MRI Examination of the Masticatory Muscles in the Gray Wolf (Canis lupus), with Special Reference to the M. temporalis

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ABSTRACT. We examined the head of the gray wolf (Canis lupus) using MRI methods. Although the arising surface of the M. temporalis was not so enlarged in the frontal bone, the small frontal bone did not disturb the M. temporalis from occupying the lateral space of the frontal area in the gray wolf as in the domesticated dog. In the gray wolf, it is suggested that the M. temporalis may not be well-developed in terms of size of arising area, but in the thickness of running bundles. We suggest that the dog has changed the three-dimensional plan of the M. temporalis during the domestication and that the M. temporalis has developed a large arising surface in the frontal bone and lost the thickness of belly in the frontal area in accordance with the enlargement of the frontal bone and the increase in brain size. — KEY WORDS: domestication, gray wolf, masticatory muscle, MRI, temporal bone.

We have already applied the computed tomography (CT) technique to the skull of the extinct Japanese wolf (Canis hodophilax), and compared the data to those of the domesticated dog (Canis familiaris) [3]. It was concluded from the results that the frontal bone and sinus are not so developed in the Japanese wolf as in the domesticated dog [3]. Because the shape and size of the frontal bone are related to the development of the masticatory system, we morphologically examined the masticatory muscles in the carcass of the gray wolf (Canis lupus), to elucidate the functional-morphological changes in the wolf masticatory system during the domestication process to the dog. We were fortunate that a rare carcass of a gray wolf was donated by Kyoto Municipal Zoo. We carried out magnetic resonance imaging (MRI) examinations to clarify the morphological relationship between masticatory muscles and frontal bone in this carcass. From the data, we expect that the occurrence of masticatory muscles will be confirmed in a three dimensional level. The functional differences will be discussed between the gray wolf with an undeveloped frontal bone and the dog with large frontal bone. And it is also expected that a functional model of masticatory muscles will be suggested in the extinct Japanese wolf from the MRI sections.

MATERIALS AND METHODS

We used one carcass head of the male gray wolf (Canis lupus), which died of heart failure in Kyoto Municipal Zoo in 1996 and was donated to Kanagawa Prefectural Museum of Natural History. The individual was born in 1986, and is an adult. We have frozen and stored the head to avoid artifacts from formalin fixation. At first, we confirmed the attachment areas of M. temporalis in the frontal area. The arising, orientation and insertion of the M. masseter and M. digastricus were observed with naked eye, after removing the skin, subcutaneous tissue and the right globe from the head. After macroscopic dissection, the head, melted in room temperature, was serially sectioned with a magnetic resonance imaging (MRI) system (FLEXART, Toshiba Medical Co., Tokyo, Japan) at 3 mm in thickness and 0-3 mm in gap. We obtained a series of T1 weighted images (Spin echo method, TR=350 msec, TE=20 msec) of parasagittal, dorsal and transverse planes, and described the three-dimensional relationship between masticatory muscles (Mm. masseter, digastricus, temporalis, pterygoidei) and skull from the MRI section images. The anatomical nomenclature are based upon the textbooks of veterinary anatomy [4, 15].

RESULTS

The MRI head sections are arranged in parasagittal (Fig. 1), dorsal (Fig. 2) and transverse (Fig. 3) planes. We show the macroscopic photographs in Fig. 4.

M. temporalis: The arising of the M. temporalis is tightly attached to the dorsal surface of the parietal and occipital bones (Figs. 1A and 4A). It arises from the undeveloped sagittal crest of the parietal and occipital bones, and becomes thicker in the more ventral region (Figs. 2A and 3B). The muscle belly is obviously separated into two and three parts (Figs. 2A, 2B and 3B).

The M. temporalis, attaching to the lateral side of the frontal bone, occupies the large space in both sides of the small frontal bone and its zygomatic process (Figs. 2B, 3A and 4A). The muscle bundle attaches only to the small area of frontal bone surface, but the huge muscle belly lies in the lateral area of the temporal and parietal bones, and dorsal part of the palatine bone. The M. temporalis runs laterally in the caudal part of the zygomatic process of the frontal.
Fig. 1. Parasagittal MRI sections are serially shown from the medial to lateral part. Rostral direction at the top. Bar=20 mm. A: The section near the sagittal plane. The thin *M. temporalis* (large arrow) attaches to the dorsal surface of the braincase and to the sagittal crest. The well-developed *M. pterygoideus medialis* (small arrow) connects the pterygoid and mandibular bone. B: brain. T: tongue. M: *M. mylohyoideus*. B: Left side section about 20 mm from the sagittal plane. The *M. temporalis* is well-developed in the frontal bone area (large arrow). The arising of the *M. digastricus* (small arrow) attaches to the auditory bulla of the occipital bone (arrowhead). E: eyeball in the orbit. C: The *M. temporalis* (large arrow) has a thick and strong belly extended near the frontal bone and dorsal part of the pterygoid bone. The *M. digastricus* (small arrow) surrounds the auditory bulla (arrowhead) and extends rostrally in the medial space of the mandibular bone. D: Left side section about 40 mm from the sagittal plane. The *M. masseter* (large arrow) is observed in the medial space of the zygomatic arch. The *M. digastricus* is well-developed in dorso-lateral direction (small arrow). E: eyeball in the orbit.
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Fig. 2. Dorsal MRI sections are shown. Rostral direction at the top. A: Dorsal level of the skull. The M. temporalis becomes thicker in this portion (arrow). B: brain. Bar=20 mm. B: Eyeball level. The M. temporalis is obviously separated into two layers (large arrows). The muscle bundle occupies the lateral space of undeveloped frontal bone and the caudal part of the orbit (small arrow). The most dorsal part of the M. masseter extends into the medial surface of the zygomatic arch (arrowhead). Bar=30 mm.

DISCUSSION

The CT and/or MRI section data have been published in the domesticated dog [1, 2, 5, 6, 17, 18]. However, in the wolf, only our section series has been published for the extinct Japanese wolf skull [3]. An examination of the morphological differences in the masticatory system between wolves and dogs has not been performed previously. Since the present study was focused on the non-invasive anatomy of soft parts related to mastication, we could indicate the advantage of MRI sectioning over the other methods such as CT examination.

The frontal bone is better-developed in size in the domesticated dog than in the wolf including the Japanese wolf [3, 4, 8–14, 16]. The frontal bone of dog skull is enlarged dorso-ventrally and medio-laterally, and provides the large arising surface to the M. temporalis. We think that mastication force may be dependent on the temporal muscle which has a large arising area in the lateral part of the frontal bone.

In contrast with the dog [1, 4], the arising surface of the frontal bone in the gray wolf is not so large in the M. temporalis, as shown in this study. Instead of an undeveloped attachment surface, however, we demonstrated in this study that the small frontal bone does not disturb the M. temporalis from occupying the lateral space of the frontal area. We indicated that the gray wolf has the well-developed muscle bundle with two or three layers in both sides of the frontal bone (Figs. 2B and 4A).

**M. masseter**: The M. masseter has some well-developed bundles from the zygomatic arch to the mandibular bone (Figs. 1C, 2B and 3). Although the M. masseter is totally a large muscle, the bellies are obviously separated into two or three large and thin layers in the MRI sections (Fig. 3). The gray wolf, of which the zygomatic arch extends caudo-laterally, has the muscle belly inserted into the caudal part of the mandibular bone (Fig. 4B).

**M. digastricus**: The muscle bundle lies from the ventral part of the occipital bone to the ventro-madial surface of the mandibular bone (Figs. 1C, 1D and 4B). The arising of the muscle surrounds largely the auditory bulla (Fig. 1D). This muscle extends mainly in the medial space of the mandible body, and the M. mylohyoideus attaches to the medial area of this muscle (Fig. 1A). We could not separate this M. digastricus belly into any parts in the MRI sections.

**Mm. pterygoidei**: The Mm. pterygoidei (M. pterygoideus medialis and M. pterygoideus lateralis) lie between the medial surface of mandibular bone, and the pterygoid, palatine and basisphenoid bones (Figs. 1A and 3). We demonstrated that the M. pterygoideus medialis possesses a well-developed bundle in the lateral part of the pterygoid and basisphenoid bones in transverse sections. The belly is thick in the dorso-ventral direction, and runs rostro-caudally in each side of this muscle (Fig. 3). The M. pterygoideus lateralis possesses a short, but thick belly in the dorsal space of the M. pterygoideus medialis (Fig. 3A).
frontal and parietal bone areas.

It is suggested in Canis lupus that the M. temporalis primarily may not be well-developed in size of arising area, but in the thickness of running bundles. We suggest that the dog has changed the three-dimensional plan of the M. temporalis. The M. temporalis has developed a large arising surface in the frontal bone and lost the thickness of belly in the frontal area because of size development of the frontal bone during domestication. Increases in brain size during domestication [7] support our suggestion that the dog has obtained the attachment area for M. temporalis, but has lost the muscle running space around and in caudal part of the orbit.

Our MRI data indicate that the M. pterygoideus medialis has a thicker and longer bundle in the gray wolf than in the dog [1]. We suggest that the M. pterygoideus medialis has become small because of functional remodeling during domestication. However, the osteological change related to this muscle has not been described, unlike for the frontal bone [8, 9, 10–13, 16]. The caudal part of the mandibular bone has changed in shape during domestication [7], and we expect that it may have an influence on the occurrence of the M. digastricus. It will be needed to compare the dog and the wolf in the M. digastricus form in the future.

Each population of wolf taxonomically belongs to one species, the gray wolf Canis lupus [19]. The Japanese wolf can be distinguished from the gray wolf at the species level [3, 8, 9] or at the subspecies level [19]. However, since the extinct Japanese wolf is similar to the gray wolf in frontal bone development [3, 8, 9], we suggest that this extinct animal may have the same modeling of the M. temporalis as the gray wolf. So, we suggest that the M. temporalis may possess a thick belly and small arising surface in the lateral side of frontal, parietal and pterygoid bones.

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Fig. 4. A: Dorso-lateral right aspect of the head. Rostral direction at the top. The M. temporalis has a large attachment area in the small frontal bone (large arrows). The bundle possesses a huge belly in the caudo-lateral space of the frontal bone (T). B: Ventro-lateral aspect of the head. The M. masseter (M) strongly connects the zygomatic arch and the caudal part of the mandibular bone. The M. digastricus (D) occupies the medial side of the mandibular bone.

REFERENCES
