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The lamination of the masseter muscle in the water deer (*Hydropotes inermis*)

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Abstract. The lamination of the masseter muscle was gross anatomically examined in the water deer (*Hydropotes inermis*). We could distinguish several layers such as the *M. masseter superficialis*, *M. masseter intermedius*, *M. masseter profundus*, *M. maxillo-mandibularis*, and *M. zygomatico-mandibularis*. The *M. masseter superficialis* was subdivided into *lamina prima* and *lamina secunda*. The *lamina prima* originated from the facial tuber, facial crest, and zygomatic arch with a broad tendinous sheet. The *lamina secunda* arose from the posterior facial crest and anterior area of the zygomatic arch and was inserted to the mandible by a broad tendinous sheet. The *M. masseter intermedius* arose from approximately same origin as the *superficialis lamina secunda* by a distinct tendinous sheet. Moreover, only one part was confirmed in the *M. maxillo-mandibularis* and the *M. zygomatico-mandibularis* and only two parts in the *M. masseter profundus pars posterior*. Moreover, the most rostral part of the *M. maxillo-mandibularis* was inserted to the mandible by a small weak tendon. This result suggests that this muscle layer may not restrict the mouth opening more remarkably than that of cervids which develop the tendon. In this study, we could confirm the lamination of the masseter muscle with the simplified layers in the water deer.

Key words: *Hydropotes inermis*, lamination, masseter muscle, water deer.

The water deer (*Hydropotes inermis*) was belonging to the subfamily Hydropotinae, family Cervidae, suborder Ruminantia, order Artiodactyla (Eisenberg 1981; Groves and Grubb 1987; Janis and Scott 1987; Scott and Janis 1987). In the recent comprehensive study on the molecular phylogeny of the Cervidae (Gilbert et al. 2006), however, it has been reported that the water deer (genus *Hydropotes*) is phylogenetically close to the European roe deer (*Capreolus capreolus*), and reclassified with the genus *Capreolus* into the tribe Capreolini, subfamily Capreolinae, family Cervidae.

The water deer which are small cervids loss their antlers in both sexes and have upper canine teeth elongated especially in male. They live among tall reeds and rushes along rivers in eastern China and Korean peninsula and feed on reeds, coarse grasses, and vegetables (Nowak 1999). The feeding type of ruminants was categorized into three types; browser (e.g., giraffe, moose, white-tailed, and roe deer), intermediate feeder (e.g., goat, fallow, and sika deer), and grazer (e.g., banteng, sheep, and Père David's deer), and the water deer is classified into the intermediate feeder (Hofmann 1988; Clauss et al. 2008).

Several studies on the lamination of the masseter muscle (*Musculus masseter*) have been reported in ruminants such as goat, sheep, cattle, takin, nilgai, Japanese serow, and giraffe (Yoshikawa et al. 1962; Heinze 1963, 1964; Suzuki 1989; Sasaki et al. 2001), In the Cervidae, the

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lamination of white-tailed, roe, and sika deer was examined (Toldt 1905; Yoshikawa et al. 1962; Turnbull 1970). In this study, we examined the lamination of the masseter muscle of the water deer, to compare with that of other cervids.

Materials and methods

The carcasses of two female Korean water deer (*H. i. argyropus*) (Sample Nos. KJ0724 and KJ0725) found in Anseong-si, Gyeonggi-do, Korea, collected by the Wildlife Rescue Center, Pyeongtaek, Gyonngi-do, Korea, and then donated to Department of Veterinary Anatomy, College of Veterinary Medicine, the Seoul National University, Seoul, Korea, were used in this study. The animals were stored at –10°C until examination. After thawing, the fresh heads were cautiously dissected to examine the lamination of the masseter muscle.

Results

The small masseter muscle was noticed after removing the skin (Fig. 1A). The most superficial layer of the masseter muscle originated from the facial tuber, facial crest, and zygomatic arch with a broad tendinous sheet connected by a tendon of the mandibular part of the sternocephalic muscle (*M. sternocephalicus*), and was inserted to the ventral area of the mandible by a fleshy portion (Fig. 1A–C). A fleshy portion of two different (rostral and caudal) layers of the masseter muscle was recognized when the tendinous sheet of the most superficial layer was cut along the ventral border of the zygomatic arch (Fig. 1B and C). The caudal layer among the two originated from the posterior facial crest and anterior area of the zygomatic arch and was inserted to the mandible by a broad tendinous sheet (Fig. 1B and C). A distinct (second) tendinous sheet of more medial layer which originated from the posterior facial crest and anterior area of the zygomatic arch appeared when cutting the proximal part of this caudal layer (Fig. 1B–D). The rostral layer originated from the facial crest and was inserted by a small weak tendon to the rostral end of the insertion part where the caudal layer was attached by a tendinous sheet (Fig. 1D). After removing the caudal layer, a flask-shaped layer inserted to the masseteric fossa was revealed (Fig. 1C and D). In the rostral and caudal margin of the distinct second tendinous sheet of this layer, a part of the fleshy portion of more medial layers was peeped (Fig. 1D), and these two deeper layers (anterior and posterior) were entirely recognized when a flask-shaped layer was removed (Fig. 1E). The anterior and posterior layers medial to the flask-shaped layer mainly originated from the zygomatic arch by a fleshy portion and was inserted to the rostro-lateral part of the base of the ramus of mandible and the masseteric fossa by a tendinous sheet, respectively (Fig. 1E and F). The masseteric nerve passed through the center of the posterior layer among the two (Fig. 1E–G). On the inside, each layer adjoined more medial (the deepest) layers of which the direction of the tendinous sheet was inversed (Fig. 1F and H). The deepest layer of the rostral region originated from the base of the temporal process of the zygomatic bone and was inserted to almost the rostral part of the ramus of mandible (Fig. 1F and G). On the other hand, the deepest layer of the caudal region arose from the base of the zygomatic process of the temporal bone and attached to the lateral part of the ramus near the bottom of the mandibular notch (Fig. 1H). The temporal muscle (*M. temporalis*) inserted to the coronoid process of the mandible was clearly distinguished from the masseter muscle (Fig. 1H).

Discussion

In this study on the masseter muscle of the water deer, the several layers ware discriminated. Yoshikawa et al. (1961, 1962) largely divided the masseter muscle into the proper (narrow sense) (*M. masseter*) and improper (broad sense) (*M. maxillo-mandibularis* and *M. zygomatico-mandibularis*) masseter muscles. Furthermore, they treated the most superficial layer which mainly originated from the facial tuber and the facial crest by a broad tendinous sheet and the layer which was adjacently located inside the most superficial layer and mainly originated from the posterior area of the facial crest and the anterior zygomatic arch by a fleshy portion as the *M. masseter superficialis lamina prima* and *M. masseter superficialis lamina secunda*, respectively. Moreover, the layer which was adjacently located inside the *M. masseter superficialis lamina secunda* and arose from approximately same origin as the *superficialis lamina secunda* by a broad tendinous sheet was named the *M. masseter intermedius*. The layer which originated from the whole facial crest and the zygomatic arch and was inserted to the rostro-lateral part of the ramus of mandible was identified as the *M. maxillo-mandibularis*. The most rostral part of the *M. maxillo-mandibularis* was individually inserted to the mandible by a tendinous sheet or a tendon.

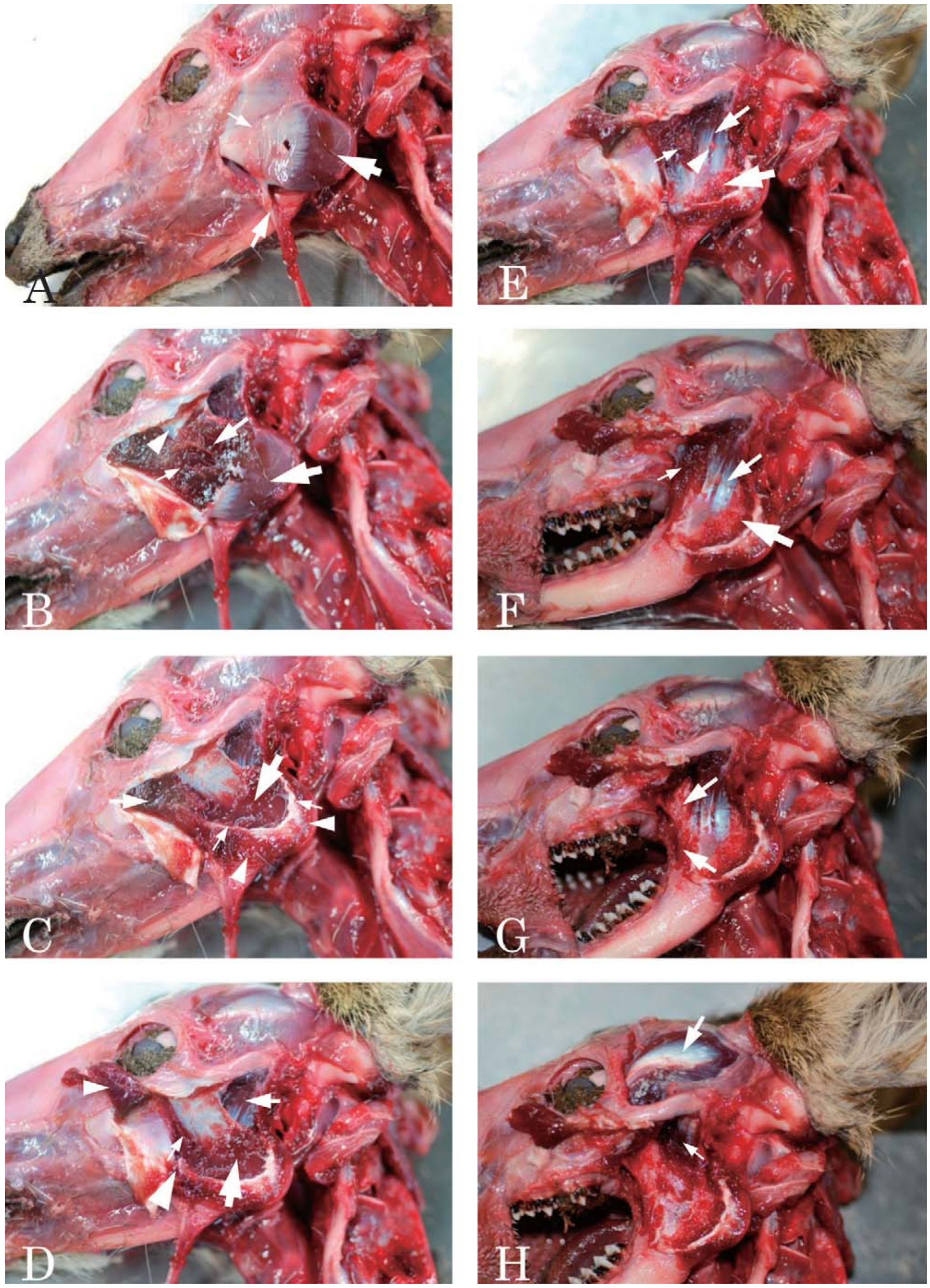

Fig. 1. The lamination of the masseter muscle of the water deer. (A) The most superficial layer originated from the facial tuber, facial crest, and the zygomatic arch with a broad tendinous sheet (small arrow) and was inserted to the ventral area of the mandible by a fleshy portion (large arrow). The tendon of the mandibular part of the sternocephalic muscle (intermediate arrow) connected to the tendinous sheet of the most superficial layer. (B) A fleshy portion of two different (rostral and caudal) layers was recognized when cutting the tendinous sheet along the ventral border of the zygomatic arch. Small arrow: rostral layer. Intermediate arrow: caudal layer. Large arrow: fleshy portion of the most superficial layer. Arrowhead: the second tendinous sheet peeped through the crevice of the caudal layer cut at the original part. (C) Small and intermediate arrows show the tendinous sheet of the caudal layer and the fleshy portion of the rostral layer in B, respectively. Large arrow: flask-shaped layer with the second tendinous sheet. Arrowheads: insertion area of the most superficial layer by a fleshy portion. (D) In the rostral and caudal margin of the second tendinous sheet, a part of the fleshy portion of more medial layers (anterior: small arrow, posterior: intermediate arrow) was peeped. The rostral layer in B was cut at the part of the tendinous sheet and turned over (small arrowhead). Large allow: flask-shaped layer. Large arrowhead: insertion part of the rostral layer by a small weak tendon. (E) Small and intermediate arrows show the anterior and posterior layers in D. Large allow: insertion area by the fleshy portion of the flask-shaped layer. Arrowhead: masseteric nerve. (F) A more medial layer (small arrow) was detected when removing the anterior layer in E. Intermediate arrow: posterior layer in E. Large allow: insertion area by the fleshy portion of the flask-shaped layer. (G) The most rostral and deepest layer in F was inserted to the rostro-lateral part of the ramus of mandible (arrows). (H) A more medial layer (small arrow) was detected when removing the posterior layer in E. Intermediate arrow: temporal muscle.

Furthermore, the layer located in the most caudal region originated from the base of the zygomatic process of the temporal bone and was inserted to the upper part of the masseteric fossa was treated as the *M. masseter profundus*. The layer which originated from the base of the temporal process of the zygomatic bone and sometimes the maxilla and attached to nearly the rostral part of the ramus of mandible was named the *M. zygomatico-mandibularis*.

We used these concepts (anatomical terms) by Yoshikawa et al. (1961, 1962) to distinguish complicate layers of the masseter muscle of the water deer precisely. The layers with the most superficial, next broad (between the most superficial and the second) and the second tendinous sheets correspond to the *M. masseter superficialis lamina prima*, *M. masseter superficialis lamina secunda*, and *M. masseter intermedius*, respectively. The layer rostral to the *M. masseter intermedius* is equivalent to the *M. maxillo-mandibularis*. It is thought that, furthermore, the layer adjacently appeared in the caudal area of this *M. maxillo-mandibularis* (anterior layer) when removing the *M. masseter intermedius* is the continuity of the *M. maxillo-mandibularis* (Yoshikawa et al. 1962), and the posterior layer medial to the *M. masseter intermedius* is the *M. masseter profundus*. Yoshikawa et al. (1961) subdivided the *M. masseter profundus* into the *M. masseter profundus pars anterior* and the *M. masseter profundus pars posterior lamina prima* bordering on the masseteric nerve, and this lamination with the masseteric nerve agreed with our result of the water deer. The layers medial to the *M. maxillo-mandibularis* and the *M. masseter profundus pars anterior* and *pars posterior lamina prima* correspond to the *M. zygomatico-mandibularis* and the *M. masseter profundus pars posterior lamina secunda*, respectively.

In the water deer, the sternocephalic muscle which connected to the tendinous sheet of the *M. masseter superficialis lamina prima* was found. This result agreed with that of the sika and roe deer (Toldt 1905; Yoshikawa et al. 1962). Same morphological feature of the sternocephalic muscle was recognized in the goat, cattle, and Japanese serow (Yoshikawa et al. 1961; Sugimura and Suzuki 1992) although not in the giraffe and sheep (Yoshikawa et al. 1961, 1962; Sasaki et al. 2001). In ruminants, therefore, it seems that this characteristic is not a matter only for cervids because same attachment style of the sternocephalic muscle to the *M. masseter superficialis lamina prima* is shown also in bovids.

The structure of the *M. masseter superficialis lamina prima* in the water deer were not largely different from the cervids examined such as white-tailed, sika and roe deer (Toldt 1905; Yoshikawa et al. 1962; Turnbull 1970) at the point of the origin from the facial tuber, facial crest, and anterior zygomatic arch with a broad tendinous sheet and the postero-ventral fiber direction. On the other hand, Turnbull (1970) did not distinguish between the *M. masseter superficialis lamina secunda* and *M. masseter intermedius* in the white-tailed deer, and described these muscles as the *M. masseter pars profundus*. Moreover, the *M. maxillo-mandibularis* and *M. masseter profundus,* and the *M. zygomatico-mandibularis* in the water and sika deer were shown as the *M. zygomatico-mandibularis* and the *M. temporalis pars superficialis* in the white-tailed deer, respectively.

Toldt (1905) examined the lamination of the superficial region of the masseter muscles in detail, but considered that the *M. masseter profundus* and the *M. zygomatico-mandibularis* according to Yoshikawa et al. (1962) were one layer and described only as the *M. zygomatico-mandibularis*, of which the part was not investigated at all.

The basic structure of the masseter muscle had no large differences among the cervids except some parts although the terminological statements of the layers were not completely in agreement. In the water deer, only one part was confirmed in the *M. maxillo-mandibularis* and the *M. zygomatico-mandibularis*, and only two in the *M. masseter profundus pars posterior*. In the sika deer cautiously examined by Yoshikawa et al. (1962), on the other hand, each muscle layer had three parts. It may be assumed that, in the water deer, other parts of these muscle layers are not fully developed to be recognized or completely lost. The increase and decrease of the lamination (i.e. number of layer parts) may result from adaptiogenesis of the masseter muscle for the physical limitation of attachment area with the change of the skull size.

It has been reported that, moreover, the improper masseter muscles with a well-developed tendon restrict a large opening of the mouth (Yoshikawa et al. 1962). In many ruminants such as sika deer, sheep, goat, cattle, nilgai, takin, and Japanese serow, the tendon and tendinous sheet of the improper masseter muscles, especially the *M. maxillo-mandibularis lamina prima* located on the most rostral part among the improper masseter muscles, were well-developed (Yoshikawa et al. 1961, 1962; Suzuki 1989; Sasaki et al. 2001). However, bactrian camels which have conspicuous upper canine teeth in artiodactyls did not develop the tendon and tendinous sheet of the *M. maxillo-mandibularis* and the *M. zygomatico-mandibularis*, suggesting that the improper masseter muscles might be adapted for the large opening of the mouth to effectively utilize their canine teeth (Yoshikawa et al. 1962). In this study, we confirmed that the most rostral part of the *M. maxillo-mandibularis* was inserted to the mandible by a small weak tendon. Therefore, this result might correlate with the large mouth opening for effective use of the upper canine teeth in the water deer.

It has been reported that there was a positive correlation between the masseter mass and the estimated proportion of grass in the natural diet when controlling for body size and phylogeny (Clauss et al. 2008). According to this report, the water and sika deer which are intermediate feeders indicate same grass percentage (50%) and masseter mass residual. It is suggested that, therefore, each masseter muscle will show a same volume when these deer has same body size. In the water deer, however, the number of the layer parts was decreased, so the remained layer part may be compensated in volume.

In this study, we made clear the lamination style of the masseter muscle with the simplified layer in the water deer by cautious dissection. To detect the correlation between lamination and feeding type or phylogeny in ruminants, we will examine the masseter muscle of other species of ruminants in further studies.

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