The Motor Nerve Supply of the Velopharyngeal Muscles

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Introduction

In order to obtain knowledge of the physiological mechanisms of the velopharyngeal movements, it is very important to clarify the motor nerve supply of the muscles related to velopharyngeal closure.

This problem has been discussed by many investigators since the last century. Turner (*26*), Rethi (*23*), Druner (*8*) and Rich (*24*) revealed innervation of the trigeminal nerve to the tensor veli palatini muscle by means of anatomical and/or experimental procedures. However there is, as yet, a great deal of disagreement concerning the nerve supply of the other velopharyngeal muscles, especially of the levator veli palatini, uvula, and superior constrictor pharyngeus muscles. Some scholars such as Cords (*5*) and Broomhead (*4*) described these muscles as innervated by branches of the pharyngeal plexus derived from the glossopharyngeal and vagus nerves. Rich (*24*) reported from experiments on dogs that contraction of the levator veli palatini muscle could be elicited by stimulation of the vagus and accessory nerves but not by facial and glossopharyngeal stimulation. Moritz (*18*) and others (*16, 20*) reported velar disability in patients who suffered from facial paralysis, and they supposed the facial nerve also took part in velar movements. However, this argument has been recently denied by Falk (*9*).

In spite of many studies of the motor nerve supply to the velopharyngeal muscles, few conclusions have been reached. Even the role of the facial nerve is not clearly understood. It is not known whether it acts in velopharyngeal movements or not.

The present investigation utilized evoked EMG to study the motor innervation of the velopharyngeal muscles.

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Method

The experiments were carried out on 20 rhesus monkeys weighing approximately, from 3.0 to 5.0 Kg. After the trachea was cannulated under Nembutal (pentobarbital sodium 35 mg/Kg, i.v.) anesthesia, the animal was kept on artificial respiration. The skull was mounted on the stand of a stereotaxic instrument, and the legs were fixed by clamps. By trepanning and opening the dura of the occipital region, the cerebellum was exposed. Partial decerebellum was carried out to expose the facial, glossopharyngeal, vagus, and accessory nerves at the petrosal area of the temporal bone. After these nerves were dissected as centrally as possible, a bipolar platinum wire electrode (200μ in diameter) was placed on the peripheral stump of each nerve. The electrical stimuli were given to each nerve through the electrode as single shock (pulse duration 0.5 msec) by means of an electrical stimulator (Nihonkohden MSE-3). To prevent spread of electrical current and drying, each nerve was surrounded by cotton and bathed in mineral oil. The reactions to the motor nerve stimuli were ascertained through muscle action potentials, M-waves (*25*). Twin needle electrodes, previously devised by Mimura (*17*), consisted of enameled stainless wire (100μ in diameter) with 1mm bare tip, were inserted perorally into the levator veli palatini, uvula, and superior constrictor pharyngeus muscles (*6, 11*) as seemed to contribute to velopharyngeal closure. The electrode was also placed percutaneously in the orbicularis oris muscle, as a control. The inter-electrode distance was 2mm in all cases. In addition, the tip resistance of the recording electrode was adjusted to 10 $\pm$ 1KΩ in normal saline solution. A diagram of the equipment used appears in Figure 1. Considering previously obtained information on sacrificed monkeys (Figure 2), orientation of the electrodes was as follows:

1. The levator veli palatini muscle: inserted 2-3mm mesial to the hamular process and about 10mm postero-superiorly.

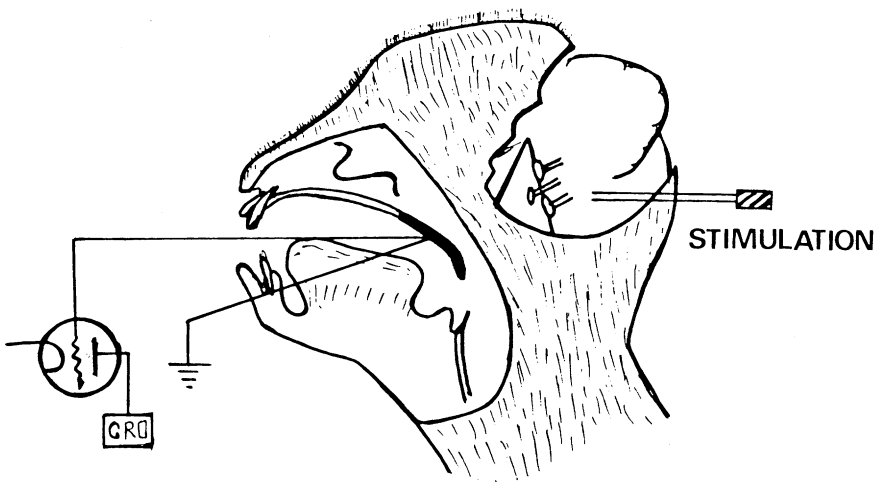

FIGURE 1. Diagram of equipment used.

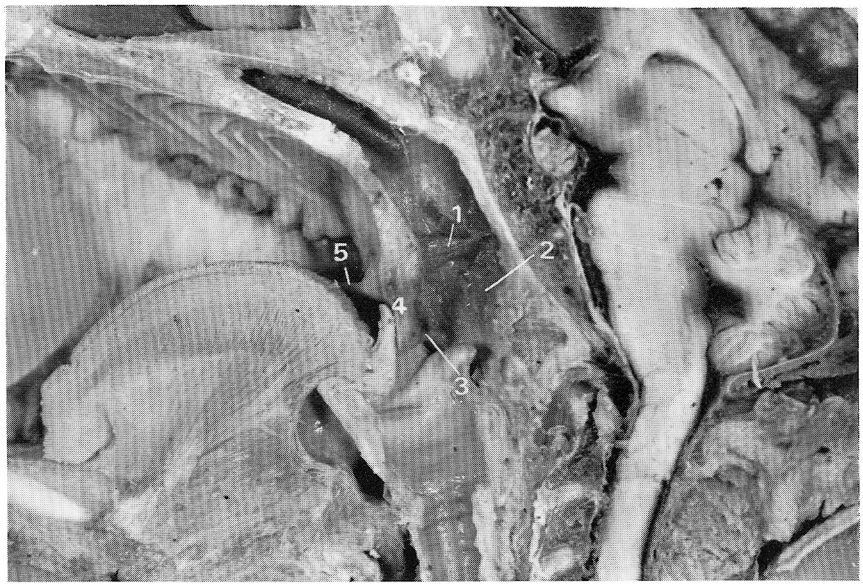

FIGURE 2. Midsagittal dissection of the velopharyngeal area of a rhesus monkey. 1. Levator m. 2. Superior constrictor m. 3. Palatopharyngeus m. 4. uvula m. 5. palatoglossus m.

2. The uvula muscle: at the middle part of the uvula.
3. The superior constrictor pharyngeus muscle: to the posterior wall of the upper pharynx and posteriorly about 3mm.

After the experiments, the monkeys were sacrificed, and the positions of the recording electrodes in the muscles were ascertained.

Action potentials of the selected muscles detected by the needle electrodes were fed into an R-C coupled preamplifier, displayed on an oscilloscope (Nihon-kohden VC-7) and, when required, recorded on film. Latency (A) and amplitude (B) of evoked EMG were measured as illustrated in Figure 3.

Results

a) Electrical Stimulation of the Facial Nerve

On stimulating the facial nerve in the petrosal area, muscle action potentials (M-waves) could be recognized from the levator veli palatini, uvula, superior constrictor pharyngeus, and orbicularis oris muscles on the stimulated side as illustrated in Figure 4 and 7, A. Figure 5 shows the relationship between the intensity of stimulation to the facial nerve and responses of the uvula muscle. Amplitude reached its maximum at an intensity slightly higher than threshold, but no further changes in amplitude occurred beyond maximal stimulation. Amplitudes of muscle action potentials at maximal stimulation ranged from 130 μv to 330 μv in the levator veli palatini, from 140 μv to 340 μv in the uvula, and from 80 μv to 260 μv in the superior constrictor pharyngeus muscles.

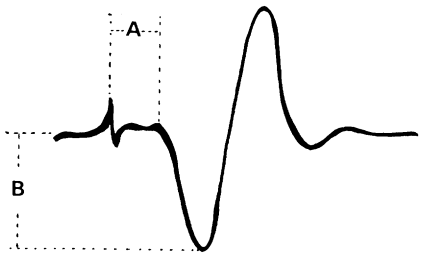

FIGURE 3. Analysis of evoked EMG. A) Latency B) Amplitude

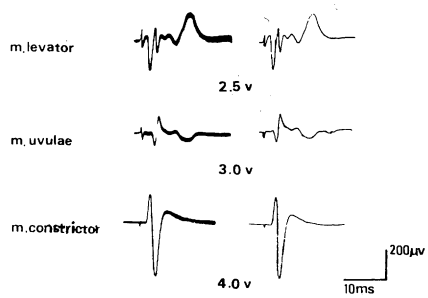

FIGURE 4. Examples of muscle action potentials on stimulating the facial nerve at the petrosal area.

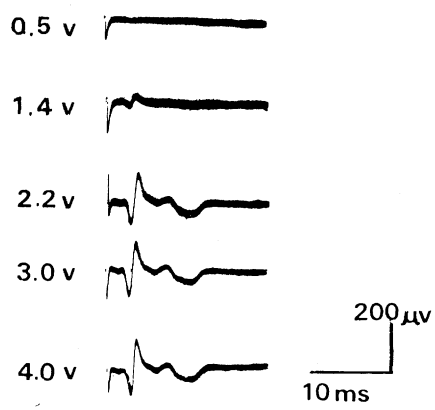

FIGURE 5. Relationship between the intensity of stimulation to the facial nerve and the responses of the uvula muscle to it.

Figure 6 indicates the relationship between the intensity of stimulation to the facial nerve and response latencies. Latencies were reduced as intensity increased and were minimum at maximal stimulation. Latencies at maximal stimulation in the levator veli palatini, uvula, and superior constrictor pharyngeus muscle ranged from 1.6 msec to 1.9 msec, from 2.1 msec to 2.3 msec, and from 1.7 msec to 1.9 msec, respectively.

Amplitude at the maximal response of the orbicularis oris muscle was about twice that of the uvula muscle as illustrated in Figure 7, A and B.

Thus, it was revealed that M-waves were picked up from the selected three muscles by stimulation to the facial nerve, but the pathway of the nerve into the velopharyngeal muscles was not clarified thoroughly. As a next step, the facial nerve was exposed below the stylomastoid foramen, and electrical stimuli were given to the peripheral end of the facial nerve in the same way as mentioned above. The M-waves could not be recognized in this case, as shown in Figure 7, C. That is, fibers of the facial nerve innervating the velopharyngeal muscles seemed to branch from the main trunk in the facial canal.

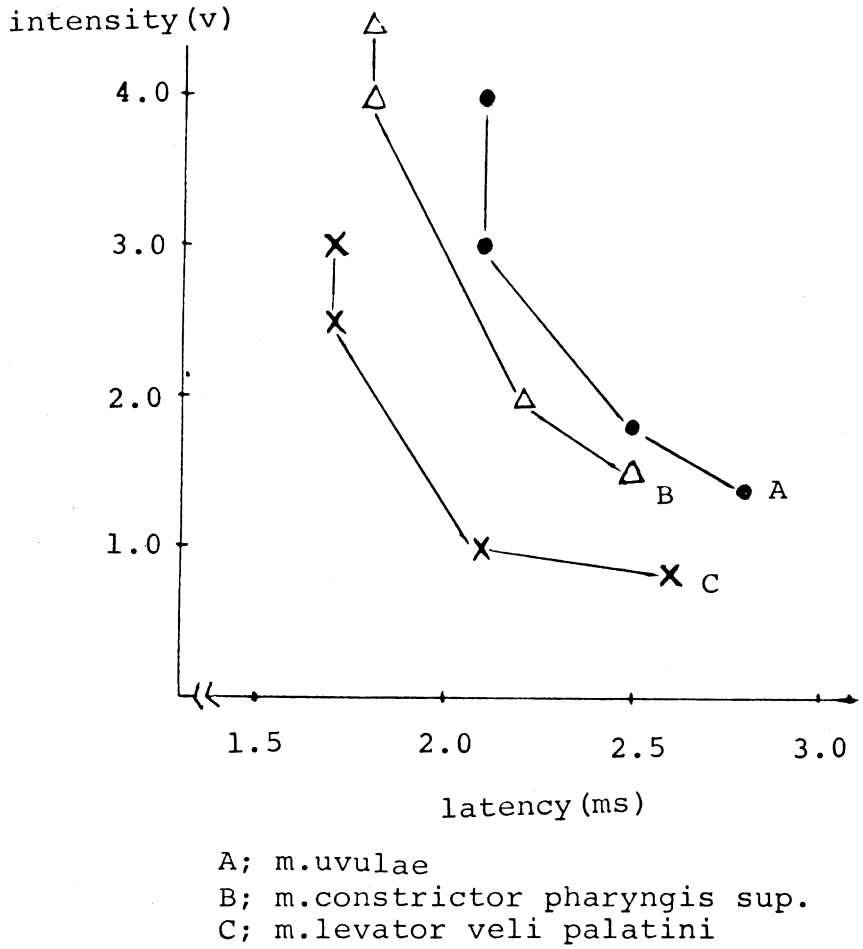

FIGURE 6. Relationship between the intensity of stimulation to the facial nerve and response latencies.

b) Electrical Stimulation of the Glossopharyngeal Nerve

On stimulating the glossopharyngeal nerve, muscle action potentials (M-waves) from the three muscles of the stimulated side could be recognized about 2 msec later than the stimulus artifact (Figure 8). Amplitudes of muscle action potentials at maximal stimulation were 400–600 μv in the levator veli palatini, 270–440 μv in the uvula, and 390–430 μv in the superior constrictor pharyngeus muscle. Latencies at the maximal stimulation were 2.1–2.3 msec, 2.3–2.5 msec, and 1.9–2.7 msec, respectively.

c) Electrical Stimulation of the Vagus Nerve

Muscle action potentials (M-waves) could be recognized from the three muscles on the stimulated side (Figure 9). Amplitudes of muscle action potentials at maximal stimulation were 690–900 μv in the levator veli palatini, 700–1100

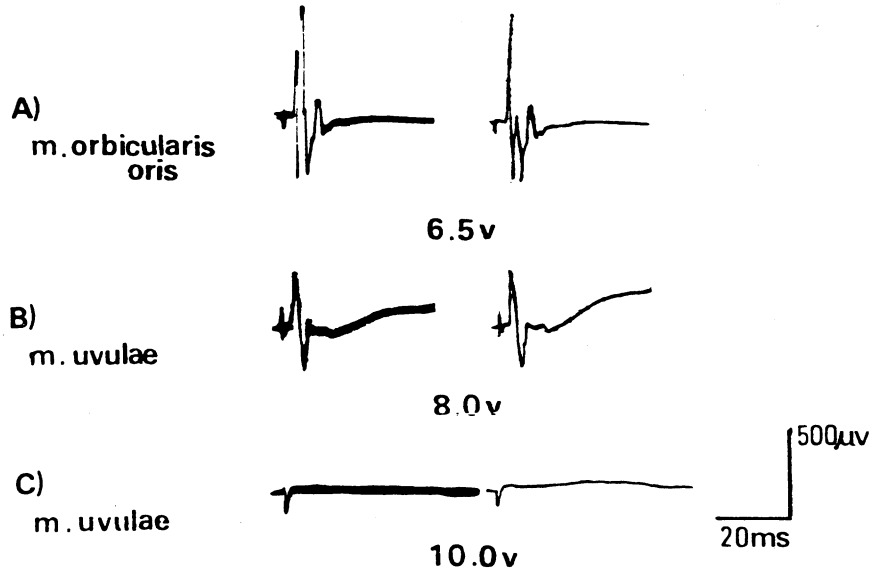

FIGURE 7. Examples of muscle action potentials on stimulating the facial nerve in various ways. A) Responses of the orbicularis oris muscle on stimulating the nerve at the petrosal area. B) Responses of the uvula muscle on stimulating the nerve at the petrosal area. C) Responses of the uvula muscle on stimulating the nerve below stylomastoid foramen. (No action potentials were recognized.)

μv in the uvula, and 650–870 μv in the superior constrictor pharyngeus muscle. Latencies at maximal stimulation were 2.7–2.9 msec, 2.3–2.6 msec, and 1.9–2.1 msec, respectively.

d) Electrical Stimulation of the Accessory Nerve

As illustrated in Figure 10, muscle action potentials (M-waves) could not be recognized. Therefore, it was found that the accessory nerve did not play a role in velopharyngeal movement.

e) Comparison of Amplitudes and Latencies by Maximal Stimulation to Each Nerve

Figure 11 shows the mean value of maximal responses of each muscle when stimulation was to the facial, glossopharyngeal, and vagus nerves. Amplitudes for the three muscles were highest when the vagus nerve was stimulated and lowest with facial nerve stimulation.

The mean value of latencies of each muscle by stimulation to the nerves is shown in Figure 12. Latencies in the levator veli palatini and uvula muscles were shortest with facial and longest with vagus nerve stimulation.

Discussion

Although many investigations (*4, 5, 8, 14, 18, 20, 23, 24, 26, 27, 28*) have been presented in human and various experimental animals, few definite conclusions can be drawn concerning the motor nerve supply of the velopharyn-

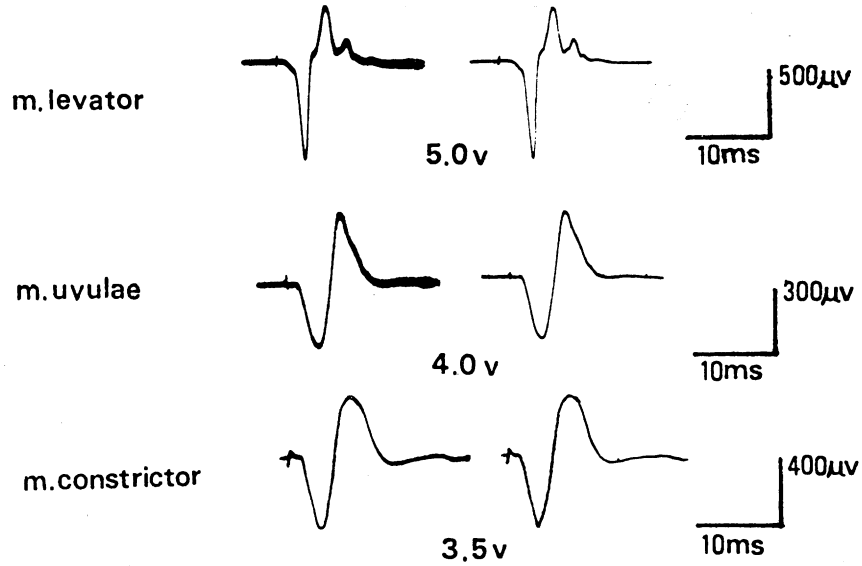

FIGURE 8. Examples of muscle action potentials on stimulating the glossopharyngeal nerve.

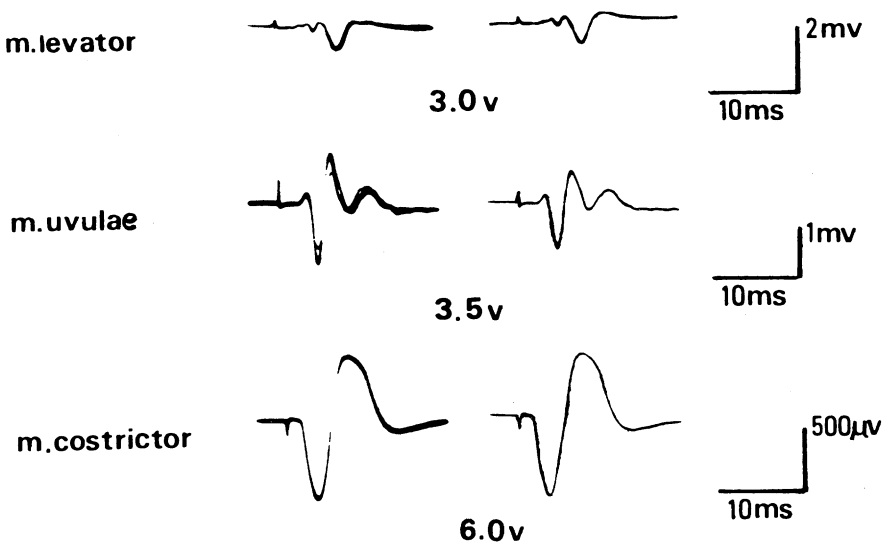

FIGURE 9. Examples of muscle action potentials on stimulating the vagus nerve.

geal muscles (*7*). These discrepancies may be attributable firstly to species differences. However, Bosma and Fletcher (*3*) have stated that basic arrangement of muscles, blood vessels, and nerves in the velopharyngeal area are similar in cats, dogs, monkeys, and human beings. Hartman and Straus (*13*) also reported that the courses of the cranial nerves of the rhesus monkey are similar to those of human beings. Thus, species differences are considered negligible.

Secondly, the differences among experimental procedures should be taken into

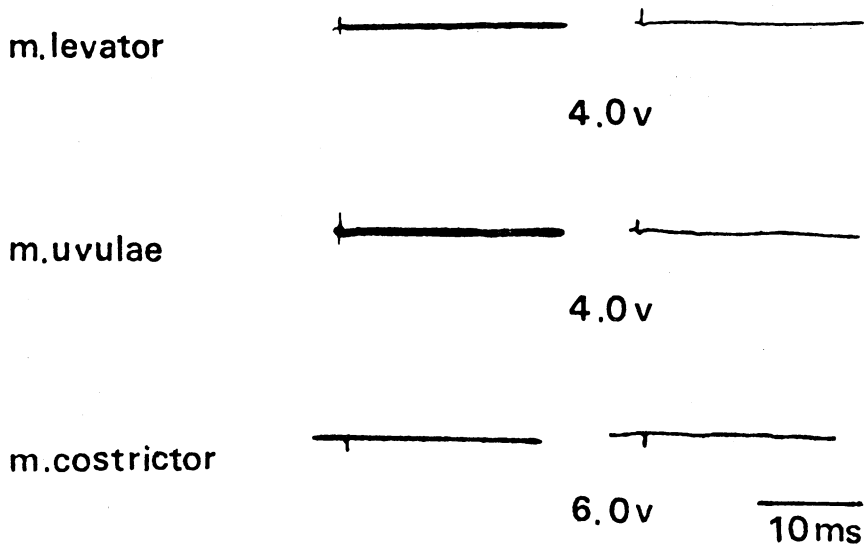

FIGURE 10. On stimulating the accessory nerve, muscle action potentials could not be recognized.

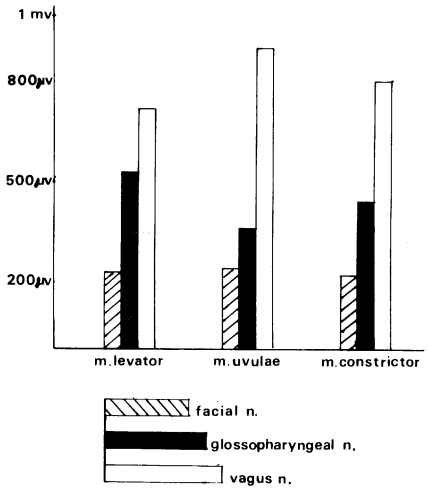

FIGURE 11. Comparison of mean maximal responses of each muscle on stimulating the facial, glossopharyngeal, and vagus nerves.

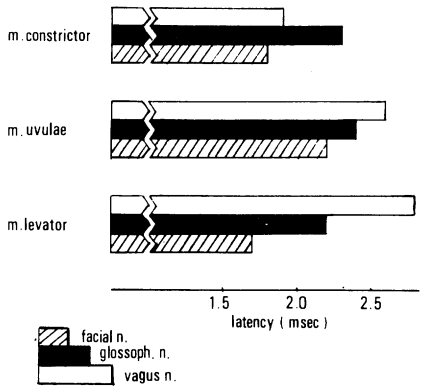

FIGURE 12. Comparison of mean value of latencies of each muscle on stimulating the facial, glossopharyngeal, and vagus nerves.

account. It seems difficult to explore the nerves of the small muscles in the velum by macroscopic-anatomical procedures and also to discriminate between motor and sensory components by histological methodology as reported by Broomhead (*4*). In an experimental study, Rich (*24*) evaluated velar movements on electrical stimulation of the nerves merely by visual impression.

Therefore, application of more precise techniques was needed to solve these problems physiologically.

Evoked EMG was selected for use in the present study. However, even in this experiment, the following questions must be raised:

1. Was cranial nerve X tested separately from the branch of XI which travels with X?
2. Were data contaminated by spread of electrical current in the operating field?

In the present investigation, glossopharyngeal, vagus, and accessory nerves were carefully exposed at the petrosal area beyond which each nerve enters the jugular foramen. In this area, the vagus nerve (X) does not run along the cranial branch of the accessory nerve (XI). Therefore, the glossopharyngeal (IX), the vagus (X), and the accessory (XI) nerve could be separated from each other.

To prevent spread of electrical current in the operating field, each nerve was surrounded by cotton and bathed in mineral oil. Effects from the central system were neglected because the electrode was placed on the peripheral stump of each nerve after the central side was dissected. Results obtained in the present study indicate no spread of electrical current. That is, evoked EMG was recognized on stimulating the glossopharyngeal (IX) or vagus nerve. On the other hand, response could not be evoked by stimulating the accessory nerve (XI) which travels beside the vagus nerve (X). In addition, latencies were different for the facial, the glossopharyngeal, and the vagus nerve. Thus, the technical problems which might have been occurred were fully solved in the present procedure.

Accordingly, the present investigation seems to be the first to reveal precisely the motor supply of the velopharyngeal muscles as evaluated by evoked EMG.

The differences among amplitudes by the maximal stimulation to each cranial nerve are considered to be dependent of the innervation ratio of the nerves in the velopharyngeal muscles. Generally, the innervation ratio is said to be smaller in muscles controlling fine movements and adjustments, and, on the other hand, larger in coarse-acting muscles (*2*). Therefore, the facial nerve is considered to be responsible for finer movements of the velopharyngeal muscles than are the glossopharyngeal or the vagus nerve.

Combining the results obtained in the present study with those of Cords (*5*) and Broomhead (*4*), the levator veli palatini, uvula, and superior constrictor pharyngeus muscles may be regarded as double innervated by the facial and branches of the pharyngeal plexus derived from the glossopharyngeal and vagus nerves. Thus each nerve is assumed to play a different role in velopharyngeal movements.

The obtained results also revealed that fibers of the facial nerve innervating the velopharyngeal muscles were branched from the main trunk in the facial canal. The pathway of the fibers has been supposed to be one of the following:

1. "N. facialis—N. petrosus major—Ganglion pterygopalatinum—N. palatinum minor—M. levator veli palatini" (Futamura (*12*)).
2. "N. facialis—Chorda tympani—Ganglion oticum—N. sphenoidalis inferior—N. petrosus major—Ganglion pterygopalatinum—N. palatinum minor—M. levator veli palatini" (Moritz (*18*), Nickl (*20*)).

Drüner (*8*) suggested that the greater petrosal nerve was equivalent to the ramus praetrematicus of the second branchial arch nerve in the Pisces and the

Amphibia. Hence, motor fibers were not involved in the greater petrosal nerve. Rabl (*22*) and Futamura (*12*) were of the opinion that two components were included in the nerve of the mammalian, one of them being the motor fibers which had entered in the maxillar process prior to information of the pterygopalatine ganglion. Foley (*10*), and Kuee and Sano (*15*) also observed histologically the motor components of the greater petrosal nerve in dogs. Although the latter theory was assumed by Moritz (*18*) and Nickl (*20*), Algaba (*1*) reported on the study in cats that action potentials from the levator veli palatini muscle could not be elicited by stimulation to the chorda tympani. As described above, fibers of the facial nerve innervating the velopharyngeal muscles are found to be separated from the trunk in the facial canal, but the pathway beyond it needs to be clarified more precisely.

It is clear, however, that the facial nerve takes part in velopharyngeal movements. If this finding is shown to apply to human beings, it may assist in treating cleft palate patients. We sometimes encounter cleft palate patients who demonstrate nasal grimace during phonation. This has been considered to be a compensatory velopharyngeal incompetence. (*19*). Recently, the authors have applied visual training to help cleft palate patients acquire adequate velopharyngeal function. As result of the training, it was noted that co-ordinating movements of lip and face, such as nasal grimace or lip-protrusion, during phonation were useful to activate velopharyngeal movements (*21*). Therefore, the nasal grimace may occur not only to compensate for velopharyngeal incompetence by increasing nasal resistance, but also to fire the facial nerve to complement velopharyngeal movements.

Summary

The present study attempted to clarify the motor nerve supply of the velopharyngeal muscles. Experiments were carried out on 20 anesthetized rhesus monkeys. Evoked EMG responses of the levator veli palatini, uvula, and superior constrictor pharyngeus muscles, which seem to contribute to velopharyngeal closure, were analyzed by stimulating the cranial nerves within the skull. Results were as follows:

1. Muscle action potentials (M-waves) from the selected muscles could be recognized on stimulating the facial, glossopharyngeal, and vagus nerves at the petrosal area of the temporal bone but were not noted upon accessory nerve stimulation.
2. At maximal stimulation, the vagus gave a greater increase in muscle amplitude than the other nerves studied. This was followed by the glossopharyngeal with the facial nerve producing the least increase in amplitude.
3. Also at maximal stimulation, latencies in the response of the levator veli palatini and uvula muscles were reduced to the greatest degree by stimulation of the vagus, to a lesser extent for the glossopharyngeal, and least for the facial nerve.

4. On stimulating the facial nerve below the stylomastoid foramen, M-waves could not be recognized.

From the present study, it was concluded that the levator veli palatini, uvula, and superior constrictor pharyngeus muscles are double innervated by the facial nerve and branches of the pharyngeal plexus derived from the glossopharyngeal and vagus nerves and that the facial nerve plays an important role as one of the motor nerves in movements responsible for velopharyngeal closure.

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