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# Synchronization Among Endplate Potential Oscillations in Jaw Closing Muscles

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## Abstract

Surface electromyograms (EMGs) in tooth clenching were recorded in a monopolar manner from paired anterior temporalis and masseter muscles of six subjects. The EPP (endplate potential) component was extracted from raw EMGs of the muscles using a digital filter. The component showed two phases, early slow wave and following oscillation. From the deflection pattern of the early EPP, the location of neuromuscular junction of the masseter muscle could be estimated at its inferior portion, and that of the anterior temporalis muscle near the temple. Frequencies of EPP oscillations for the muscles were around 30Hz, and the oscillation showed synchronization among the ipsilateral and contralateral temporalis and masseter muscles, suggesting the existence of a neural mechanism integrating sensory signals of different roots. The frequencies for non-preferred sided clenching tended to be lower than those for preferred sided clenching of subjects. This led us to conjecture that abnormal tremors in humans would be the result of a decline of the frequency of the EPP oscillation. It is concluded that the contraction of jaw closing muscles is regulated in an oscillating fashion of the EPP, and that the cooperative work among the muscles is controlled by synchronizing the oscillations.

## Introduction

Surface EMG recordings are generally performed in a bipolar manner, as there is an advantage of eliminating common mode noises. However, electrical activities of muscles can be also recorded in a monopolar fashion in reference to a probable electrical neutral point (reference point)—for example, the forehead in masticatory muscle recordings[1]. Monopolar recordings have an advantage in that they can describe the absolute electrical activity near the recording electrode. In EMG analysis, various parameters of muscular action potentials are popularly focused on, but the recordings should also contain the neuromuscular synaptic potential, the so called the endplate potential (EPP), which might be effectively recorded in a monopolar manner.

From an ionic mechanism of the synapse, the region of postsynaptic membrane forms the sink for the current of the depolarizing potential [2,3],so a negative potential field should be produced in the external medium around the endplate with reference to a distant point. In a previous paper[4], I actually demonstrated in the masseter muscle that the EPP component can be extracted from the monopolar raw EMG as a slow wave using a digital filter. The deflection of the extracted slow wave exhibited a negative–positive pattern with recording sites, and it was concluded that the site showed the most negative deflection corresponded to the neuromuscular junction. Subsequently, I also reported that the masseter EPP component showed an oscillation with a frequency of about 30 Hz[5] and the oscillation was widely observed in the EPP component of other muscles[6].

In most muscular movements, cooperative work among multiple muscles is very important. Here, an interest arises whether the oscillation of the EPP would synchronize among the involving muscles or not. In the present study, this is examined in the jaw closing muscles.

## Methods

### 1. *Subjects and recordings*

Surface EMGs were recorded from six healthy subjects, 21 to 32 years of age, using traditional disc electrodes. All subjects gave informed consent prior to participating in this examination. Their dental conditions were briefly checked before recordings (Fig.1). Muscles used in EMG recordings were the jaw closing muscles, the anterior part of the temporalis muscle and the masseter muscle. All recordings were carried out in a monopolar manner, in which the reference electrode was placed at the tip of the nose (Fig.2A). A piece of chewing gum was used both in clenching and chewing examinations, and EMG recordings were started after the bolus had fully softened. Electrical signals were amplified through an analogue filter ranging from 0.5Hz to 10kHz and fed into a computer system.

### 2. *Extraction of EPP component*

The EPP component in EMGs has two phases, an early slow wave and a following oscillation with a relatively high frequency[5], which in this article are called the "early slow EPP" and the "EPP oscillation" (or simply "oscillation"), respectively. The difference in the deflection of the EPP wave with recording sites was first examined independently in the temporalis muscle and in masseter muscle of a subject, subject-a in Fig.1. EMGs were recorded simultaneously from eight sites (0-7) aligned equally from the upper end to the lower end of the muscles (Fig.2A). Recordings were carried on in a pre-triggering mode synchronized with a start of gum clenching with the molar teeth on his preferred side, the left side. The analogue signals (0.5Hz-10kHz) were sent to a computer system with a sampling rate of 20kHz and a sampling number of 10,000 points, so the recording period for one trial was 0.5 secs. The EPP component was extracted from each of the raw EMG recordings by removing the action potential component using a high-cut digital filter (Butterworth type). The cut-off frequency of the filter was set to 12.5 Hz for the extraction of the early slow EPP, and 45 Hz, for the extraction of the EPP oscillation.

**3. *Synchronization between EPP oscillations***

Then, synchronization among EPP oscillations for the jaw closing muscles was examined, where recording electrodes were placed bilateral symmetry, the superior portion of the anterior part of paired temporalises and the inferior portion of paired masseters (Fig.3A). The locations corresponded approximately to 1 for the anterior temporalis and 5 for the masseter in Fig.2A, respectively. The subject was instructed to clench the gum bolus alternatively on the left and right side, and EMGs were recorded simultaneously from the four sites. To extract only the oscillation, both the action potential and the early slow EPP were eliminated from the raw EMGs with the high-cut digital filter at 45Hz and with the low-cut digital filter at 12.5 Hz, respectively. A Lissajous graph, an x/y graph between oscillations for two muscles, was plotted to observe their synchronizing manner. Although six combinations are possible in plotting x/y graphs, two combinations, between right (x-axis) and left (y-axis) signals for the temporal and masseter, were chosen for this examination.

**4. *Data analysis***

In each subject, correlation coefficients of the x/y graphs were calculated as a simple indicator of the oscillation synchronization. Mean (±standard deviation) of the correlation coefficient in ten samples showed distinctive oscillation was calculated for both the left- and right-sided clenchings. Frequency of the EPP oscillation in each sample was measured from FFT analysis (hamming window). It was applied on the temporalis and masseter oscillations of the clenching side, and means (±standard deviation) of the frequency in ten samples for the muscles were calculated in each subject. Depending on the examination, the frequency was calculated from the time (wave length) between successive two positive (and two negative) peaks,

**5. *Vector smoothed EMG graph***

Before starting these examinations, the mastication manner of each subject was checked with vector EMG patterns in gum chewing[7]. Bilateral temporalis and masseter EMGs, in which the electrodes were placed symmetrically on both sides of the superior portion of the anterior temporalis and the inferior portion of the masseter, were recorded simultaneously; these were the same as the positions for the examination of the oscillation synchronization (Fig.3A). Subjects chewed the gum bolus, first on the left side, and changed to the right side; each chewing time was about 6 secs. The analogue signals (0.5Hz-10kHz) were sent to a computer system with a sampling number of 240 kpoints (=12 secs).

Only action potentials were extracted from the raw EMGs using the low-cut digital filter at 45Hz. Then the extracted signals were rectified bipolarly and smoothed with successive averaging for 150 points. Three x/y graphs between the smoothed EMGs were plotted. They were (1) right-side (x-axis) and left-side (y-axis) temporalis signals, (2) right-side (x-axis) and left-side (y-axis) masseter signals, and (3) the difference between the paired masseter signals (x-axis) and the difference between the paired temporalis signals (y-axis) (Fig.1). The differences in (3) were obtained by subtracting the left smoothed EMG from the right smoothed EMG. These x/y graphs, which are called the "vector EMG graphs (or patterns)" in this article, are composed of loops, each corresponding to a chewing stroke, and express well the coordination between the corresponding muscles. They were also referred to judge their preferred chewing side supplementary as there were subjects who did not necessarily recognize their preferred side.

# Results

**1. *EPP component in masserter EMG***

B1 in Fig.2 is a sample of the masseter raw EMG recordings from eight sites (trace-0 to trace-7) for a left, preferred, sided clenching of subject-a in Fig.1. When the action potential component was eliminated from the raw recordings using the high-cut digital filter at 12.5 Hz, the slow wave appeared in the traces, which is superimposed on each raw EMG in Fig.2B2. The extracted wave, especially in its early phase, deflected positive or negative, depended on the traces. This slow wave might be a signal reflecting the EPP, and the trace showing the most negative deflection must correspond to the site locating the neuromuscular junction[4]. In this sample, it observed in trace-5.

The EPP signal became oscillating with an increase in the frequency of the filter. Fig.2B3 shows filtered signals of eight traces in setting the filter at 45Hz, where we can recognize the oscillation obviously. Fig.2B3 also shows that the phase of the oscillation reversed at trace-3, which was the same as the phase change of the early slow EPP.

**2. *EPP component in temporalis EMG***

C1 in Fig.2 is a sample of the temporalis raw EMG recordings from eight sites (trace-0 to trace-7) for the left sided clenching of the same subject. When the action potential component was eliminated from the raw EMGs using the high-cut digital filter with 12.5 Hz, similar slow wave to the masseter one appeared in each of eight traces (Fig.2C2). The deflection manner was, however, complex comparing to the masseter pattern. In the recordings, early negative deflection was not large but was recognized widely from trace-2 to trace-7, and that in trace-3 showed most negative. Relatively large positive deflection, which seemed to correspond to the early negative deflection in trace-3, was observed in trace-0 and trace-1, which was followed with a large negative deflection. This deflection manner suggested the existence of multiple synaptic sites, but one of them might be located near the portion for electrode-3.

The oscillation also emerged in the temporalis EPP by increasing the value of the high-cut digital filter. Fig.2C3 shows filtrated signals of eight traces in setting it to 45Hz, where oscillations as observed in masseter EPP signals are observed clearly. The phase of the oscillation reversed at around trace-2.

**3. *Synchronization of the EPP oscillation among muscles***

EMGs were recorded from paired anterior temporalis and paired masseter muscles simultaneously to examine whether EPP oscillations occur synchronously or independently among them. Traditional recording sites were adopted for the temporalis recording mainly from a convenience of the electrode attachment (Fig.3A). (It aroused, however, no serious problems limiting to examining the oscillation aspect.) Fig.3B is a sample of EPP oscillations for the symmetrical four recording sites in a left-sided clenching of the same subject to Fig.2. In the recordings, the EPP oscillation was observed in every trace, but those for the clenching sided (left) muscles were larger. Fig.3B further shows that phases of the oscillations matched well between paired temporalises and between paired masseters, but the temporalis phase was the reverse of that for the masseter. The match, including the same and the reversal, of the phases, was, however, incomplete. A little shift was recognized, which became more obvious when the four oscillations were superimposed (Fig.3C). Features of the phase shift between oscillations were visualized as a Lissajous pattern on x/y graphs. In the possible six x/y combinations, four combinations were presented in Fig3D; right-left temporalis, right-left masseter, left masseter-temporalis, and right masseter-temporalis. These Lissajous graphs express well that EPP oscillations for the paired muscles synchronized with same phase, and those for the different muscles of same side, with reversal phase in these electrode positions.

**4. *Frequency of the EPP oscillation***

The synchronization of EPP oscillations among two paired muscles means that all of them oscillate with the same frequency. In Fig.3B, we can count about seven cycles of the oscillation between 2,000-6,000 sampling points (=0.2 sec), so the frequency is roughly estimated to be 35Hz. Frequencies of the EPP oscillations for the ipsilateral (left) temporalis and masseter were measured more precisely by two methods. One was calculated from the time (wave length) between successive two positive (and two negative) peaks, and another, from FFT analysis. In the oscillations in Fig.3B, mean frequencies (±standard deviations) measured from the former method were 36.4 (±3.1) Hz (n=8) for the temporalis muscle, and 36.7 (±3.6) Hz (n=11) for the masseter muscle, and the frequencies obtained from the latter method were 36.0 for both the left temporalis and the left masseter (Fig.4a,b).

**5. *EPP oscillation in other subjects***

The oscillation phenomenon of EPP was also examined in other subjects. Fig.5 shows the profiles of the oscillation in six subjects for their preferred sided clenching, where oscillation x/y graphs for paired temporalises and for paired masseters are also shown. (Fig.5a is another recording sample in the same subject in Fig.2 and Fig.3.) Their plain dental conditions are presented in Fig.1a-f, where vector patterns of smoothed EMGs in gum chewing are also presented on the right side of each dental profile.

The subjects can be roughly grouped: subjects a, b, and c had relatively good dental conditions; subjects d, e, and f, had dental problems (subject-d had light TMD; subject-e, too much dental treatment; and subject-f, had orthodontic wire on the upper dental arch.) The vector EMG patterns expressed well their chewing characteristics. In subjects a, b, and c, the patterns indicated that their muscle work differentiated well between the left-sided and right-sided chewings. On the other hand, those for subject-d, -e, and -f suggested any irregular coordination: in subject-d, its small size of the differential vector pattern indicates that both the temporalis and masseter muscles work in almost same manner between ipsilateral and contralateral sides in either sided chewing, suggesting a poor grinding movement; in subject-e, both the muscular force and the pattern separation between the left- and right-sided chewings for temporalis muscles were weak; in subject-f, cycles for the masseter graph in the right-sided chewing were unstable, and cycles of the differential EMGs for the right sided chewing were not drawn on the 1st quadrant, suggesting rough jaw movements in the right sided chewing.

As a simple indicator of the degree of the oscillation synchronization, correlation coefficients of Lissajous x/y graphs between oscillations were calculated. In this examination, it was done limiting on the graphs for the bilateral temporalises and for the bilateral masseters in both right-sided and left-sided clenchings. Table 1 is the means (±standard deviations) in ten trials in six subjects .

Frequencies of the oscillations for the clenching sided temporalis and masseter were measured in each subject. FFT method was used for the measurement because the accurate measurement was difficult with the method based on the wave length as the peak points of cycles of the oscillation were not necessarily obvious in many recordings. Table 2 is the result, where probabilities in student t-test between right and left muscles are attached. The ipsilateral frequencies were variable with subjects, but considered to be roughly 30Hz: means of the frequency for preferred side temporalis and masseter in the subjects, except for subject-d, whose preferred side was not certain, were 30.9Hz and 31.3 Hz, respectively. (FFT spectrums, in many records of subjects, did not necessarily show a single peak like the spectrums in Fig.4, so it must be kept in mind that the means of each subject were obtained from the frequencies showed the highest peak in each spectrum.) As we observed oscillations synchronize well across the four muscles, frequencies for the clenching sided temporalis and masseter were almost the same in every subject.

# Discussion

### 1. *Neuromuscular junction of the masseter and temporalis muscles*

The deflection manner of the masseter early slow EPP with recording sites indicated its neuromuscular junction to be located at its inferior portion, which was the same as the result reported in our previous paper[4]. This also coincided with the result obtained from a propagating pattern of the muscular action potential[8]. On the other hand, the deflection manner for the temporalis muscle with recording sites was ambiguous for estimating its neuromuscular junction. Two reasons are suggested for this deflection manner: 1) the recording electrodes were not close enough to the synaptic site, and 2) EPPs of multiple synaptic sites were reflected in the recordings. The temporalis muscle spreads upward widely like a fan, and is known to function differently with its parts in mastication, but in this examination the EMGs were recorded from the anterior part. The motor neurons innervating the temporalis muscle could possibly synapse to multiple sites, and the synapses are not necessarily activated with the same time course. (In actuality, multiple branches of the deep temporal nerve controlling the temporalis muscle are shown in most anatomy textbooks, although accurate locations of their terminals are not necessarily designated.) Applying widely more electrodes over the muscle might help to specify more precisely the synaptic location(s) of this wide muscle. From the deflection pattern of the early slow wave with recording sites, it was, however, suggested that one of the temporalis synapses exists around the temple.

### 2. *Oscillation of the EPP wave*

The early EPP wave of the temporalis and masseter was followed by oscillation. The EPP oscillation means that muscular contraction is not controlled monotonously. This is also suggested from a phenomenon, the so called silent period, which is a short pause of muscular discharges for about 10-50msec (depended on experimental situations) in muscle contractions. This interruption of muscular activity is observed, especially in the contraction of jaw closing muscles[9,10]. The mechanism of the silent period is thought to be a suppressive effect of sensory signals mainly from mechanical receptors of the periodontal tissue on the corresponding trigeminal motor neurons[10-12]. (Involvement of mechanical receptors of temporomandibular joints or (and) proprioceptive receptors of muscles is also supposed[13,14].

 

EMG investigators occasionally observe a rhythmic burst of muscular discharges. (The silent period of jaw closing muscles can be regarded as a part of the rhythmic discharge.) Rhythmic discharges of EMG were observed also in this examination. We can, for example, recognize them in EMG recordings in Fig.2B1 and C1, and the discharge coincides with the negative phase of EPP oscillations recorded near the synaptic sites. Muscular rhythmic discharges are apparently built by the EPP oscillation. The EPP oscillation is expedient in adjusting the strength of muscle contraction, and the silent period that might be a partial reflection of the EPP oscillation functions for protecting chewing apparatuses from its excessive bite force.

**3. *Synchronization of the EPP oscillation between muscles***

The most interesting finding in this examination was that EPP oscillations synchronize across the bilateral temporalis and masseter muscles, which is understood straightly by observing over oscillations for the four muscles in Fig.5. In the phenomenon of the silent period, the discharge interruption is known to happen almost simultaneously on multiple elevator muscles involved[10,15-17], which is another sign of the synchronization of EPP oscillations. In this examination, temporalis oscillations synchronized with masseter oscillations in reverse fashion (Fig.3B), but it is apparent that they synchronized in almost same phase as if the temporalis oscillation would be recorded from an appropriate portion close to its synapse site. Although the phase of ipsilateral oscillation tended to precede shortly from that of the contralateral oscillation in both the temporalis and masseter muscles (Fig.3C), correlation coefficient of oscillation x/y graphs, as a whole, showed a high (positive or negative) correlation (Table 1). Although a high correlation does not necessarily mean harmonic mastication as the mastication is executed delicately with a different time course of the contraction among the relating muscles, it is certain that the contractions of the four muscles (and probably other related muscles) are controlled cooperatively at their EPP level in oscillating fashion.

**4. *Mechanism of the EPP oscillation***

In the silent period of jaw closing muscles, suppressive feedback from periodontal mechanical receptors to the corresponding motor neurons is of primarily considered, as the discharge interruption synchronizes with tooth contact[9-11].In the building of the EPP oscillation, the possibility of the participation of proprioceptive receptors, such as the muscle spindle and tendon organ is of foremost thought. Thus, we need to discuss another phenomenon similar to the EPP oscillation.

Muscular movements of the finger, hand, and jaw of humans are accompanied by involuntary rhythmic movement which is too small to resolvable by the human eye[18]. Such microtremor, known as physiological tremor, can be well detected especially during isometric conditions. Although the damped mechanical resonance effect of asynchronous firing of motor units may be involved[19-21], a more likely cause of the tremor is the rhythmic discharge of muscle fibers[22-26]. The tremor frequency of the human jaw in isometric condition (and also during slow chewing) was measured approximately 6-12 Hz[27-29]. Some authors have expounded that the stretch reflex is primary responsible for the physiological tremor[22,30,31]. Others have postulated the existence of a cortical oscillator, which is based on the coherence between cortical activity (EEG or MEG) of the motor area and EMG of the corresponded muscles[32-37]. About the jaw physiological tremor, there are authors insisting that feedback effect of exteroceptors, periodontal mechanical receptors, is involved strongest with its generation[28,38-40].

Although the frequency of the jaw physiological tremor is considerably lower than the frequency of the EPP oscillations measured in this examination, both may represent the same phenomena. There are, however, the following differences between the two; EPP oscillations represent a phenomenon occurring in the muscular synaptic potential during quick isotonic contraction, whereas jaw physiological tremors primarily represent a phenomenon on the jaw mainly during the isometric condition. It must be also considered that EPP manner is not necessarily reflected directly in terms of jaw movements as many transmitting steps lie between the two.

How are the two phenomena, EPP oscillation and jaw physiological tremor, explained from the view point of sensory-motor reflex? It seems, at the present time, difficult to answer completely. One idea is that both proprioceptors and exteroceptors participate in building them, but the feedback effect of proprioceptors would become dominant under the isotonic condition, jaw motion phase, whereas that of exteroceptors would become dominant under the isometric condition, occluding situation. These could produce different frequencies of rhythmic discharges of the motor neurons with the degree of the respective feedback effect.

In harmonic mastication, multiple muscles need to work cooperatively, and EPP oscillations for the four muscles were demonstrated to synchronize well in this examination. It seems to be difficult to produce the synchronization if the oscillation for each muscle would be built independently through the distinct motor-sensory connection. The good synchronization strongly suggests the existence of any neural mechanism integrating widely the sensory inputs from different roots and generating the common oscillation.

**5. *Oscillation feature for subjects***

Recordings in six subjects of this examination demonstrated that EPP oscillations for masticatory muscles and their synchronization are general phenomena (Fig.5). The values of the correlation coefficient of oscillation x/y graphs showed, as a whole, high correlation in most subjects examined, but the temporalis correlations tended to be higher than the masseter ones without regard to their preferred or non-preferred sided clenching (Table 1). This tendency must be the reflection of different roles of the muscles that the anterior temporalis functions as a jaw positioner, and the masseter, as a worker[41]. The different roles were also expressed by their vector EMG patterns for gum chewing. In most subjects, the pattern separation between the left- and right-sided chewings for temporalis was smaller than that for the masseter (Fig.1).

The correlation coefficient of oscillation x/y graph reflects the degree of match between contractions of the two muscles. A too high correlation might indicate a difficulty of jaw sliding movement, and its too low correlation, a lack of the harmonic jaw movement. The former type was observed in subject-d, and the latter type, in subject-f. The correlation coefficients in subject-d were overall high, and the vector EMG patterns for both the temporalis and masseter also showed a poor separation between the left-sided and right-sided gum chewings, which is especially expressed in its differential vector EMG pattern. On the other hand, the correlation coefficients of the masseter in subject-f showed fairly low, and the vector EMG pattern of the masseter suggested a strong irregular jaw movement. These are, however, only rough tendencies. Many more subjects are needed in order to examine the relation between chewing manner and the oscillation synchronization.

The frequency of the oscillation for subjects in this examination was measured to be around 30 Hz. There was, however, a noticeable feature in the frequency for each subject (Table 2). The frequency for the non-preferred sided clenching tended to be lower than that for the preferred sided clenching. The tendency was observed in all subjects, except subject-d. Subject-d had TMD on the right side, which seemed to be induced by habitual mastication of his preferred, right, side[42], and the lower frequency for the right sided clenching might come from the TMD.

**6. *About human abnormal tremors***

Various types of abnormal tremor are known in humans. They are classified, for example, as resting tremor, postural tremor, intention tremor, and kinetic tremor with their physiological situations[43,44], all of which occur involuntary and unwilling with a frequency of about 5-10 Hz. The EPP oscillation phenomenon observed in this examination produces a conjecture that abnormal tremors would be its outcome, the frequency of which becomes lower due to any cause. The main cause of abnormal tremors is generally thought to lie in disorders of the central nervous network[45-49], but the participation of peripheral sensory-motor reflex circuits would also be involved[50,51]. One definite finding from this examination is that frequency of the EPP oscillation of jaw closing muscles in the non-preferred sided clenching tended to be lower than that in the preferred sided clenching.

Apart from abnormal tremors and their origins, the trembling of muscles is not a special phenomenon of itself. Even healthy people often experience strong muscle trembling under fatigue or frigid conditions, after ingesting too much alcohol or caffeine, and under specific psychological stress. All of these trembles must be substantially due to low frequency EPP oscillations, although it remains debates whether the oscillation is built in the central nervous system or through peripheral reflexes

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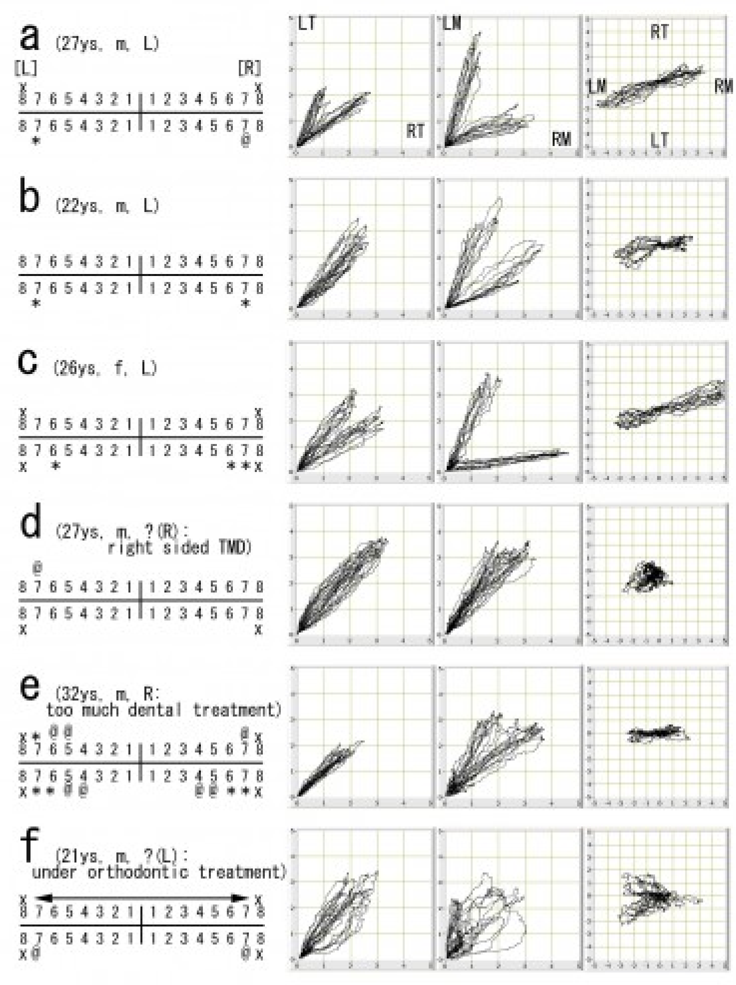
# Illustrations

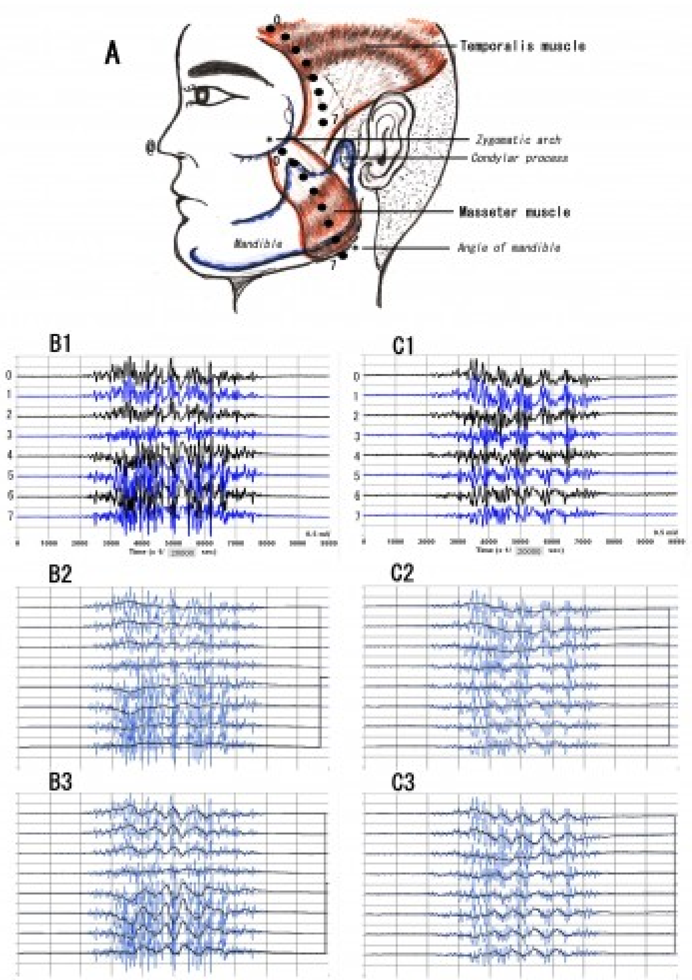
## Illustration 1

Plain dental profiles for six subjects (a-f) examined. In each subject, the *-mark means inlay; @-mark, crown; and x-mark, loss of teeth. Ages, sex, preferred chewing side are written in parenthesis. Three vector graphs of smoothed EMGs in gum chewing between left (LT) and right (RT) temporalis, left (LM) and right (RM) masseters, and bilateral difference for temporalis and for masseter are also shown.




## Illustration 2

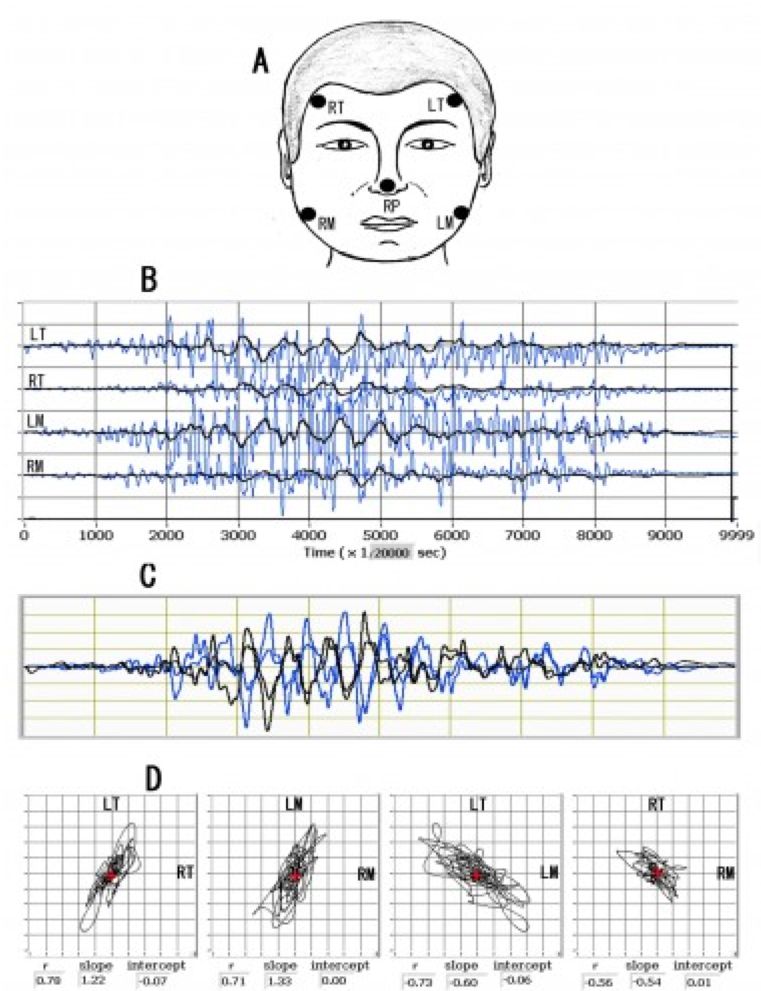
A: Representation of eight recording sitesÂ¬ over the temporalis and masseter muscles (*: reference point (RP)). B1: Sample of simultaneous raw masseter EMGs in response to an ipsilateral gum clenching. B2-B3: EPP component extracted from the raw EMGs through a high-cut digital filter with a cut-off frequency of 12.5Hz and 45Hz. C1-C3: The same examinations for the temporalis muscle as for B1-B3.


A
Temporalis muscle
Zygomatic arch
Condylar process
Masseter muscle
Mandible
Angle of mandible
B1
C1
B2
C2
B3
C3

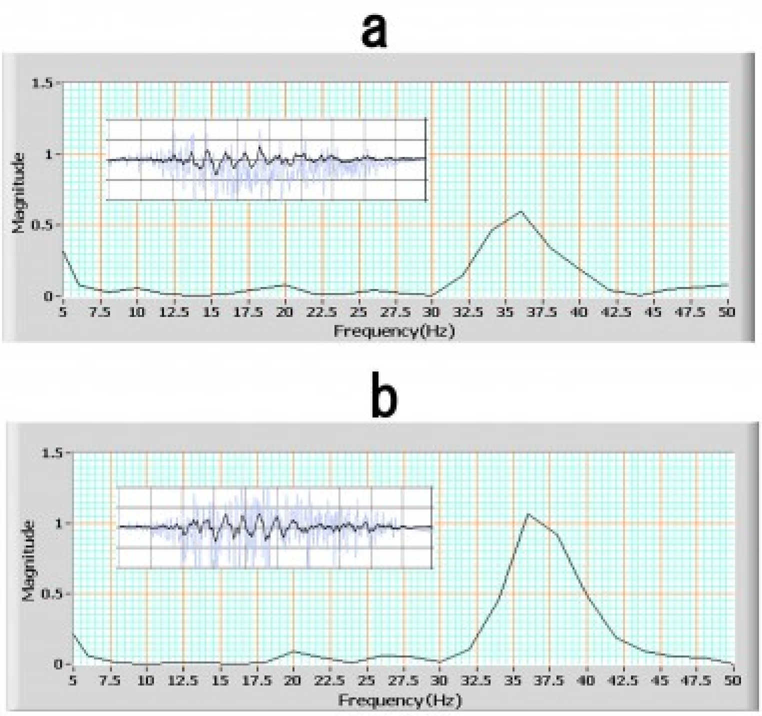
# Illustration 3

A: Representation of four bilateral recording sites (means of LT, RT, LM, and RM are same to those in Fig.1). B: EPP oscillations for the four sites extracted through a low-cut digital filter with 12.5Hz and a high-cut digital filter with 45Hz in same subject to Fig.2. C: Superimpose of the four EPP oscillations in B. D: Four Lissajous graphs between oscillations within vertical lines in C. r: correlation coefficient.




# Illustration 4

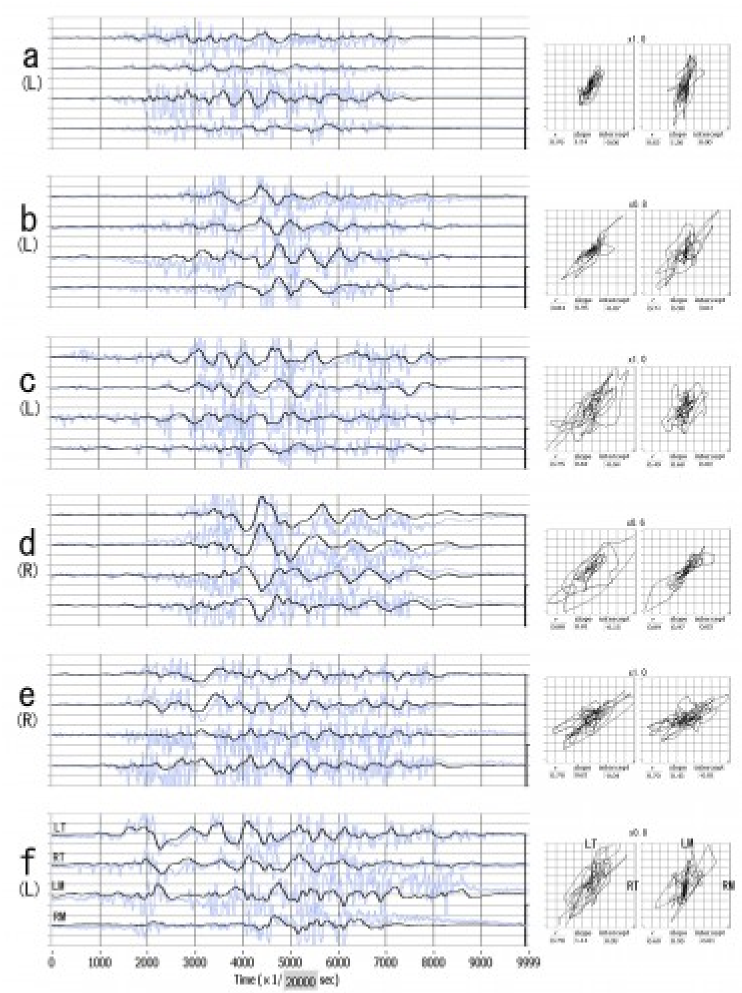
Spectrums of FFT analysis of EPP oscillations for the left (clenching sided) temporalis (a) and masseter (b) muscles in Fig.3B within 5- 50 Hz. Vertical axis is actual voltage sampled.


a
1.5
1
0.5
0
Magnitude
5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30 32.5 35 37.5 40 42.5 45 47.5 50
Frequency(Hz)
b
1.5
1
0.5
0
Magnitude
5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30 32.5 35 37.5 40 42.5 45 47.5 50
Frequency(Hz)

# Illustration 5

Overview of EPP oscillations for paired temporalis and masseter muscles in sixsubjects in Fig.1 in their preferred sided clenching ((L:left) or (R:right) under alphabets). Lissajous graphs between bilateral temporalis muscles and bilateral masseter muscles are also presented, where amplitudes are suitably adjusted, but the same between the two graphs for each subject.



# Illustration 6

## Table-1

**Table1: Correlation coefficient (±SD) of oscillation x/y graph**

| Subjects | a | b | c | d | e | f |
|---|---|---|---|---|---|---|
| **[Left sided clenching]** paired | | | | | | |
| temporalis | 0.76(0.07) | 0.82(0.05) | 0.73(0.11) | 0.80(0.06) | 0.73(0.05) | 0.73(0.14) |
| Paired masseter | 0.69(0.05) | 0.81(0.08) | 0.45(0.13) | 0.85(0.03) | 0.66(0.10) | 0.43(0.25) |
| **[Right sided clenching]** paired | | | | | | |
| temporalis | 0.71(0.07) | 0.75(0.13) | 0.65(0.05) | 0.80(0.07) | 0.71(0.09) | 0.63(0.19) |
| paired masseter | 0.66(0.09) | 0.88(0.03) | 0.47(0.09) | 0.81(0.06) | 0.59(0.11) | 0.35(0.17) |

a-f correspond to subjects in Fig.1.

# Illustration 7

Table-2

**Table 2: Frequency (±SD) of EPP oscillation (Hz)**

| Subjects | | a | b | c | d | e | f |
|---|---|---|---|---|---|---|---|
| [Left sided clenching] | **LT** | 33.1(7.1) | 28.0(1.6) | 36.8(6.8) | 27.3(7.1) | 24.1(10.2) | 25.2(3.2) |
| | **LM** | 33.6(3.3) | 29.3(3.2) | 37.5(6.1) | 26.3(11.6) | 27.8(9.0) | 24.9(2.2) |
| [Right sided clenching] | RT | 31.6(9.0) | 26.9(4.0) | 29.7(5.6) | 18.5(2.6) | 31.4(9.9) | 20.6(2.8) |
| | RM | 30.7(8.1) | 26.5(4.2) | 31.8(6.3) | 21.8(12.7) | 31.3(9.1) | 20.6(2.5) |
| Left-Right t-test | | 0.14 | 0.06 | 0.01 | 0.03 | 0.06 | 0.00 |

LT, RT, LM, and RM mean left temporalis, right temporalis, left masseter, and right masseter muscle, respectively. **a-f** correspond to subjects in Fig.1.

# Disclaimer