Positional relationships between the masticatory muscles and their innervating nerves with special reference to the lateral pterygoid and the midmedial and discotemporal muscle bundles of temporalis

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ABSTRACT

For an accurate assessment of jaw movement, it is crucial to understand the comprehensive formation of the masticatory muscles with special reference to the relationship to the disc of the temporomandibular joint. Detailed dissection was performed on 26 head halves of 14 Japanese cadavers in order to obtain precise anatomical information of the positional relationships between the masticatory muscles and the branches of the mandibular nerve. After complete removal of the bony elements, the midmedial muscle bundle in all specimens and the discotemporal muscle bundle in 6 specimens, derivatives of the temporalis, which insert into the disc were observed. On the anterior area of the articular capsule and the disc of the temporomandibular joint, the upper head of the lateral pterygoid, the midmedial muscle bundle of temporalis and the discotemporal bundle of temporalis were attached mediolaterally, and in 3 specimens the posterosuperior margin of the zygomaticomandibularis was attached to the anterolateral area of the disc. It is suggested that these muscles and muscle bundles contribute to various mandibular movements. Although various patterns of the positional relationships between the muscles and muscle bundles and the their innervating nerves are observed in the present study, relative positional relationships of the muscles and muscle bundles and of nerves of the mandibular nerve are consistent. A possible scheme of the developmental formation of the masticatory muscles based on the findings of the positional relationships between the muscles and the nerves is presented.

Key words: Lateral pterygoid muscle; mandibular nerve; masticatory muscles.

INTRODUCTION

The lateral pterygoid muscle, from the viewpoint of physiology, is unique and complex: it plays a key role in the movement of the temporomandibular joint. Some authors have proposed an integrated activity of the lateral pterygoid during opening and protrusion movements (Auf der Mur, 1980; Lehr & Owens, 1980). In contrast, many reports have stated that this is made up of 2 functionally different parts; the upper part is active during closing movement, whereas the lower part is active during protraction, opening and eccentric lateral movements (Kamiyama, 1961; Grant, 1973; MacNamara, 1973; Lipke et al. 1977; Juniper, 1983; Mahan et al. 1983; Gibbe et al. 1984; Widmalm et al. 1987). However, from the viewpoint of morphology, the lateral pterygoid is unique and complex, and the division of this muscle into functional units remains unclear.

The lateral pterygoid has generally been described as a muscle composed of 2 separate heads: upper or superior and lower or inferior heads (Eisler, 1912; Griffin & Sharpe, 1960; Sicher & DuBrul, 1970; Honee, 1972; Rouvière & Delmas, 1974; Testut & Latarjet, 1975; Clemente, 1985; Leonhardt et al. 1987; Williams et al. 1995). However, the muscle is not clearly separated into 2 independent muscles based on innervation findings near its insertion (Eisler,

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1912; Sicher & DuBrul, 1970; Schumacher et al. 1976; Naito, 1979; Terada & Sato, 1982; Tomo, 1990). The muscle frequently shows not only a 2-head pattern but also the 1-head or a 3-head pattern (Troiano, 1967; Naohara, 1989; Abe, 1992; Birou et al. 1992). In addition, Foucart et al. (1998) recently suggested that the lateral pterygoid is composed of 5 to 6 independent functional musculo-aponeurotic layers based on nerve distribution findings.

Temporalis is also complex morphologically. Various muscle bundles are observed in the main part of the muscle. The anteromedial bundle which originates from the infratemporal crest of the sphenoid bone has been given various names: the deep sphenoid part of temporalis (Eisler, 1912), the medial portion of temporalis (Zenker, 1954), the second layer of zygomaticomandibularis (Yoshikawa & Suzuki, 1962), the accessory head of temporalis (Tomo, 1990) and sphenomandibularis (Dunn et al. 1996). The anterolateral bundle of temporalis which is located on the lateral surface of the aponeurosis of the main part of the muscle has also been variously named: the sphenofrontal part of temporalis (Eisler, 1912), the first layer of zygomaticomandibularis (Yoshikawa & Suzuki, 1962) and the pre-anterior belly of temporalis (Shankland et al. 1996). The midlateral bundle which is located on the lateral surface of the middle region of the muscle has been reported as the lateral muscle bundle of temporalis (Eisler, 1912) and the superficial temporalis (Yoshikawa & Suzuki, 1962). Shimokawa et al. (1998), based on an innervation investigation, proposed that these 3 bundles are considered as parts of temporalis rather than as independent muscles, and simply called these bundles the anteromedial, anterolateral and midlateral muscle bundles of temporalis. In addition, a bundle (discotemporal bundle) from the posterior part of temporalis which attaches to the lateral third of the disc has been reported (Couly et al. 1975*a*, *b*, 1976; Couly, 1980; Le Toux et al. 1989; Naohara, 1989; Merida Velasco et al. 1993).

The nerves to the muscles of mastication are as follows: the nerve to medial pterygoid, the nerve to the lateral pterygoid, the anterior, middle and posterior deep temporal nerves and the masseteric nerve. The nerves to temporalis have been classified and described in various ways (Eisler, 1912; Hovelacque, 1927; Rouvière & Delmas, 1974; Terada & Sato, 1982; Clemente, 1985; Leonhardt et al. 1987; Williams et al. 1995). Here we consider the nerve to temporalis based on its positional relationship to the lateral pterygoid and according to Terada & Sato (1982) based on the classifications of Eisler (1912) and Hovelacque (1927) as follows. (1) The anterior deep temporal nerve arises from the buccal nerve (temporobuccal nerve) and is distributed in the anterior portion of temporalis. (2) The middle deep temporal nerve forms a common trunk with the masseteric nerve, and separates early from the main nerve to distribute in the middle portion of the muscle. (3) The posterior deep temporal nerve arises from the masseteric nerve independently of the middle deep temporal nerve (temporomasseteric nerve) and is distributed in the posterior portion of the muscle.

In the present study, we found that the midmedial muscle bundle of temporalis frequently adjoins the lateral surface of the upper head of the lateral pterygoid, and inserts into the anterior extension of the articular disc (Rees, 1954) adjacent to the insertion of the upper head of the lateral pterygoid. The aim of the present study was to examine (1) the discotemporal and the midmedial bundles of temporalis, (2) the ramification of nerves distributed to the lateral pterygoid and temporalis, (3) the positional relationship between the masticatory nerves and the lateral pterygoid muscle, and (4) the intramuscular distribution of the nerves of these muscles. A possible scheme to account for the positional relationships between the masticatory muscles and the branches of the mandibular nerve based on the present findings and our recent studies (Shimokawa et al. 1998, 1999) is proposed.

MATERIALS AND METHODS

Twenty-six head halves of 14 Japanese cadavers (8 males, 6 females) were used for this study. These cadavers were fixed in 10% formalin and preserved in 30% alcohol. In order to examine the lateral pterygoid and temporalis, especially the muscle bundles which are attached to the disc of the temporomandibular joint in situ, the bony elements (parietal bone and frontal bones squamous part of the temporal bone and the greater wing of the sphenoid) were entirely removed from the inside of the cranium according to the superior approach reported by Pinto (1962). Then the positional relationships of the lateral pterygoid and temporalis to the surrounding nerves (including the zygomatic nerve) originating from the maxillary nerve were investigated. After removal of the masticatory muscles en bloc with the mandibular nerve and its branches, the innervation patterns of temporalis and the lateral pterygoid were examined. These muscles were then immersed in water to examine the intramuscular nerve distribution in detail under a binocular microscope.

RESULTS

Most of the muscle fibres from the upper head of the lateral pterygoid inserted into the disc of the temporomandibular joint, and most of the fibres from the lower head inserted into the neck of the condyle of the mandible. The remaining fibres inserted into the border area between the capsule and the neck. Both upper and lower heads were not clearly divided, since the muscle fibres in the border area between them were intermingled, especially near the insertion of the muscle.

Various muscle bundles of temporalis

The anterolateral and anteromedial muscle bundles of temporalis were observed as described by Shimokawa et al. (1998). On the broad fan-shaped main part of temporalis, the anterolateral temporalis bundle was located on the lateral surface of the aponeurosis of the main part of the muscle. The anterolateral bundle originated from the posterior region of the orbital part of the zygomatic bone and the outer lateral region of the main part of temporalis, and inserted directly into the lateral surface of the aponeurosis and frequently into the anterior margin of the coronoid process. The anteromedial muscle bundle originated from the infratemporal crest and the lateral part of the infratemporal surface of the sphenoid bone, and inserted into the anterior region of the medial surface of the coronoid process.

After removal of the lateral surface of the skull, we found that the midmedial bundle, which was located on the medial surface of temporalis, ran posteriorly, and inserted into the disc of the temporomandibular joint just lateral to the area into which muscle fibres of the upper head of the lateral pterygoid were inserted (Figs 1*A*, *B*). The midmedial bundle of temporalis originated from the lateral part of the infratemporal fossa just posterior to the area from which the anteromedial muscle bundle of temporalis originated. In some specimens, the midmedial bundle was tightly adjoined to the lateral surface of the upper head of the lateral pterygoid in the posterior half of the muscle (Fig. 1*C*).

In 6 specimens the discotemporal bundle originated

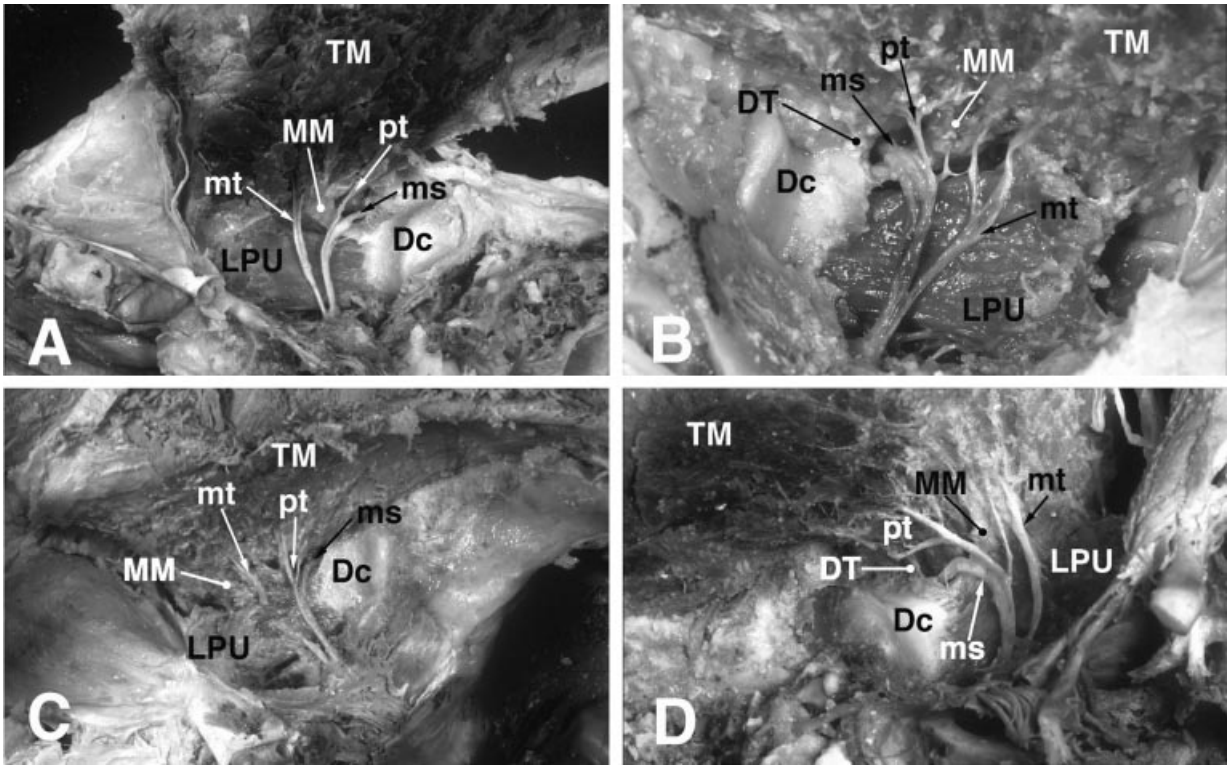

Fig. 1. Muscle bundle between temporalis and lateral pterygoid after removal of the bony elements as viewed from the superomedial aspect. This midmedial muscle bundle was found in all specimens examined. This bundle, located on the medial surface of temporalis, ran posteriorly, and inserted into the disc of the temporomandibular joint. The midmedial bundle is frequently observed to contact the lateral surface of the upper head of the lateral pterygoid muscle. In addition, the discotemporal muscle bundle was sometimes observed; it originated from the medioposterior part of temporalis, ran posteroinferiorly, and inserted into the disc of the temporomandibular joint. (*A*) Specimen 1 (right). (*B*) Specimen 2 (left). (*C*) Specimen 3 (right). (*D*) Specimen 4 (left). Dc, temporomandibular joint disc; DT, discotemporal temporalis bundle; LPU, upper head of the lateral pterygoid; MM, midmedial temporalis bundle; ms, masseteric nerves; mt, middle deep temporal nerve, pt, posterior deep temporal nerve; TM, main part of temporalis.

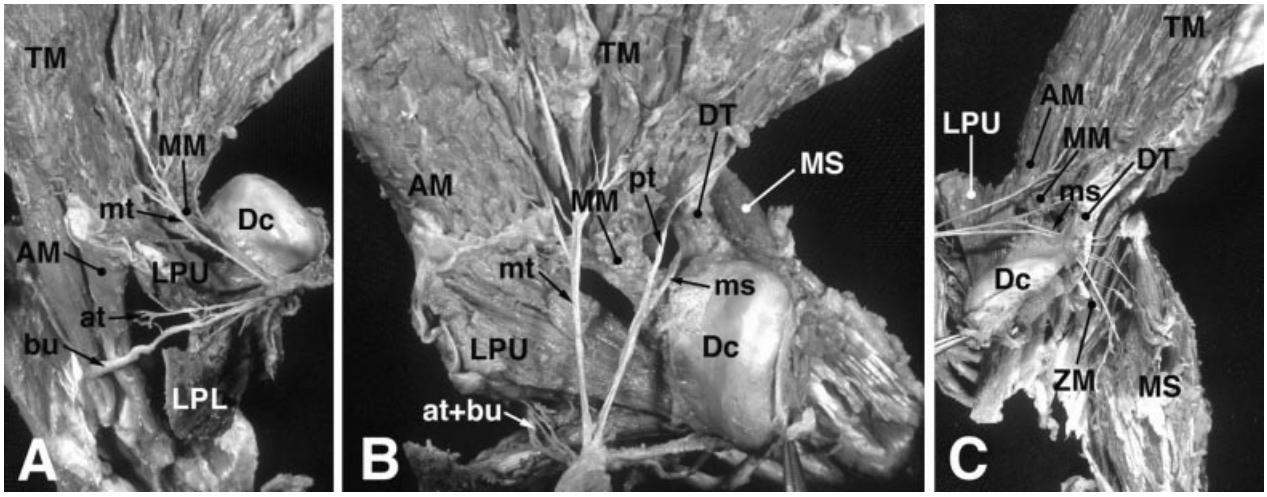

Fig. 2. Specimen 5 (right). Typical pattern of the positional relationships between the masticatory muscles and the mandibular nerve branches. The medial pterygoid muscle has been removed. (*A*) Viewed from the anterior aspect. The buccal nerve and the anterior deep temporal nerve pass between the upper and lower heads of the lateral pterygoid. (*B*) Viewed from the superomedial aspect, the middle and posterior deep temporal nerves run over the superior surface of the upper head, and the masseteric nerve runs between the midmedial and discotemporal muscle bundles of temporalis. (*C*) Viewed from the posterior aspect, the masseteric nerve runs between the zygomaticomandibularis and masseter. AM, anteromedial temporalis bundle; at, anterior deep temporal nerve; bu, buccal nerve; Dc, temporomandibular joint disc; DT, discotemporal temporalis bundle; LPL, lower head of the lateral pterygoid; LPU, upper head of the lateral pterygoid; MM, midmedial temporalis bundle; MS, masseter; ms, masseteric nerve; mt, middle deep temporal nerve; pt, posterior deep temporal nerve; TM, main part of temporalis; ZM, zygomaticomandibularis.

from the medioposterior part of temporalis, ran posteriorly and inferiorly, and inserted into the disc of the temporomandibular joint through the anterior extension lateral to the area to which the midmedial muscle bundle inserted (Fig. 1*D*). The masseteric nerve ran between the midmedial bundle and the main part of temporalis and then between the midmedial bundle and the discotemporal bundle (Fig. 1*B*, *D*). These muscle bundles and the main part of the temporalis were therefore clearly distinguishable from each other.

Positional relationships between the masticatory muscles and the mandibular nerves

Varying positional relationships were observed between the masticatory muscles and branches of the mandibular nerve. The nerves to the masticatory muscles arose radially from the outer surface of the mandibular nerve. In general, the buccal nerve and the anterior deep temporal nerve passed through the lateral pterygoid near the border between the upper and lower heads, the middle and posterior deep temporal nerves ran on the superior surface of the upper head, and the masseteric nerve ran between the zygomaticomandibularis and the masseter (Fig. 2). After passing through the lateral pterygoid, the buccal nerve ran on the anterior margin of the anteromedial temporalis bundle to reach the skin covering buccinator. In 3 specimens (11.5%), the buccal nerve pierced the anteromedial temporalis bundle, and gave off twigs to this bundle. In 1 specimen, the anterior deep temporal nerve and buccal nerve ran on the superior surface of the lateral pterygoid (Fig. 3*A*). The middle deep temporal nerve usually ran on the superior surface of the lateral pterygoid muscle, and branches or the main trunk of the middle deep temporal nerve frequently pierced the upper head of the muscle (17 specimens, 65.4%) (Fig. 3*B*). The posterior deep temporal nerve ran on the superior surfaces of the upper head and the midmedial muscle bundle of temporalis in all specimens.

The main trunk of the mandibular nerve usually ran on the medial surface of the lower head of the lateral pterygoid, but in 1 specimen the trunk passed through the lower head (Fig. 4). The nerve to the medial pterygoid was frequently observed to form a common trunk with the branch to the lower head of the lateral pterygoid, which originated from the mandibular nerve trunk.

Nerve distribution to the lateral pterygoid

With regard to the nerve distribution to the lateral pterygoid, twigs of the anterior deep temporal nerve innervated the upper and lower pterygoid heads from their respective contact surfaces to the nerve in all specimens. Twigs from the mandibular nerve trunk

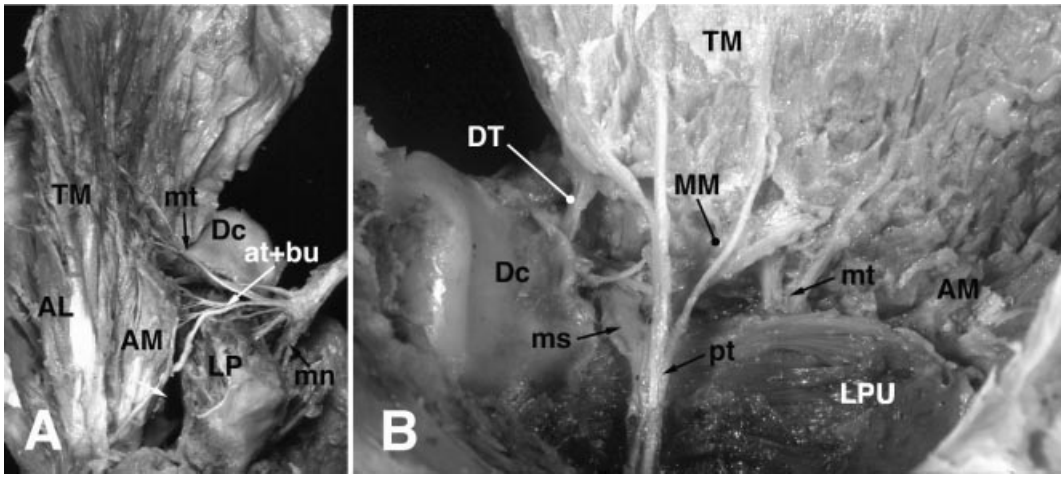

Fig. 3. Atypical relationships of the nerves to the upper head of the lateral pterygoid. (*A*) Specimen 8 (right anterior aspect). In this specimen, the anterior deep temporal nerve and the buccal nerve run over the superior surface of the upper head, and the buccal nerve pierces the anteromedial muscle bundle of temporalis. (*B*) Specimen 9 (left superomedial aspect). The middle deep temporal nerve pierces the upper head. AL, anterolateral temporalis bundle; AM, anteromedial temporalis bundle; at, anterior deep temporal nerve; bu, buccal nerve; Dc, temporomandibular joint disc; DT, discotemporal temporalis bundle; LP, lateral pterygoid; LPU, upper head of the lateral pyerygoid; MM, midmedial temporalis bundle; mn, main trunk of the mandibular nerve; ms, masseteric nerve; mt, middle deep temporal nerve; pt, posterior deep temporal nerve; TM, main part of temporalis.

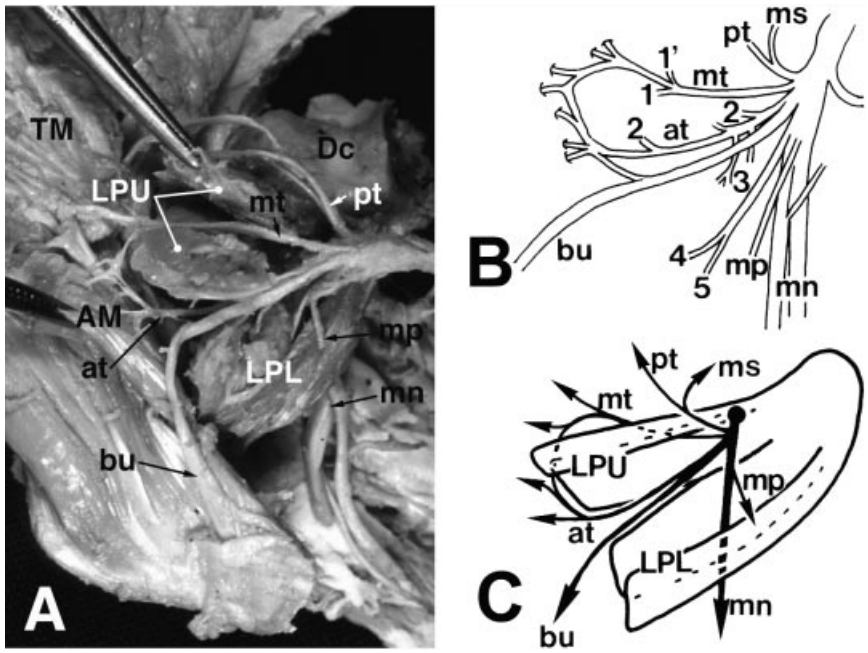

Fig. 4. Specimen 11 (right). (*A*) In a highly atypical specimen, viewed from the anterior aspect, the middle deep temporal nerve runs between the superior and inferior parts of the upper head, and communicates with the anterior deep temporal nerve between the upper head and temporalis. In addition, the main trunk of the mandibular nerve pierces the lower head, dividing it into lateral and medial parts. (*B*) Branching pattern of the mandibular nerve from the medial aspect. Twig 1′ innervates the superior part of the upper head. Twigs 1 and 2 innervate the inferior part of the upper head. Twigs 3 and 4 innervate the lateral part of the lower head. Twig 5 innervates the medial part of the lower head. (*C*) The positional relationship between the nerves and the lateral pterygoid. The masseteric nerve and the posterior deep temporal nerve run on the superior surface of the upper head. The middle deep temporal nerve runs between the superior and inferior parts of the upper head. The main trunk of the mandibular nerve runs between the lateral and medial parts of the lower head. The nerve to the medial pterygoid runs on the medial surface of the medial part of the lower head. The anterior and middle deep temporal nerves communicate with each other on the lateral surface of the upper head. AM, anteromedial temporalis bundle; at, anterior deep temporal nerve; bu, buccal nerve; Dc, temporomandibular joint disc; LPL, lower head of the lateral pterygoid; LPU, upper head of the lateral pterygoid; mn, main trunk of the mandibular nerve; mp, nerve to the medial pterygoid; ms, masseteric nerve; mt, middle deep temporal nerve; pt, posterior deep temporal nerve; TM, main part of temporalis.

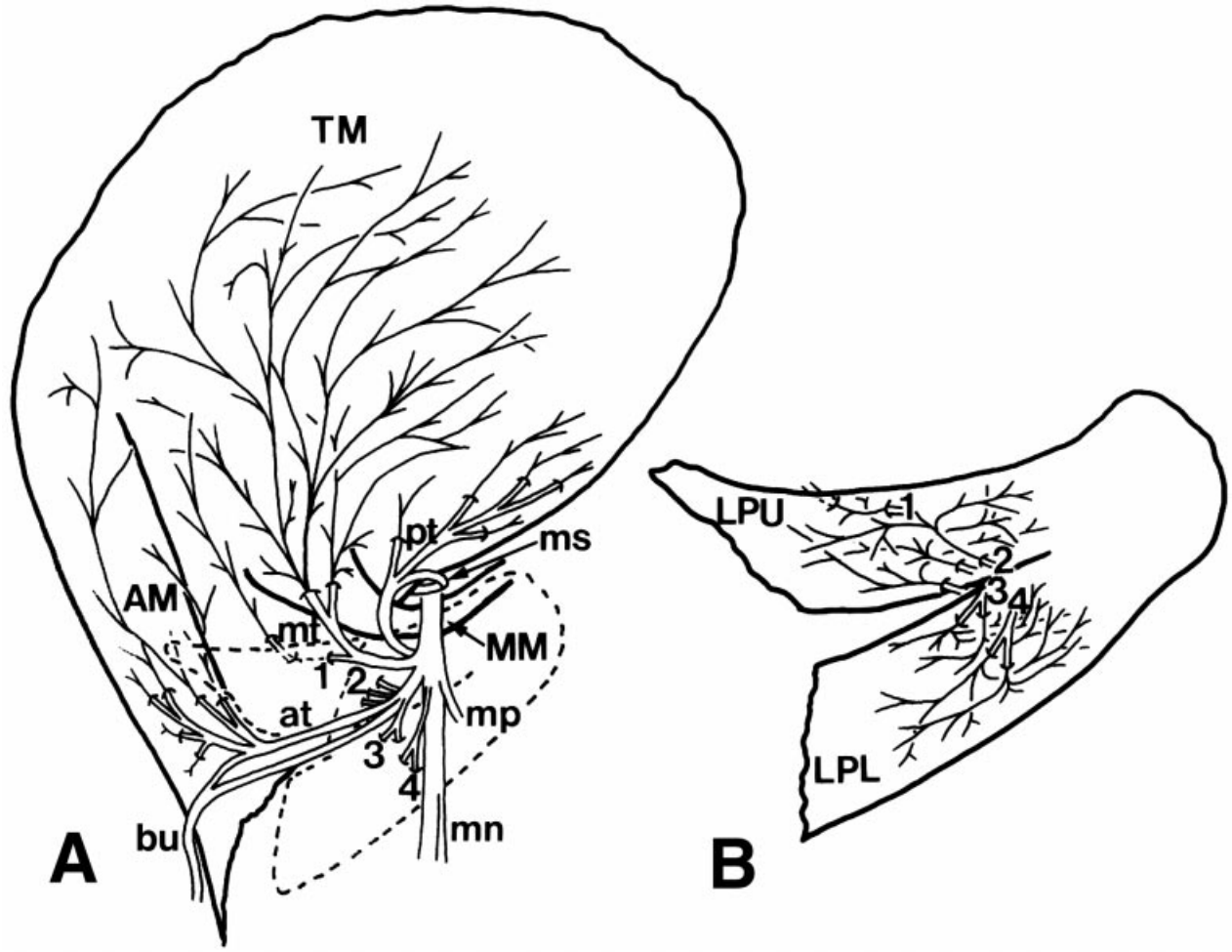

Fig. 5. Intramuscular nerve distribution. Specimen 13 (right). (*A*) Branch (1) of the middle deep temporal nerve pierces the upper head to distribute to the region between the parts innervated by the anterior and middle deep temporal nerves. The midmedial muscle bundle of the temporalis is innervated by twigs from the middle deep temporal nerve. (*B*) The lateral pterygoid is innervated by a branch (1) of the middle deep temporal nerve, branches (2 and 3) of the anterior deep temporal nerve and branches (4) from the main trunk of the mandibular nerve. AM, anteromedial temporalis bundle; at, anterior deep temporal nerve; bu, buccal nerve; LPL, lower head of the lateral pterygoid; LPU, upper head of the lateral pterygoid; MM, midmedial temporalis bundle; mn, main trunk of the mandibular nerve; mp, nerve to the medial pterygoid; ms, masseteric nerve; mt, middle deep temporal nerve; pt, posterior deep temporal nerve; TM, main part of temporalis.

innervated the lower head in 20 specimens (76.9%; Fig. 5). The upper head was additionally innervated by twigs from the middle deep temporal nerve in 16 specimens (61.5%; Figs 5, 6).

Examination of the intramuscular nerve distribution of the lateral pterygoid muscle revealed that twigs of the anterior deep temporal nerve were distributed to both upper and lower heads, twigs of the middle deep temporal nerve were distributed to the upper head, and twigs of the mandibular nerve trunk to the lower head (Figs 5, 6). Within the lateral pterygoid the twigs were divided into tiny twigs which ran both anteriorly and posteriorly. According to the nerve distribution, the upper and lower heads were not clearly divided, especially in the posterior half of the muscle. In the posterior half, it was frequently observed that some of the twigs to the lower head from the anterior deep temporal nerve also supplied the upper head, and vice versa (Fig. 6). Twigs of the anterior and middle deep temporal nerves communicated with each other in the upper head in 6 specimens (23.1%). In 5 specimens (19.2%), the communicating branches between the anterior and middle deep temporal nerves were observed between the upper head and the midmedial bundle of temporalis. The anterior and middle deep temporal nerves thus communicated with each other outside and/or inside the upper head in 9 specimens (34.6%). The twigs to the midmedial muscle bundle of temporalis pierced the bundle and were distributed to the main part of temporalis, and therefore the midmedial muscle bundle was not divided from the main part of temporalis according to the nerve distribution (Figs 5, 6). In 1 specimen, the main trunk of the mandibular nerve pierced the lower head dividing it into lateral and medial parts (Fig. 4). In this specimen the lateral

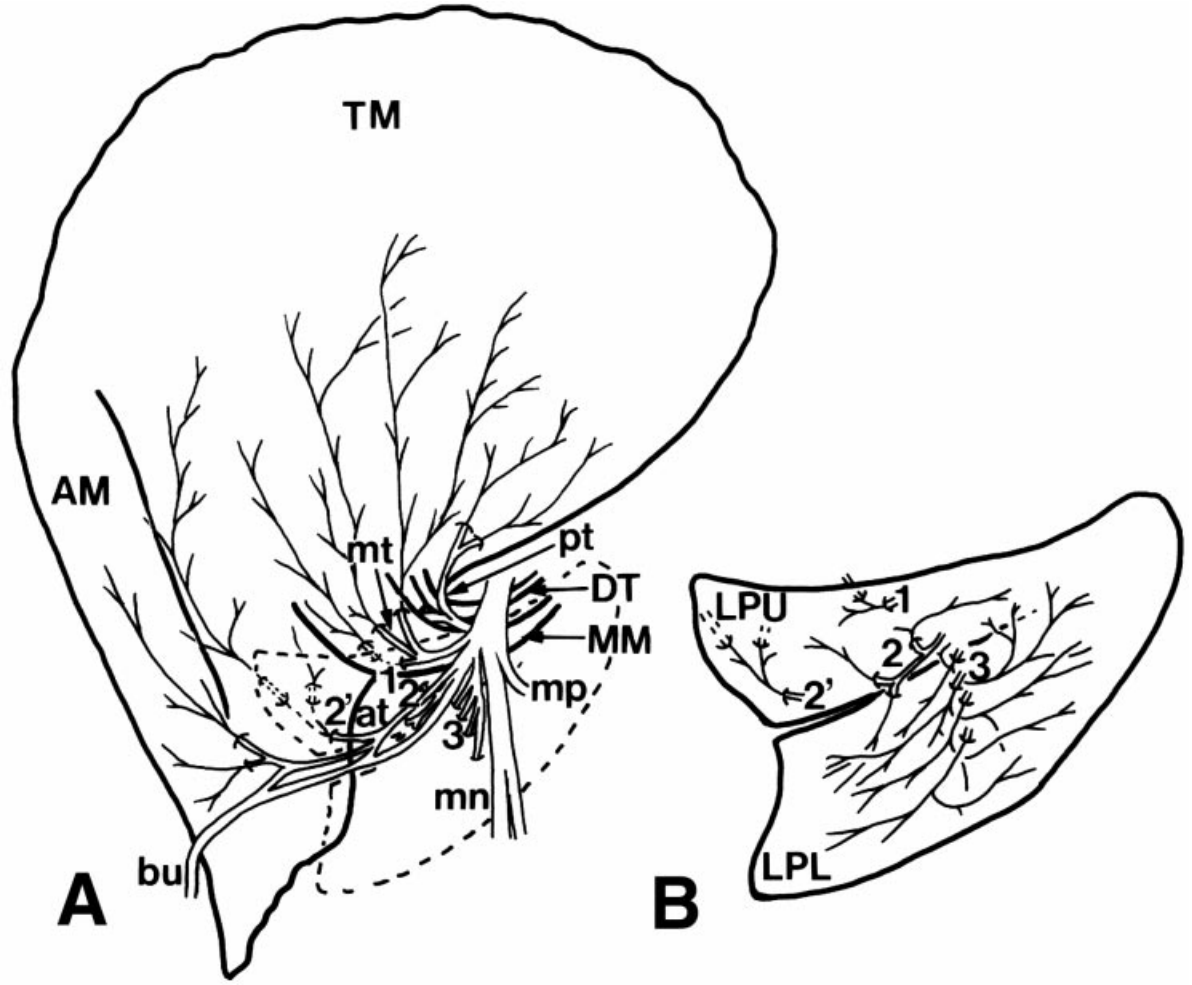

Fig. 6. Intramuscular nerve distribution. Specimen 15 (right). (*A*) Branch (2′) of the anterior deep temporal nerve pierces the upper head to distribute to the region between the parts innervated by the anterior and middle deep temporal nerves. The midmedial muscle bundle of temporalis is innervated by twigs from the middle deep temporal nerve, and the discotemporal muscle bundle is innervated by a twig from the posterior deep temporal nerve. (*B*) The lateral pterygoid muscle is innervated by a branch (1) of the middle deep temporal nerve and branches (2 and 3) of the anterior deep temporal nerve. Some twigs to the lower head from the anterior deep temporal nerve also distribute to the upper head, and vice versa. AM, anteromedial temporalis bundle; at, anterior deep temporal nerve; bu, buccal nerve; DT, discotemporal temporalis bundle; LPL, lower head of the lateral pterygoid, LPU, upper head of the lateral pterygoid; MM, midmedial temporalis bundle; mn, main trunk of the mandibular nerve; mp, nerve to the medial pterygoid; mt, middle deep temporal nerve; pt, posterior deep temporal nerve; TM, main part of temporalis.

part was innervated by twigs of the anterior deep temporal nerve and by a twig of the mandibular nerve trunk from medial aspect, while the medial part was innervated by a twig of the main trunk from lateral aspect.

Nerve distribution to the temporalis

The anterior deep temporal nerve was distributed to the anterior part of the temporalis including its anteromedial bundle, the middle deep temporal nerve was distributed to the middle part of the muscle, and the posterior deep temporal nerve, to the posterior part (Figs 5, 6). In addition, in 3 specimens, although the zygomaticotemporal nerve (a terminal branch of the maxillary nerve) pierced the main part of temporalis, it did not give off muscular branches to the main part. The midmedial muscle bundle of temporalis was innervated by twigs of the middle and posterior deep temporal nerves from medial and/or sometimes from lateral. The discotemporal muscle bundle was innervated by twigs of the posterior deep temporal nerve. This nerve, which passed through the more superior region of the lateral pterygoid, was distributed to the more posterior region of the temporalis.

Muscles attached to the temporomandibular joint and their nerve supply

On the anterior area of the articular capsule and the disc of the temporomandibular joint from medial to

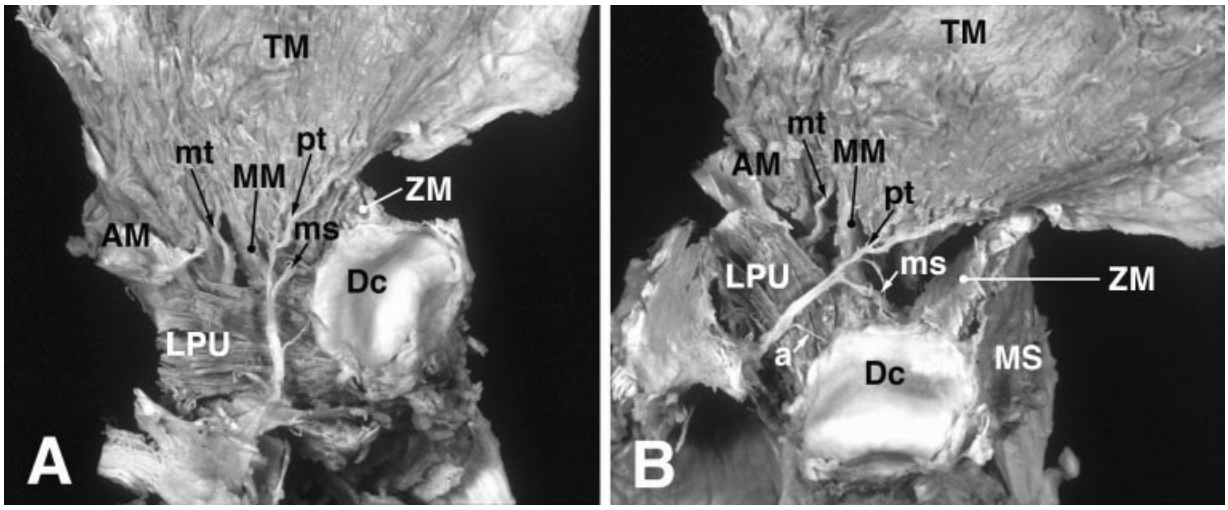

Fig. 7. Specimen 17 (right). Manner of attachment of the muscles to the disc following en bloc removal of the masticatory muscles. (*A*) Viewed from the superomedial aspect, the upper head of the lateral pterygoid and the midmedial muscle bundle of temporalis attach to the disc of the temporomandibular joint. In addition, the posterosuperior margin of zygomaticomandibularis attaches to the anterolateral area of the disc. (*B*) Viewed from the posterior aspect, the upper head of the lateral pterygoid, the midmedial muscle bundle of temporalis and zygomaticomandibularis attach to the disc mediolaterally. The superior margin of masseter attaches the lateral surface of the articular capsule. a, articular branch; AM anteromedial temporalis bundle; Dc, temporomandibular joint disc; LPU, upper head of the lateral pterygoid; MM, midmedial temporalis bundle; MS, masseter; ms, masseteric nerve; mt, middle deep temporal nerve; pt, posterior deep temporal nerve; TM, main part of temporalis; ZM, zygomaticomandibularis.

lateral, the upper head of the lateral pterygoid, the midmedial muscle bundle of temporalis and the discotemporal muscle bundle of temporalis were attached (Figs 1, 2*B*, *C*, 3*B*, 7). In addition, in 3 specimens the posterosuperior margin of the zygomaticomandibularis was attached to the anterolateral area of the disc (Fig. 7*B*). Only the small posterosuperior part of masseter was attached to the lateral surface of the articular capsule (Fig. 7*B*). The masseteric nerve ran between the midmedial muscle bundle and the discotemporal muscle bundle and ran between zygomaticomandibularis and masseter. During its course, the masseteric nerve gave off articular branches from the anterior surface of the capsule mainly between the areas to which the midmedial and discotemporal bundles were inserted. In addition, the auriculotemporal nerve ran on the medial and posterior surface of the neck of the mandible, and gave off branches to the articular capsule.

DISCUSSION

In electromyographic studies, the lateral pterygoid muscle is generally described as a single muscle having 2 different functions (Kamiyama, 1961; Grant, 1973; MacNamara, 1973; Lipke et al. 1977; Juniper, 1983; Mahan et al. 1983; Gibbs et al. 1984; Widmalm et al. 1987). Based on findings of the human fetus, Merida-Velasco et al. (1993) and Ögütcen-Toller & Juniper (1993) believed that the lateral pterygoid is divided into 2 or 3 main parts. In contrast, according to morphological studies including the present study, this muscle is not clearly divided into distinct parts, although it does show various patterns of 1 to 3 heads in the anterior half (Eisler, 1912; Troiano, 1967; Schumacher et al. 1976; Naito, 1979; Terada & Sato, 1982; Naohara, 1989; Tomo, 1990; Abe, 1992; Birou et al. 1992; Foucart et al. 1998). The insertion area of the lateral pterygoid is broadly spread between the disc of the temporomandibular joint and the condyle of the mandible, and there is no clear division between the heads near their posterior halves. The lateral pterygoid may first differentiate to form 2 or 3 parts, but these parts are not clearly divided during the expansion of their insertion areas on the disc and the condyle of the mandible.

Textbooks indicate that the nerve to the lateral pterygoid mainly originates from the buccal nerve (Henle, 1858; Poirier & Charpy, 1901; Rauber, 1903; Paturet, 1964; Rouvière & Delmas, 1974; Clemente, 1985; Williams et al. 1995). Foucart et al. (1998) recently reported that this muscle is primarily innervated by branches which arise from the anterior trunk of the mandibular nerve as 1 to 3 terminal nerves, and the muscle is additionally innervated by branches from the buccal, auriculotemporal and masseteric nerves. In the present study, the lateral pterygoid was innervated by twigs of the anterior deep temporal nerve which runs along with the buccal nerve, the middle deep temporal nerve and the main trunk of the

mandibular nerve. However, muscular branches to the lateral pterygoid from the auriculotemporal nerve and the masseteric nerve were not found. The present findings showed that branches of the middle deep temporal nerve frequently pierce the upper head of the lateral pterygoid, and the branches of the anterior and middle deep temporal nerves have communications with each other inside and/or outside the upper head. Therefore, it was frequently observed that the lateral pterygoid has a close relationship with temporalis based on the findings of their innervation. The anterior and middle deep temporal nerves innervated the anterior and middle parts of temporalis respectively, after giving off twigs to the upper head of the lateral pterygoid. Therefore, the lateral pterygoid and the temporalis are considered to differentiate from a common anlage, the deeper layer of which becomes the lateral pterygoid.

Among the muscle bundles attached to the disc of the temporomandibular joint, it is well known that most of the upper head of the lateral pterygoid inserts into the disc (Couly et al. 1975*a*, *b*, 1976; Couly 1980; Meyenberg et al. 1986; Sugisaki et al. 1986; Le Toux et al. 1989; Naohara, 1989; Merida-Velasco et al. 1993). Le Toux et al. (1989) described the bundle as the discotemporal muscle bundle having a supplementary function of guiding the articular disc anteriorly. Sugisaki et al. (1986) and Naohara (1989) observed a muscle bundle, which originates from the medial surface of the middle part of temporalis and inserts into the articular disc, but the details of this bundle remain unclear. In the present study, we observed the midmedial muscle bundle of temporalis in all specimens. This midmedial muscle bundle originates from the deep layer of the middle and posterior part of temporalis, runs posteroinferiorly parallel to the upper head of the lateral pterygoid, and inserts into the disc adjacent to the insertion of the upper head. The upper head of the lateral pterygoid is active during closing movements (Kamiyama, 1961; Grant, 1973; MacNamara, 1973; Lipke et al. 1977; Juniper, 1983; Mahan et al. 1983; Gibbs et al. 1984; Widmalm et al. 1987), and therefore, the bundle functions to guide the articular disc anteriorly during closing in cooperation with the upper head and the discotemporal muscle bundle of temporalis. The midmedial bundle is innervated by twigs of the middle and posterior deep temporal nerves. Based on the nerve distribution findings, the midmedial muscle bundle is independent from the upper head of the lateral pterygoid muscle, but is not clearly divided from the main part of temporalis. The midmedial muscle bundle is therefore considered as a medial part of temporalis rather than an independent muscle or a part of the lateral pterygoid. In addition, although few reports discuss the midmedial muscle bundle, this bundle is considered to occupy a very critical position between the lateral pterygoid and temporalis and to contribute to temporomandibular joint movement.

Merida-Velasco et al. (1993) stated that temporalis and masseter muscle bundles attached to the temporomandibular joint disc oppose the anteromedial traction sustained by the disc due to the action of the upper head of the lateral pterygoid during closing. However, since masseter attaches to the articular capsule just near its origin, it is considered that the muscle has only a passive action on the articular disc rather than an active function. In addition, in the present study, in some specimens the posterosuperior margin of zygomaticomandibularis was also found to attach to the anterolateral area of the disc. The upper head, the midmedial and discotemporal muscle bundles, and sometimes zygomaticomandibularis attach to the anterior area of the disc radially. It is therefore suggested that these muscles and muscle bundles contribute to various mandibular movements in the anterior direction.

A scheme we wish to propose is based on the findings of the positional relationships between the branches of the mandibular nerves and the masticatory muscles. Some studies classify the masticatory muscles according to the positional relationships with the mandible into lateral and medial groups consisting of the masseter and temporalis muscles on the one hand and the lateral and medial pterygoids on the other (Sappey, 1876; Reuter, 1897; Lewis, 1910; Romer, 1962; Paturet, 1964; Rayne & Crawford, 1971). However, other studies have classified the muscles into lateral and medial groups according to their positional relationship with the main trunk of the mandibular nerve, i.e. the masseter, temporalis and lateral pterygoid laterally and the medial pterygoid medially (Gegenbaur, 1903; Edgeworth, 1914; Lubosch, 1938; Terada & Sato, 1982; Tomo, 1990; Tomo et al. 1993). From comparative embryological studies, Edgeworth (1914) reported that the common anlage of the masticatory muscles is first divided into medial and lateral parts; the medial part of the anlage becomes the medial pterygoid. In the present study, in 1 specimen it was observed that the mandibular nerve trunk passed through the lower head of the lateral pterygoid. In addition, the nerve to the medial pterygoid sometimes formed a common trunk with the branch to the lower head. Therefore, the mandibular nerve trunk may not serve as a clear demarcation between the medial and lateral anlagen. Based

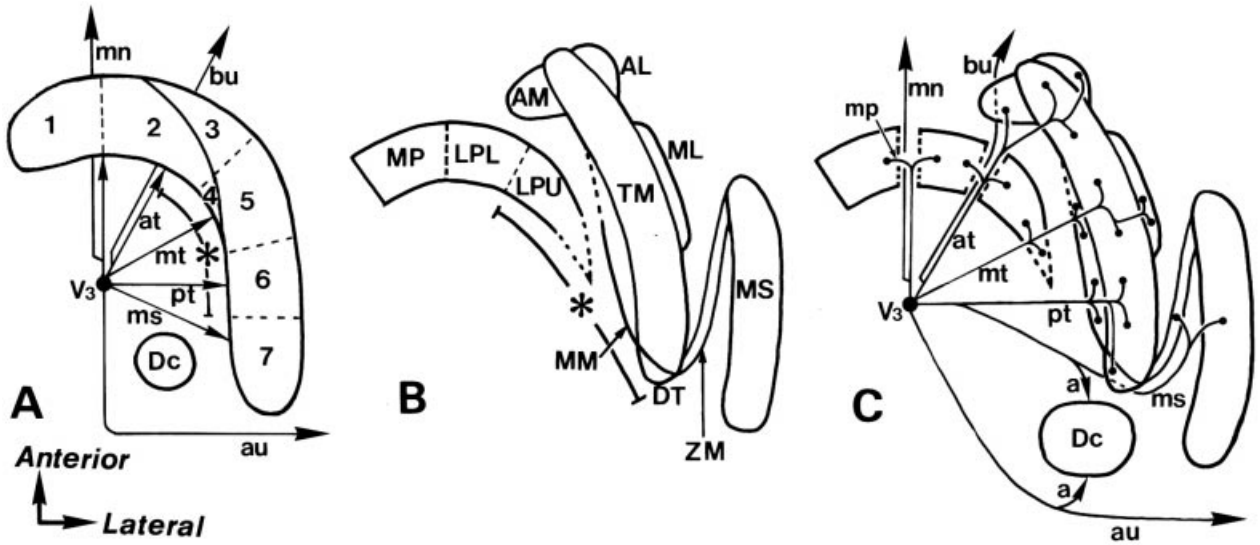

Fig. 8. Schematic transverse sections showing a possible model of the developmental formation of the masticatory muscles based on the embryological study of Edgeworth (1914) as well as the present innervation findings. The muscles which attach to the disc of the temporomandibular joint are derived from the midmedial part of the anlage of the masticatory muscle, and are indicated by an asterisk. (*A*) Initial stage. The common anlage of the masticatory muscles is presumptively classified into several parts according to the innervating nerves. The branches of the mandibular nerve supply the common anlage of the masticatory muscles radially. The parts which are innervated by the anterior and middle deep temporal nerves are divided into medial and lateral parts. (*B*, *C*) Definitive stages. The positional relationship between the masticatory muscles and the branches of the mandibular nerve. The innervation of the anteromedial, anterolateral and midlateral muscle bundles was reported by Shimokawa et al. (1998), and that of zygomaticomandibularis and masseter by Shimokawa et al. (1999). Based on the findings of the innervation patterns and the positional relationships between the muscles and nerves, the origins of the masticatory muscles are considered as follows. The medial pterygoid derived from most of Part 1. The lower head of the lateral pterygoid is derived from the lateral small part of Part 1 and the medial half of Part 2. The upper head of the lateral pterygoid is derived from the lateral half of Part 2 and sometimes from Part 4. Temporalis and its derivatives are derived from Parts 3, 5 and 6. Zygomaticomandibularis and masseter are derived from Part 7. a, articular branch; AL anterolateral temporalis bundle; AM, anteromedial temporalis bundle; at, anterior deep temporal nerve; au, auriculotemporal nerve; bu, buccal nerve; Dc, temporomandibular joint disc; DT, discotemporal temporalis bundle; LPI, lower head of the lateral pterygoid; LPL, upper head of the lateral pterygoid; ML, midlateral temporalis bundle; MM, midmedial temporalis bundle; mn, main trunk of the mandibular nerve; MP, medial pterygoid; mp, nerve to the medial pterygoid; MS, masseter; ms, massereric nerve; mt, middle deep temporal nerve; pt, posterior deep temporal nerve; TM, main part of temporalis; V_3, mandibular nerve; ZM, zygomaticomandibularis.

on comparative anatomical studies, Lubosch (1938) and Tomo et al. (1993) pointed out that the anteromedial muscle bundle of temporalis is closely related to the upper head of the lateral pterygoid. In the present study, it was observed that the upper head of the lateral pterygoid frequently adjoined the anteromedial and midmedial bundles of temporalis, and therefore the lateral pterygoid in man seems closely related to the anterior and middle part of temporalis as mentioned above. Masseter and zygomaticomandibularis arise from the posterior part of the anlage of the masticatory muscles (Edgeworth, 1914). Shimokawa et al. (1999) suggested that during migration the muscle bundle medial to the masseteric nerve trunk might form zygomaticomandibularis, and the muscle bundle lateral to the trunk might form masseter. In addition, it is considered that some muscle bundles are the derivatives of temporalis, and Shimokawa et al. (1998) described the anteromedial, anterolateral and midlateral muscle bundles as parts of temporalis. The anteromedial muscle bundle may be derived from the anteriormost part of the anlage of temporalis, and may move to the medial surface of the main part of temporalis (Shimokawa et al. 1998). According to the findings of the present study, the midmedial muscle bundle of temporalis is considered to derive from the middle and posterior part of temporalis.

During development, it is thought that the lateral pterygoid muscle maintains a close relationship with the disc of the temporomandibular joint (Wong et al. 1985; Merida-Velasco et al. 1993). However, it has been suggested that the disc formation is independent of the muscle development (Baume, 1962; Baume & Holz, 1972; Van der Linden et al. 1987; Öğütecen-Toller & Juniper, 1993). The muscle bundles which attach to the articular disc are the upper head of the lateral pterygoid, and the midmedial and discotemporal muscle bundles of temporalis. It is considered that these muscle bundles are derived from the midmedial part of the anlage of the masticatory muscles. The muscle bundle, which is derived from the

more anterior region of the midmedial part of the anlage, attaches the disc in the more medial region.

Figure 8 schematically represents the positional relationships between the masticatory muscles and the branches of the mandibular nerve based on the present findings and our recent studies (Shimokawa et al. 1998, 1999). In the present study, various combinations of innervation patterns were observed. The lateral pterygoid was frequently pierced by branches of the anterior and middle deep temporal nerves and the main trunk of the mandibular nerve; it seems to have various pattern of 3 or 4 heads. In addition, we observed in 1 specimen that the buccal and anterior deep temporal nerves run on the superior surface of the muscle, and the muscle is considered as the muscle consisting of only a single head as Tomo et al. (1995) described in the dog. These patterns and routes are considered to reflect variability of the differentiation patterns of the common anlage and of the branching patterns of the nerves. Therefore, the present findings revealed that the positional relationships among the branches of the mandibular nerve and those among the masticatory muscles and their derivatives are relatively consistent, although the branching patterns and innervation patterns are very variable. Various combinations of branching patterns of the nerves and differentiating patterns of the muscles could explain various findings of the positional relationships of the muscles and the nerves.

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