Mechanomyographic activity in human lateral pterygoid muscle during mandibular movement

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Abstract

The activity of the lateral pterygoid muscle has been regarded to be related to the pathological condition of the temporomandibular joint (TMJ) in the craniomandibular disorders. Because the lateral pterygoid muscle is a deep muscle, a needle electrode is necessary for EMG recordings. The purpose of this study was to establish a non-invasive method for the evaluation of muscle activity of the lateral pterygoid muscle using mechanomyogram (MMG). In three male subjects, surface electromyogram (EMG) in the left masseter muscle, left anterior and posterior belly of the temporal muscle, left anterior belly of the digastric muscle and needle EMG of the inferior head of the lateral pterygoid were recorded during mandibular movement tasks simultaneously with the MMG derived from a condenser microphone in the external ear canal. There were significant positive correlations between the needle EMG signal of the lateral pterygoid muscle and the MMG signal for the tasks of static jaw opened position of 30 mm of interincisal distance ($p=0.000$, $R^2=0.725$), static jaw opened position of 40 mm of interincisal distance ($p=0.000$, $R^2=0.753$), 5 mm protruded mandibular position ($p=0.000$, $R^2=0.653$), the most protruded mandibular position ($p=0.000$, $R^2=0803$). On the contrary, for the task of maximal clenching, there was no significant correlation between the EMG signal of the lateral pterygoid muscle and the MMG signal. These results suggest that the activity of the lateral pterygoid muscle could be evaluated by the MMG signals recorded in the external ear canal, unless jaw closing major muscles show active contraction.

Keywords

Mechanomyogram; Electromyogram; lateral pterygoid muscle; Jaw movement

Highlights

> We compared mechanomyogram to electromyogram for the lateral pterygoid muscle. > Significant positive correlations between electromyogram and mechanomyogram are observed. This study suggest a non-invasive method for the lateral pterygoid muscle.

1. Introduction

Muscle activity in function and coordination of muscle groups during mandibular movement has been known to be affected in the condition of craniomandibular disorders (Cooper et al., 1991). Because the lateral pterygoid muscle is attached to the articular disk, the joint capsule, and the condylar process of the mandible, its muscle activity is believed to be related to the pathological condition of the temporomandibular joint (TMJ) in craniomandibular disorders. Studies on lateral pterygoid muscle activity have been conducted using electromyography (EMG). However, because the lateral pterygoid muscle is a deep muscle, a needle electrode is necessary for EMG recordings, and confirmation of the needle location is determined using computed tomography (CT) (Murray et al., 1999). This makes it difficult to routinely evaluate lateral pterygoid muscle activity in patients with craniomandibular disorders, who often complain of pain in the TMJ region. Therefore, the establishment of a non-invasive method for the evaluation of the lateral pterygoid muscle activity is needed.

Mechanomyography (MMG) is one method for the evaluation of muscle activity, and has been applied to surface skeletal muscles (Kruger et al., 2010; Alves et al., 2010). MMG is commonly defined as the recording of the low-frequency lateral oscillations of active skeletal muscle fibers (Orizio, 1993), and is considered to be the ‘‘mechanical counterpart’’ of motor unit electrical activity, which is measured by the surface EMG (Ryan et al., 2008a). Although many studies have been conducted to evaluate the characteristics and properties of MMG in biceps, quadriceps, and lower-back muscles (Kimura et al., 2004; Ryan et al., 2008b; Yoshitake et al., 2001), only a few studies can be found on the masseter muscle (Ioi et al., 2008), and no study has been reported on the lateral pterygoid muscle in stomatognathic muscles. The anatomical distances from the center of external auditory canal to the adjacent muscle bellies are approximately 26.3 mm for lateral pterygoid muscle, 33.3 mm for masseter muscle, 40.3 mm for medial pterygoid muscle and 38.5 mm for temporal muscle, which could be measured on the photographic anatomy of the human body (Yokochi et al., 1989). Therefore, the lateral pterygoid muscle locates in the most predominant distance for the detection of MMG from the external auditory canal. The purpose of this study was to establish a method for the evaluation of muscle activity of the lateral pterygoid muscle using MMG.

2. Materials and methods

Three male subjects without signs or symptoms of temporomandibular disorders (age 27-32 years; mean ± SD, 29.3 ± 2.5) participated in this study. In all subjects, the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) (Dworkin and LeResche 1992) were used to verify the absence of signs and symptoms of Temporomandibular Disorders. All subjects received an explanation of the nature and purpose of the study, and all gave their written informed consent to participate in the study. Experimental procedures were approved by the Ethics Committee of Okayama University.

2.1. Experimental procedures

Each subject sat in a chair with an earplug (Ear holiday, PIP, Osaka, Japan) in his left ear, in which a condenser microphone (B6P4FF05B, bandwidth 20 Hz-20 kHz, diameter 2.5 mm, weight 2g, sensitivity 120 dB ± 3 dB, Countryman, CA, USA) (Fig. 1a) was installed, as shown in Fig. 1b. The MMG signal in the left external auditory canal was recorded on a digital data recorder (PCM-D50, Sony, Tokyo, Japan) in WAV format, using 16-bit samples with a sampling rate of 44.1 kHz. The MMG signal was band-pass filtered (15-20 Hz).

For surface EMG recording, bipolar electrodes (Ag/AgCl) were applied on the left masseter muscle, left anterior and posterior belly of the temporal muscle, and left anterior belly of the digastric muscle. A reference electrode was placed on the left wrist. A needle EMG of the inferior head of the lateral pterygoid was recorded simultaneously with the MMG recording. For the needle EMG recording for the inferior head of the lateral pterygoid, a needle was used (30 mm, 25G, Densply Sankin, Tokyo, Japan), carrying two urethane-coated fine stainless-steel wires, bare at the tip. A guide tube for the needle was installed to the resin occlusal splint which fits to the upper dental arch, according to the relative angles reported by Salame et al (2007). The location of the guide tube was evaluated using a magnetic resonance (MR) image to provide the precise estimation of the direction and distance to the muscle for the reliable installation of the electrodes. The insertion of the needle was achieved through the guide tube. MR imaging was performed with a 1.5 T Magnetom Vision MRI scanner (Siemens, Erlangen, Germany) using a circularly polarized head-neck coil. T1-weighted MR images in a sagittal plane were acquired using the Magnetization Prepared Rapid Gradient Echo sequence (repetition time = 9.7 ms, echo time = 4.0 ms flip angle = 12 degree, slice thickness = 1 mm, pixel size = 0.16 mm × 0.16 mm, acquisition time = 1.57 min). Immediately after the insertion of the needle, a cone-beam CT (CBCT) image was taken to confirm the electrode placement. The CBCT unit used was the Veraviewepocs 3D (J Morita MFG. Corp., Kyoto, Japan). The reconstructed voxel size was 0.25 mm × 0.25 mm × 0.25 mm. A tube voltage of 80 kV and tube current of 5 mA were selected. After the confirmation, the needle and the occlusal splint were removed, leaving the wires within the inferior head of the lateral pterygoid muscle. The EMG signals were amplified with an AC amplifier (input impedance 5 MΩ, gain 100-200, common-mode rejection ratio > 80 dB), and band-pass filtered (0.5-1000 Hz). The EMG signals were recorded on an attached computer (Chart 5, AD Instruments, Australia) via an A/D convertor (Power-Lab ML870, AD Instruments, Australia), at a sampling rate of 4 kHz, and data were displayed in real time. The movement of the mandible was recorded by a 3D motion capture system (Move-tr/3D, Library, Tokyo, Japan) using two video cameras. Two target markers were placed on the subnasal point and gnathion point in each subject, and the relative position of the markers was calculated with a sampling rate of 33 Hz.

2.2. Test Protocol

EMG and MMG were recorded for the nine mandibular static tasks, for 7 s each separated with 60 s intervals, as follows: (1) static jaw opened position of 10 mm of interincisal distance, (2) static jaw opened position of 30 mm of interincisal distance, (3) static jaw opened position of 40 mm of interincisal distance, (4) 5 mm protruded mandibular static position, (5) the static jaw position of the most mandibular protrusion, (6) the static jaw position of 5 mm mandibular protrusion against the resistance of 50kPa, (7) the static jaw position of 5 mm mandibular protrusion against the resistance of 100kPa and (8) the static jaw position of 5 mm mandibular protrusion against the resistance of 150kPa, (9) maximal voluntary clenching at intercspal position. The above mentioned resistance force for the jaw protruded static position to the posterior direction was regulated utilizing a pressure algometer (Algometer, Somedic, Sollentuna, Sweden).

2.3. Analysis of data

The MMG data during 7 s of a particular task was processed using the 4096-point fast Fourier transform (FFT) Hamming window function. To evaluate the correlation between the EMG and MMG signals, 28 digitized data samples (sampling rate of 4 Hz, from the whole 7 s of each task) were collected from each of the muscles.

2.4. Statistical Analysis

The significance of the correlation between MMG and EMG of five muscles was evaluated using Pearson's correlation coefficient. Statistical significance was established with a P value less than 0.05. These statistical analyses were performed using the statistical software package SPSS Statistics, Release 18.0 (IBM Japan Ltd., Tokyo, Japan).

3. Results

Figure 2a shows an MR image of a subject wearing a resin splint with a guide tube which was used to determine the direction and distance for the needle electrode insertion. Figure 2b shows a corn-beam CT image of the same subject, confirming the placement of the electrode in the lateral pterygoid muscle, and Fig. 2c shows a scheme of the cross-section around the lateral pterygoid muscle. Using this procedure, it was confirmed that the electrode was within the inferior head of the lateral pterygoid in all the subjects.

In all three subjects, clear EMG activity of the lateral pterygoid muscle was observed for the various tasks: 30 mm jaw open, 40 mm jaw open, 5 mm protruded mandibular position, the most protruded mandibular position, and the 5 mm protruded mandibular positions with mechanical resistances. Whereas only limited EMG activities of the other four muscles could be observed for these tasks (Fig. 3a). Frequency analysis of the MMG data revealed a peak frequency around 15 to 20 Hz (Fig. 4). Statistical analysis revealed a significant positive correlation between the EMG signals of the lateral pterygoid muscle and the MMG signal (Table 1). Figure 5 shows a scattered diagram during the most protruded mandibular position, showing the relationship between MMG and EMG for each target muscle.

In two out of three subjects, EMG activity of the lateral pterygoid muscle could not be observed for the 10 mm jaw open task, thus showing no significant relationship between the EMG and MMG signals for the task. In one subject who showed EMG activity of the lateral pterygoid muscle for the 10 mm jaw open task, significant and positive correlation between the EMG signal of the lateral pterygoid muscle and the MMG signal was observed. In the jaw opening wider than 10 mm task, significant and positive correlation was observed between the EMG signal of the lateral pterygoid muscle and the MMG for all three subjects. Conversely, EMG signals for four other muscles showed no significant correlation with the MMG signal for any of the tasks in the present study.

For the maximal clenching task, even though an EMG burst could be observed for the lateral pterygoid muscle, there was no significant correlation between the EMG signal of the lateral pterygoid muscle and the MMG signal (Fig. 3b). Also, no correlation could be observed between the EMG signals of the other four muscles and the MMG signal.

4. Discussion

The characteristics and properties of the MMG in biceps, quadriceps, and lower-back muscles have been reported in several studies (Kimura et al., 2004; Ryan et al., 2008a; Yoshitake et al., 2001). However, there are only few studies (Ioi et al., 2008) using MMG on the masseter muscle, and to date, no reports on the lateral pterygoid muscle or any other muscles in the stomatognathic system. The lateral pterygoid muscle is known to be one of the important muscles for the mechanical stability of the TMJ (Murray et al., 2007; Juniper, 1984; Hiraba et al., 2000; Fujita et al., 2001). Although the muscle activity of the lateral pterygoid muscle has been of great clinical interest, the requirement of the needle electrode to be precisely inserted into the deep masseter has been an obstacle for the evaluation of its activity. In this study, the needle electrode was inserted with the aid of MR imaging. Figure 2b shows verification of needle placement within the inferior head of the lateral pterygoid muscle by a corn-beam CT image, thus showing this procedure is safe and reliable. However, considering the painful conditions of TMD patients, it would be desirable to avoid the insertion of the needle into the pterygoid muscle with the potential for extreme discomfort. The MMG evaluation of the pterygoid muscle, therefore, would be valuable for clinical use.

So far, MMG signals have been recorded by an accelerometer or a condenser microphone. Kim et al. (2008) reported that an accelerometer is more strongly affected by muscle tremor than is a condenser microphone. In addition, Watanabe et al. (2001) recommend an air chamber at least 10 mm in diameter and 15 mm in length, with a cut-off frequency of 2-4 Hz, because the frequency responses of the condenser microphone were strongly influenced by the volume of the air chamber. Therefore, the frequency analysis would not be applied to the signals of 2-4 Hz. The comparison of these two recording systems were not fully characterized in relation to the recording settings, and any conclusive opinion has not yet been drawn at present. Regarding the lateral pterygoid muscle, an accelerometer cannot be used, because it is not a superficial muscle. Kim et al. (2008) reported that the MMG recorded by a condenser microphone showed higher correlation with the EMG in a wider muscle activity range than those recorded by an accelerometer.

The peak of the frequency of the MMG observed in this study was around 15-20 Hz (Fig. 4), and it was consistent with the frequency components of the MMG reported in a previous study (Orizio et al., 1996), thus supporting the validity of the MMG recording method used in this study.

In two subjects, there was no relationship between the EMG signals of the lateral pterygoid muscle and the MMG signals when the jaw was open 10 mm. This would be related to the kinesiology of the TMJ, that the jaw opening of 10 mm would mainly be achieved by the hinge movement of the joint. As the function of the lateral pterygoid muscle is mainly related to the translational movement of the condyle, the activity of the muscle itself may have been too small to be detected.

EMG activity of the lateral pterygoid muscle was observed for the various tasks, including 30 mm jaw open, 40 mm jaw open, 5 mm protruded mandibular position, the most protruded mandibular position, and the 5 mm protruded mandibular positions with mechanical resistances of 50, 100, and 150 kPa. Significant positive correlations between the EMG signals of the lateral pterygoid muscle and the MMG signals were observed. However, no significant correlations between the EMG signals and the MMG signals could be observed in the other four muscles during the same tasks. These findings indicate that the activity of the lateral pterygoid muscle can be evaluated by MMG signals recorded in the external ear canal.

Although active EMG signals of the lateral pterygoid muscle and the MMG signals were recorded during the maximal voluntary clenching task, no significant correlation in this activity could be observed. This might be caused by the muscle tremor of the strong jaw closing muscles, such as the medial pterygoid, masseter, and temporal muscles. The muscle tremor of the lateral pterygoid muscle might be hidden by the tremor of these strong muscles. Therefore, the activity of the lateral pterygoid muscle may not be able to be evaluated by the MMG, especially during the jaw movement under strong contraction of the jaw closing muscles. However, the MMG signals did not show significant correlation with EMG signals of the masseter muscle or the temporal muscle. This finding suggests that the MMG recorded in the external ear canal is not directly influenced by the masseter muscle and the temporal muscle, even though these muscles are the principal bulk closing muscles.

The results of the present study revealed that the activity of the lateral pterygoid muscle could be evaluated by the MMG signals recorded in the external ear canal, unless the major jaw closing muscles show active contraction.

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Tables

Table. 1 Relationship between MMG amplitude vs. EMG amplitude from the inferior head of the lateral pterygoid (IHLP), the masseter (Mass), the anterior belly of the temporal (AT), the posterior belly of the temporal (PT) and the digastric (Dig) for the nine tasks in each subject.

Task	Sub. 1									
	EMG amplitude IHLP		EMG amplitude Mass		EMG amplitude AT		EMG amplitude PT		EMG amplitude Dig	
	p	R^2	p	R^2	p	R^2	p	R^2	p	R^2
10 mm open	0	0.758	0.861	0.033	0.995	0.001	0.953	0.011	0.641	0.088
30 mm open	0	0.792	0.063	0.314	0.467	0.134	0.73	0.065	0.838	0.039
40 mm open	0	0.701	0.456	0.137	0.451	0.139	0.84	0.039	0.661	0.083
5 mm protruded	0.138	0.258	0.997	0	0.977	0.005	0.904	0.023	0.993	0.001
most protruded	0	0.572	0.983	0.004	0.995	0.001	0.985	0.003	0.943	0.013
50 kPa	0	0.514	0.634	0.089	0.987	0.003	0.264	0.2	0.583	0.103
100 kPa	0.014	0.397	0.995	0.001	0.997	0	0.65	0.086	0.999	0
150 kPa	0.002	0.472	0.773	0.055	0.914	0.021	0.678	0.078	0.915	0.02
maximal clenching	0.514	0.121	0.989	0.002	0.28	0.194	0.998	0	0.577	0.104

Task	Sub. 2									
	EMG amplitude IHLP		EMG amplitude Mass		EMG amplitude AT		EMG amplitude PT		EMG amplitude Dig	
	p	R^2	p	R^2	p	R^2	p	R^2	p	R^2
10 mm open	0.367	0.164	0.9	0.024	0.923	0.018	0.596	0.099	0.46	0.136
30 mm open	0.046	0.334	0.926	0.018	0.584	0.102	0.937	0.015	0.923	0.018
40 mm open	0.003	0.46	0.762	0.058	0.879	0.029	0.958	0.01	0.957	0.01
5 mm protruded	0	0.762	0.759	0.058	0.917	0.02	0.936	0.015	0.967	0.008
most	0	0.854	0.612	0.095	0.999	0	0.229	0.213	0.313	0.182

protruded										
50 kPa	0	0.814	0.771	0.055	0.947	0.012	0.954	0.011	0.657	0.084
100 kPa	0	0.616	0.979	0.005	0.843	0.038	0.973	0.006	0.292	0.189
150 kPa	0	0.691	0.957	0.01	0.957	0.01	0.711	0.07	0.998	0
maximal clenching	0.379	0.16	0.964	0.008	0.995	0.001	0.97	0.007	0.999	0

Task	Sub. 3									
	EMG amplitude IHLP		EMG amplitude Mass		EMG amplitude AT		EMG amplitude PT		EMG amplitude Dig	
	p	R^2	*p*	R^2	*p*	R^2	*p*	R^2	*p*	R^2
10 mm open	0	0.738	0.98	0.004	0.722	0.068	0.982	0.004	0.986	0.003
30 mm open	0	0.725	0.996	0	0.861	0.034	0.962	0.009	0.887	0.027
40 mm open	0	0.753	0.916	0.02	0.953	0.011	0.991	0.002	0.954	0.011
5 mm protruded	0	0.653	0.953	0.011	0.942	0.014	0.689	0.076	0.647	0.086
most protruded	0	0.803	0.948	0.012	0.841	0.038	0.842	0.038	0.767	0.056
50 kPa	0	0.56	0.923	0.018	0.435	0.143	0.969	0.007	0.945	0.013
100 kPa	0	0.656	0.952	0.011	0.563	0.108	0.837	0.039	0.673	0.08
150 kPa	0	0.658	0.901	0.024	0.999	0	0.995	0.001	0.868	0.032
maximal clenching	0.23	0.213	0.701	0.073	0.983	0.004	0.916	0.02	0.972	0.006

Legends

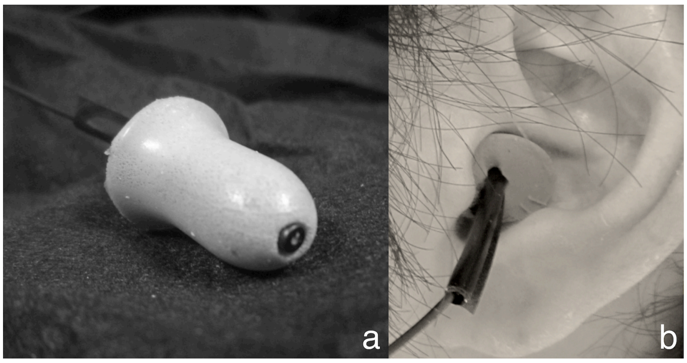

Fig. 1 (a) The earplug in which a condenser microphone was installed in the left ear. (b) The earplug inserted in the left external auditory canal.

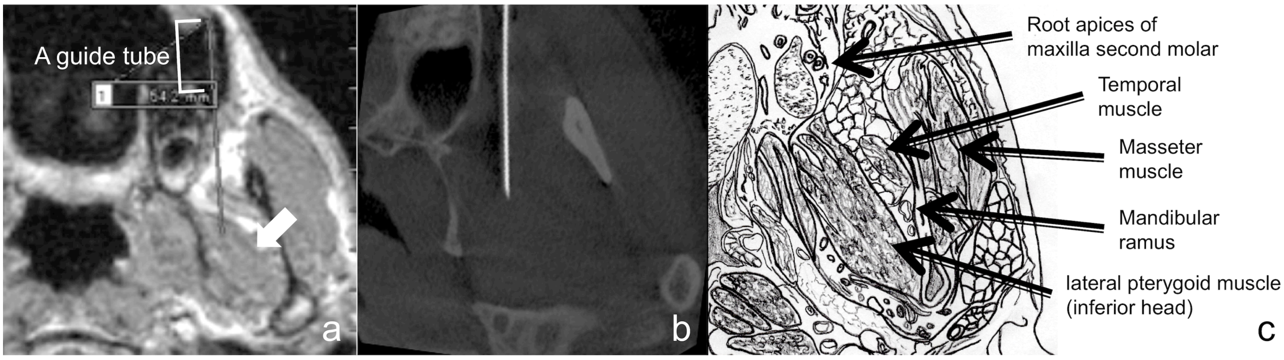

Fig. 2 (a) An example of a magnetic resonance (MR) image of a subject wearing a resin splint with a guide tube, which was used to determine the direction and distance for the insertion of the needle electrode. The arrow shows the lateral pterygoid muscle. (b) An example of the corn-beam computed tomography (CBCT) image of the same subject, confirming the placement of the electrode in the lateral pterygoid muscle. The arrow shows the lateral pterygoid muscle. (c) Scheme of the cross-section around the lateral pterygoid muscle.

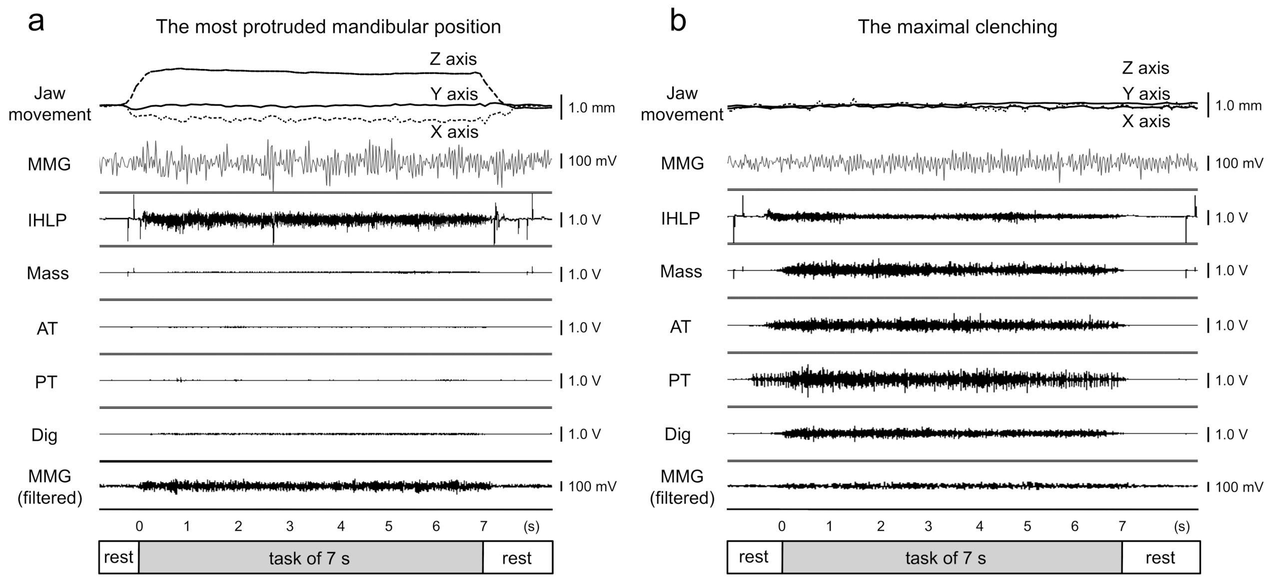

Fig. 3 An Example of recorded MMG, EMG, and jaw movement for (a) the most protruded mandibular position and (b) the maximal clenching tasks. IHLP; inferior head of the lateral pterygoid muscle, Mass; the masseter muscle, AT; anterior belly of the temporal muscle, PT; posterior belly of the temporal muscle, Dig; anterior belly of the digastric muscle, MMG (filtered); The MMG signal was band-pass filtered (15-20 Hz). Jaw movement is expressed in the x-axis (anterior-posterior), y-axis (medio-lateral), and z-axis (superior-inferior).

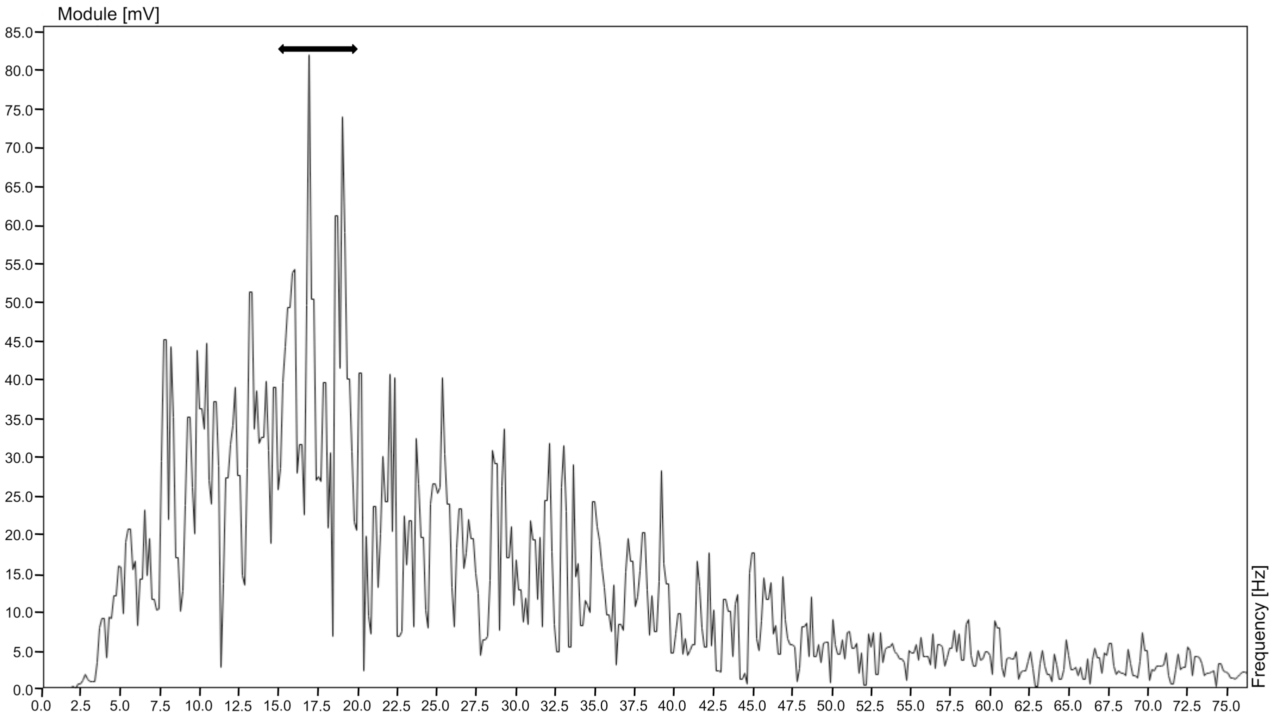

Fig. 4 Frequency analysis example of the MMG data from one trial in a subject, showing a peak frequency around 15 to 20 Hz.

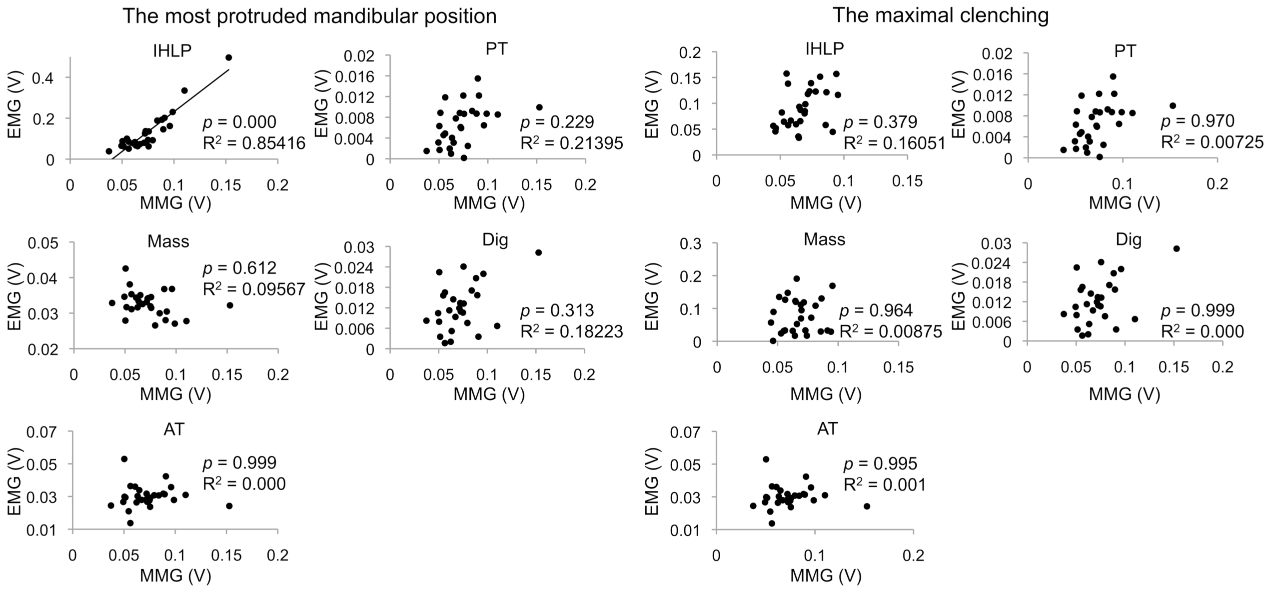

Fig. 5 The relationships between the MMG amplitude and EMG amplitude from five muscles during the most protruded mandibular position task.