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Electromyographic Analysis of Masticatory Muscle Function in Patients with Myogenous Temporomandibular Disorders

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Abstract: Electromyographic (EMG) analysis was conducted to evaluate the functional characteristics of masticatory muscles in patients with myogenous temporomandibular disorders (TMD), aiming to enhance the clinical understanding of muscle activity in these conditions. Based on the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD), 28 patients with myogenous TMD, characterized by persistent pain exceeding six months, were examined alongside a control group of 35 asymptomatic subjects. EMG assessments were performed on the masseter, temporalis, and suprahyoid muscles during resting states and maximum intercuspation clench. Quantitative parameters, including myoelectric indices in the amplitude domain and mean power frequency (MPF) in the frequency domain, were evaluated. Significant differences in muscle activity patterns between the TMD and control groups were observed. During maximum clenching, temporalis muscles (TA) in TMD patients exhibited a markedly higher asymmetry index and activity index, alongside a lower MPF, compared to the control group. Conversely, the MPF of the suprahyoid muscles was elevated, while masseter muscles (MM) displayed a reduction in MPF. In the resting state, the MPF of the TA was found to be higher than that of both the control group and the MM. These findings indicate that patients with myogenous TMD exhibit increased muscle activity asymmetry, reduced coordination, and altered frequency-domain characteristics of the masticatory muscles. The results suggest that the TA may play a more significant role in the compensatory mechanisms associated with myogenous TMD, potentially contributing to the observed dysfunction and pain. This study underscores the utility of EMG as a diagnostic tool for elucidating the pathophysiological changes in masticatory muscle function in TMD and highlights the potential for targeted therapeutic interventions based on these findings.

Keywords: Myogenous temporomandibular disorders (TMD); Electromyography (EMG); Masticatory muscles; Mean power frequency (MPF); Muscle asymmetry

1. Introduction

TMD primarily affects the nerves, muscles, and bones, involving the masticatory muscles, temporomandibular joint (TMJ), and surrounding structures, making it a common condition (Skármeta et al., 2019). TMD is a multifactorial disease, with muscle and joint symptoms often coexisting, complicating diagnosis and subsequent treatment (De Leeuw & Klasser, 2018).

Currently, magnetic resonance imaging (MRI) is considered the most accurate technique for observing morphological changes in the joint area and is the gold standard for diagnosing disc displacement. However, studies have shown that the primary obstacles for TMD patients are not only joint structural disorders but more often muscle activity changes (Santana-Mora et al., 2009). TMD patients experience many changes in their masticatory muscle electrical activity due to functional impairments or compensatory mechanisms related to their symptoms. Therefore, surface EMG (sEMG) has emerged as a biopotential and non-invasive instrument, becoming an important tool for analyzing muscle performance during oral-facial activities. It can obtain objective, effective, and reproducible data on the functional status of masticatory muscles in patients with myogenic TMD, thereby assisting in the clinical diagnosis of myogenic TMD (Cao et al., 2009).

Existing assessments of muscle electrical activity have typically analyzed root mean square (RMS) in the time domain, integrated EMG (IEMG) signal values, and MPF in the frequency domain, allowing observation of the electrophysiological behavior of muscles under different physiological conditions. Xu et al. (2017) used unilateral bite force dynamometry to evaluate the masticatory muscle electrical activity of the control group during maximum unilateral molar clenching within the maximum tolerable time. They found that the normalized RMS EMG of masticatory muscles in the TMD group was significantly lower than that of the control group. Other studies have analyzed the normalized RMS values of the masseter and anterior TA in acute muscle pain TMD patients and control groups during short-term clenching, finding no changes in RMS between the two groups (Santana-Mora et al., 2009). Therefore, even in TMD patients, masticatory muscles do not show signs of muscle fatigue in the short term.

Currently, there are few reports on the evaluation of fatigue and symmetry of masticatory muscles in TMD patients with chronic persistent pain (more than six months). It hypothesizes that there are compensatory changes in the neuromuscular condition of patients with chronic persistent pain. Previous studies have mostly focused on the evaluation of RMS in masticatory muscles, with less analysis of the symmetry, lateral displacement, and range of motion of the masseter and TA (Campillo et al., 2017). Calculating these variables through RMS in the time domain helps to accurately evaluate the functional impairment characteristics of long-term pain TMD patients, detect pathological muscle activity states, and provide objective data for clinical diagnosis and treatment. Additionally, MPF is one of the indices for evaluating the functional status of the masticatory system. Tartaglia et al. (2011) found that MPF values in joint-origin TMD patients significantly decrease with the severity of TMD. Based on these studies, this study hypothesizes that the pathogenic mechanism of masticatory muscle pain or TMJ inflammation affects the intensity and frequency of muscle fiber activity, leading to functional impairment. However, it is currently unclear how TMD affects MPF.

In summary, this study aims to evaluate the standardized EMG indices of the masseter, temporalis, and suprahyoid muscles in long-term pain myogenic TMD patients and asymptomatic normal individuals during maximum clenching. By using the more advanced BIO-EMG III electromyograph and precise electrode positioning technology, multiple EMG parameters were combined for the first time, including the overlap coefficient (POC), torque coefficient (TC), relative activity (Ac), IMPACT index, and MPF, to correctly assist in the clinical diagnosis of TMD.

2. Study Design

As shown in Table 1, a total of 28 patients who visited the joint department of Baoding Second Hospital due to TMJ/maxillofacial muscle pain between 2023 and 2024 were included. The age range was 18-40 years, with an average age of (25.32 ± 2.46) years. A control group of 35 asymptomatic normal individuals with joint disorders was included, with an age range of 18-40 years and an average age of (28.64 ± 3.91) years.

Table 1. Classification of clinical symptoms in subjects under DC/TMD (n = 63)

Diagnosis	Number of Subjects (n)
No TMD (control group)	35
Localized muscle pain	16
Myofascial pain	9
Referred myofascial pain	3
Concurrent joint-origin symptoms	21
Reducible disc displacement (left/right)	3（2/2）
Reducible disc displacement with locking (left/right)	5（3/2）
Irreducible disc displacement with limited opening (left/right)	9（5/6）
Irreducible disc displacement without limited opening (left/right)	4（1/4）
Joint pain (left/right)	24（13/17）

The inclusion criteria for the TMD group are as follows:

- Pain duration of more than six months;
- Diagnosis of myogenic TMD according to the DC/TMD criteria (Schiffman et al., 2014): localized muscle pain/myofascial pain/referred myofascial pain;
- Concurrent joint-origin diseases allowed: reducible disc displacement/reducible disc displacement with locking/irreducible disc displacement with limited opening/irreducible disc displacement without limited opening.

The inclusion criteria for the control group are as follows:

- Not within the DC/TMD: no orofacial or joint area pain;
- No clicking;
- No mandibular movement disorders;
- Mentally healthy.

The exclusion criteria for both groups are as follows:

- Missing teeth;
- Systemic diseases (such as arthritis, joint disease, or diabetes);
- History of facial or TMJ trauma, surgery, or TMJ dislocation;
- Current orthodontic treatment;
- Neurological or cognitive disorders.

All case data in this study were approved by the Ethics Committee of Baoding Second Hospital and obtained informed consent from the patients.

3. Test Content

3.1 Instrumentation

The BIO-EMG III electromyograph was used to read sEMG signals, with an impedance > 10 MΩ, 16-bit resolution analog-to-digital converter, and a sampling frequency of 2000 Hz. Four differential surface electrodes with an electrode spacing of 10 mm were used. The gain was set to 20 times, with a common-mode rejection > 130 dB, an input impedance of 10 GΩ, and a signal-to-noise ratio < 3 μV.

3.2 Test Procedure

The subjects were instructed to sit in a quiet and comfortable environment, with their eyes looking straight ahead and the occlusal plane parallel to the ground. The skin surface of the subjects was cleaned with 75% alcohol cotton balls. The reference electrode (30 × 40 mm) was placed on the manubrium sterni, following the standard positioning proposed by Cram et al. (1998). Four disposable silver bipolar electrodes (Duo-Trode, Kent, USA) were then attached according to the direction of the muscle fibers on the left and right MM, TA, suprahyoid muscles, and sternocleidomastoid muscles, and the EMG signals of the first three muscle groups were extracted, as shown in Figure 1. According to verbal instructions from the researchers, the subjects were asked to clench their teeth as tightly as possible in the rest and intercuspal positions, maintaining the same contraction level for five seconds. The clenching intensity for the experimental group should be able to feel facial muscle/TMJ pain, and EMG readings were recorded three times at 5-second intervals every three minutes.

Figure 1. Electrode placement for EMG leads

3.3 Data Processing

Muscle activity was evaluated using the RMS of the amplitude (μV) and the MPF (Hz) in the frequency domain. The EMG data were processed using Matlab® software (R2015a, MathWorks Inc, USA) (Ferrario et al., 2007). Since sEMG signals are weak biopotential signals with a spectrum primarily in the 0-500 Hz range, they are susceptible to interference, resulting in a low signal-to-noise ratio, which is unfavorable for subsequent analysis. To improve signal quality, preprocessing steps are required, including removal of direct current (DC) components and baseline drift using Fast Fourier Transform (FFT), exclusion of irrelevant frequencies using a Butterworth band-pass filter, amplitude normalization, full-wave rectification, and smoothing of the signal envelope extraction using a Butterworth low-pass filter, as shown in Figure 2. These steps help to reduce noise, highlight muscle activity characteristics, and provide a basis for feature extraction and pattern recognition.

The recorded EMG potentials in this test were expressed as a percentage of the average potential in the standardized test. The following calculations are all performed using standardized potentials. For each subject, the average value obtained from three tests was taken. A set of standardized EMG indices was calculated through the RMS (Rodrigues-Bigaton et al., 2017; De Felício et al., 2009).

(a) POC (%): It evaluates muscle symmetry by comparing the EMG waves of paired muscles (left and right muscles, masseter and temporalis) of the subjects. POC is an indicator of the symmetrical distribution of muscle activity determined by clenching, and the range is between 0% and 100%. When the two paired muscles contract perfectly symmetrically, POC is 100%, as shown in the top-left schematic in Figure 3.

(b) TC (%): It evaluates the potential lateral displacement component caused by the unbalanced contraction activity of the contralateral masseter and TA, with a range between 0% (no lateral displacement force) and 100% (maximum lateral displacement force), as shown in the bottom-right schematic in Figure 3.

(c) Ac (%): By differentiating the most common pairs of masticatory muscles, it is the difference between the average standardized potentials of the masseter and TA divided by the sum of the same standardized potentials (Tartaglia et al., 2008). When the standardized potential of the MM is greater than that of the TA, Ac is positive (maximum 100%); when the TA potential is greater, Ac is negative (maximum 100%); when they are equal, Ac is zero, as shown in the top-right schematic in Figure 3.

(d) IMPACT index (μV/μV.S): The average (masseter and temporalis) total standardized muscle activity is the integrated area of the EMG potential over time (6, 11), as shown in the bottom-left schematic in Figure 3.

(e) MPF (Hz): It conducts EMG analysis in the frequency domain by determining the MPF of the signal power spectral density through a 50% overlapping FFT.

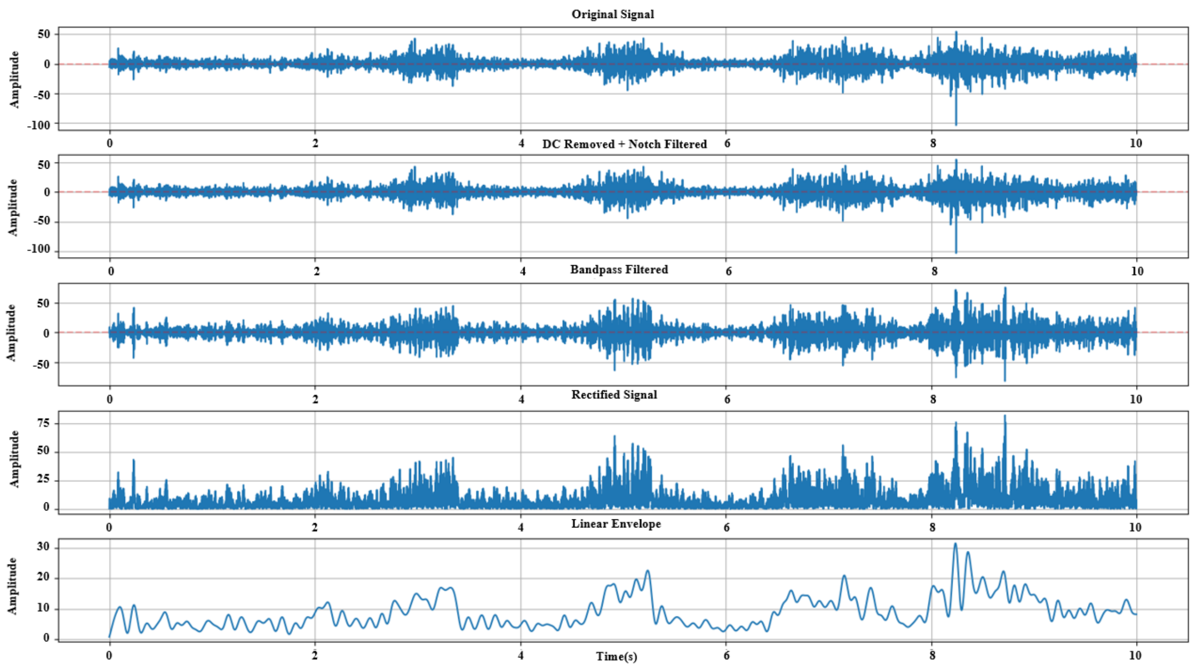

Figure 2. Results of sEMG signal preprocessing

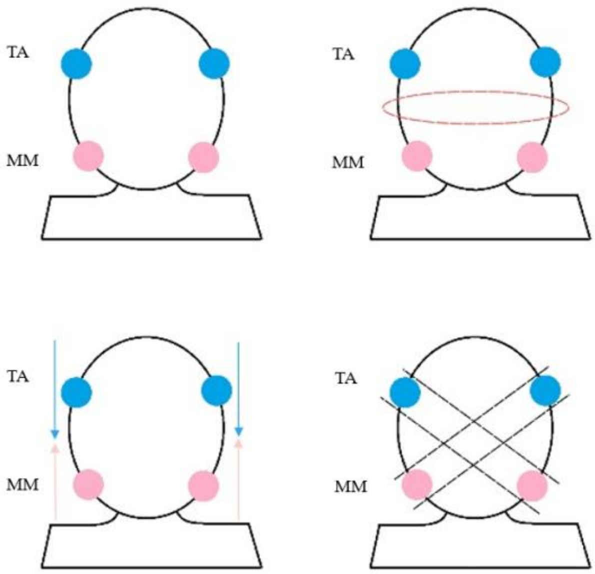

Figure 3. Schematic diagram of standardized EMG indices for TA and MM

3.4 Statistical Analysis

This study applied SPSS 25.0 for statistical analysis. All data underwent normality testing (Kolmogorov-Smirnov) with a 95% confidence interval. A two-way factorial Analysis of Variance (ANOVA) was used to compare EMG indices in the amplitude domain between subject groups, and a mixed-model ANOVA was used to compare MPF between groups, muscles, and sides. Independent sample t-tests were used to compare MPF of the masticatory muscles. A p-value < 0.05 was considered statistically significant.

4. Results

Twenty-eight patients diagnosed with TMD were included in the study, who met the DC/TMD for muscle pain, and were possibly accompanied by disc displacement and joint pain. Thirty-five normal individuals without TMD were included in the control group, as detailed in Table 1.

During maximum clenching, significant differences in POC TA and Ac between groups were observed ($P < 0.05$). TMD patients exhibited greater asymmetry in the TA (lower POC) and higher Ac. Within the TMD group, significant differences in TC were observed ($P < 0.05$), with greater lateral displacement during maximum clenching compared to the rest position. No significant differences were found in POC MM index, TC, and impact between groups ($P > 0.05$). Within the control group, no significant differences were observed in the standardized EMG indices ($P > 0.05$). See Table 2 for details.

Table 2. Standardized EMG indices of 28 TMD patients and 35 control subjects (X ±S)

Measurement Items	Control Group		TMD Group	
	Rest	Maximum Clenching	Rest	Maximum Clenching
POC TA (%)	90.21±3.25	87.24±2.01	87.35±2.28	81.06±1.63*
POC MM (%)	84.26±2.64	85.31±1.88	89.82±1.86	83.24±0.96
TC (%)	8.26±0.96	7.92±0.52	7.81±1.37	8.94±0.37△
Ac (%)	0.21±1.59	-0.36±3.24	-1.36±2.24	-4.32±5.27*
IMPACT(μV/μV.S)	109.2±10.27	115.0±16.58	105.4±18.34	109.4±20.31

Note: In the two-way factorial ANOVA, * represents the main effect of the group, and P < 0.05; △ represents the main effect of the action, and P < 0.05.

During maximum clenching, significant differences in MPF values of the left temporalis and suprahyoid muscles between groups were observed ($P < 0.05$). The MPF values of the masseter and TA were lower than those of the control group, while the MPF value of the suprahyoid muscle was higher than that of the control group. At rest, significant differences in MPF values of the TA between groups were observed (P < 0.05), with the MPF value of the TA being higher than that of the control group. No other significant differences were found between groups (P > 0.05). Within the TMD group, the MPF value of the MM was lower than that of the TA. See Table 3 for details.

Table 3. MPF of masticatory muscles in 28 TMD patients and 35 control subjects (X ± S)

MPF（Hz）	Control Group		TMD Group	
	Rest	Maximum Clenching	Rest	Maximum Clenching
Left masseter	80.46±17.52	149.52±32.18	94.54±34.87	131.68±29.26
Right masseter	82.39±20.64	157.61±26.42	92.46±20.34	142.57±30.18
Left temporalis	79.68±31.24	171.65±35.63	106.59±40.25*	150.49±43.27*
Right temporalis	76.59±25.66	162.58±26.27	109.63±29.84*	158.27±34.63
Suprahyoid	89.65±34.57	76.58±15.84	93.67±25.63	89.27±20.36*

Note: The * symbol denotes statistically significant differences between the TMD and the control group under the same condition (P < 0.05) without considering between-group factors in the t-test.

The mixed-model ANOVA showed significant interactions between the MPF values of the masticatory muscles and the group, muscle, and action (P < 0.05). See Table 4 for details.

Table 4. Comparison of MPF of masticatory muscles between 28 TMD patients and 35 control subjects

Main Effect	Main Effect	F	P
Between-group	Group	18.672*	<0.01
	Muscle	9.347*	<0.05
Within-group	Left and right sides	1.613	8.49
	Action	30.682*	<0.01

Note: In the mixed-model ANOVA, the between-group factor is the group; the within-group factors are MM and TA, left and right sides, and rest and maximum clenching; P > 0.05 indicates no statistical significance.

5. Discussions

Currently, sEMG has not yet become a widely used method for diagnosing and monitoring TMD (Han et al., 2024). The main issue limiting its clinical application is the standardization/normalization of sEMG recordings. It is believed that to compare EMG data from different subjects, the measurement results should be linked to muscle electrical activity detected in standardized recordings, such as maximum clenching. Relevant literature has proven that the EMG potentials collected during maximum clenching in the intercuspal position have the best reproducibility (Pires & Rodrigues-Bigaton, 2018). Normalized EMG data can reflect the impact of occlusion (tooth contact) on joint, nerve, and muscle activity, avoiding interference from individual differences (anatomical differences, physiological and psychological states, etc.) and technical differences (muscle crosstalk, electrode placement, etc.). TMD is more common in young female populations, but previous studies comparing EMG data between normal control groups and TMD patient groups have not found significant gender-related differences (Ferrario et al., 2006). Therefore, gender was not considered as a control condition in the inclusion of samples in this study. Secondly, to limit inter-individual differences (Cairns, 2010), young adult patients were selected for this study. The BIO-EMG III electromyograph was used to accurately capture EMG signals, and Matlab® software was used to process and convert EMG data. The POC, TC, Ac, and impact indices were used to evaluate muscle symmetry, activity, and coordination, while MPF was used to assess muscle fatigue and functional status. Compared to traditional EMG evaluation relying on RMS, this study converted multiple standardized EMG indices through time domain values, not only quantifying muscle asymmetry in TMD patients but also revealing compensatory changes in masticatory muscle function due to chronic pain for the first time. These data provide a scientific basis for a deeper understanding of the neuromuscular mechanisms of TMD.

5.1 Evaluation of Standardized EMG Indices in the Amplitude Domain

A slight asymmetry in muscle activity in healthy subjects is a common phenomenon. Due to differences in the morphology and function of paired structures on the left and right sides of the body (Wieczorek & Loster, 2015), asymmetry in masticatory muscle electrical activity exists in both the control group and TMD patients, but the latter exhibits greater imbalance. The standardized contraction ratio (POC index) of the anterior TA in TMD patients is more asymmetric than that of the healthy control group. Additionally, the standardized activity of the TA is greater than that of the MM (negative activity index), while the standardized activities of the TA and MM in the normal control group are almost equal (activity index close to zero). Grünheid et al. (2009) showed that patients with chronic orofacial pain have changes in myoglobin and cross-sectional area of jaw muscle fibers, with an increased proportion of fast myoglobin fibers and a reduced cross-sectional area of slow myoglobin fibers, resulting in decreased activity frequency and intensity of jaw muscles, and asymmetric contraction of the TA with greater Ac of the MM. This study is consistent with the research viewpoints of the above literature. Tartaglia et al. (2008) studied the EMG of the TA and MM in 103 TMD patients and 32 healthy individuals, finding significant differences in standardized muscle activity between the two groups. However, in this study, no significant differences were found in the integrated area of EMG potentials over time between the two groups. It is believed that it is related to the different composition of the samples. Their study included not only myogenic patients but also joint-origin and acute TMD pain, with a larger age group than the current study. Secondly, the POC of masticatory muscles during clenching is lower than that during rest, indicating that the POC is higher when muscle activity is lower, and muscle contraction activity is more symmetrical. De Felício et al. (2009) found that the torque index was higher in the healthy control group during rest and lower during clenching, i.e., the torque index during clenching was lower than that during the mandibular posture position. This is consistent with this study, even without statistical differences. The torque effect in the horizontal plane is usually counterbalanced by forces generated by other anatomical structures. During rest, this balance is maintained by other muscles, such as the suprahyoid, lateral pterygoid, and medial pterygoid muscles, while during maximum clenching, the force of tooth contact increases, thereby preventing lateral displacement of the mandible (Leuin et al., 2011). In this study, in the TMD group, the lateral displacement during maximum clenching was greater than that during rest, inconsistent with the above research. This phenomenon was more pronounced in patients with unilateral orofacial pain. This study speculates that the lateral displacement of masticatory muscles during clenching may be a compensatory mechanism to relieve pain, a specific protective functional adaptation of the neuromuscular system due to nociceptive input (Cheng et al., 2012). Therefore, when distinguishing TMD patients from healthy individuals, the asymmetric characteristics of the TA seem to be more meaningful. It is believed that the positional effect of the anterior TA and increased occlusal contact may make this muscle more sensitive to occlusal adjustment and nerve conduction. Secondly, the increased activity of the TA in TMD patients may be a result of protective adjustments to reduce joint load. Understanding the EMG patterns of masticatory muscles in myogenic TMD patients can help develop treatment strategies aimed at normalizing muscle activity and improving the function of the orofacial system.

5.2 Evaluation of Standardized EMG Indices in the Frequency Domain

In the frequency domain, especially in TMD patients, the MPF of the anterior TA is higher than that of the MM. This is consistent with previous studies. Hugger et al. (2012) pointed out that the difference between the MM and anterior TA is due to the heterogeneity of human masticatory muscle fiber composition, and they also exhibit different behaviors in fatigue tests: the MPF of the MM decreases faster than that of the anterior TA. This conclusion can also be explained by the function of the muscles and the relationship between function and the number of muscle spindles (Cha et al., 2007). Among the analyzed closing muscles, the TA has the highest number of muscle spindles; the MM has the second highest number. The closing muscle spindles should have a strong proprioceptive influence, making the TA play a major role as a postural muscle during rest and clenching.

During rest, the EMG activity of the masticatory muscles is minimal, indicating that the jaw elevators and depressors are in a state of balance (Wang et al., 2004). The comparison of MPF values of the TA between groups showed statistical significance. This may be due to an increased recruitment pattern of motor units in the TA in patients with orofacial pain when the mandible is in a resting state. De Felício et al. (2012) showed that the EMG of the TA in healthy individuals is lower than that in TMD patients during the rest position, while TMD patients have lower EMG during maximum intercuspal clenching than healthy individuals. Tartaglia et al. (2011) studied the MPF of the TA and MM in TMD patients with orofacial pain and healthy normal individuals, finding that the masseter MPF of healthy individuals was significantly higher than that of the TMD group during maximum intercuspal clenching. In this study, the comparison of MPF values between groups during maximum clenching showed a decrease in both the MM and TA, both lower than the control group, with a statistically significant difference in the TA. This study suggests that the decrease in MPF of masticatory muscles may be due to increased muscle fatigue caused by TMD parafunctional habits. TMD patients with chronic orofacial pain have reduced average power due to functional impairment or compensatory changes related to symptoms, and increased muscle asymmetry and coordination. The MPF of masticatory muscles showed significant interactions between groups, muscles, and actions, but no significant interactions between left and right sides. This may be because the patients included in this study had fewer unilateral symptoms, and subsequent studies should include patients with chronic unilateral TMD to observe the differences between the activities of the two sides of the muscles. The MPF values of the suprahyoid muscles showed significant differences between groups, with higher MPF values in the TMD group, indicating a decrease in the average frequency of motor units in the antagonistic muscles of TMD patients. Whether in myogenic or joint-origin TMD patients, there is little research on the MPF values of the suprahyoid muscles in the literature.

6. Conclusion

In summary, the standardized activity range and asymmetry of the TA in TMD patients with myogenic pain increase, and coordination decreases. In addition, the average frequency of masticatory muscles decreases. EMG is an effective tool for evaluating the masticatory function of TMD patients, thereby assisting in clinical diagnosis and treatment. This study also has certain limitations. It only evaluated patients with chronic pain in the myogenic TMD group, and did not include patients with acute pain and joint-origin TMD. Higher pain intensity may lead to more significant changes and functional impairment in EMG parameters of masticatory muscles. In the future, TMD patients should be classified in detail according to the DC/TMD; the sample size should be increased; and follow-up should be conducted. Additionally, dynamic activities, such as chewing and swallowing, should be evaluated to obtain more comprehensive and complete dynamic EMG characteristics to guide clinical practice.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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