloceros giganteus*, which is classified as 1 of Cervinae family and thought to be an ancestor of the Tribe Cervini (true deer) and *Cervalces scotti*, a member of the Capreolinae family, and an ancestor of the genus *Alces* [2]. The pelvic fossils of these 2 extinct deer possess a large notch on the OF, whereas none of the specimens of the other ancestral species of *Alces*, *C. latifrons* or *C. carnutorum* preserve the OF edge to verify the presence/absence of the notch [2]. In the present study, the ON was also observed in a few Cervinae species and in a significant number of *Axis axis*, *C. elaphus* and *C. nippon* specimens. In contrast, the ON was found in all Capreolinae species, and the Type III OC was observed in all, but 2 species, *A. alces* and *R. tarandus*. The separated OC characteristic of Type IV was found in 4 Capreolinae species; most frequently in *H. inermis* and *M. gouazoubira*. Overall, 93.8% (106/113 deer) of Capreolinae were classified as Types II, III or IV. Thus, our results suggest that the ON or a separate bony OC is more common in Capreolinae than Cervinae deer.

Changes in the OC shape among Types I–IV were observed in this study. These results suggest that the OC was formed at various stages among deer. The appearance of the ON appears to have facilitated development in Capreolinae compared to Cervinae, allowing *Hydropotes*, *Mazama*, *Ozotoceros* and *Odocoileus* to reach the progressive stage with the small bony OC structure.

We confirmed that the obturator vessels and nerve passed through the OC and that the skeleton had no congenital defects. Thus, the bony OC is a normal structure in deer species including *H. inermis*, *M. gouazoubira*, *O. bezoarcticus* and *Odocoileus hemionus*. Furthermore, the bony OC characteristic of Type IV may be considered a unique structure in these deer, because it has not been reported in domestic or wild mammals.

Our findings are not consistent with a previous study that did not find ONs in several hip bones of *A. alces* [2]. This discrepancy may be explained by the origin and age of deer. Previous authors examined young Eurasia elk, whereas we primarily studied the North American moose. Our specimens were also older. Alternatively, previous authors may have overlooked the OT, because the opening between the OC and OF is large in the Eurasia elk [2].

In this study, the reason that deer had a conspicuous notch or a separated bony OC compared with other mammals was not found. We can infer that the relationship between obturator nerve and the OC developed because the obturator groove was formed by the nerve passing craniolaterally through the OF from the internal to external pelvis [6, 18, 19]. However, this could not explain why the ON or the bony OC was absent in other animals, except for deer [2, 4, 10, 12, 14] and some goats [1, 10, 12]. A further study of this subject is required.

In conclusion, deer have various forms of obturator canal morphology, and deep notches or canals separated by bony structures are more common in telemetacarpal than in plesiometacarpal deer.

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