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Is SEMG recorded "hyperactivity" during mandibular rest a sign of dysfunctional jaw muscle activity and temporomandibular disorders (TMD)?

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Abstract

Background: Some authors state that above-normal surface electromyography (SEMG) levels during mandibular rest (MR) are a general sign of temporomandibular disorders (TMD).

Objective: The *aim* was to compare SEMG levels in the masseter and anterior temporalis areas during MR between patients with disc displacement (DD) and subjects identified as healthy. The *hypothesis* was that average SEMG levels would be higher in the patients during MR before and after repeated clenches with maximal effort.

Methods: Thirty-six healthy subjects, and 42 patients with DD, were included. SEMG levels were recorded bilaterally in the temporalis and masseter areas during MR before clenching and after repeated clenches with maximal effort. Multivariate analysis of variance (MANOVA) was used to compare the means of the log-transformed SEMG-values for the subject groups.

Results: The mean MR levels in the four areas before clenching ranged from −0.19 log (μV) to 1.20 log(μV) in healthy subjects and from −0.22 log(μV) to 0.96 log(μV) in patients. The mean MR levels in the four areas after repeated clenches ranged from −0.19 log (μV) to 1.04 log(μV) in healthy subjects and from −0.27 log(μV) to 0.93 log(μV) in patients. The MANOVA test showed no significant differences in the means for MR for the four areas between the groups at the 5% significance level.

Conclusion: The hypothesis that jaw muscle SEMG levels during MR are on average generally higher in TMD patients is not supported. A possible explanation for the previous findings is that activity in other muscles was mislabelled as jaw muscle activity.

KEYWORDS

anterior temporalis muscle area, disc dysfunction, hyperactivity, masseter muscle area, SEMG, TMD, TMJ

Jianlai Hu and Yan Dong are first co-authors.

1 | INTRODUCTION

The jaw position during mandibular rest (MR) refers to "the position that the mandible passively assumes when the mandibular musculature is relaxed".[1] The term *postural jaw muscle activity* refers to activity needed to keep the mandible in a well-balanced position during rest. At normal and deliberate rest with the lips, but not the teeth, occluded, there is no or only negligible activity in the temporalis and masseter muscles.[2,3]

There is normally no recordable electromyographic (EMG) activity in jaw-closing muscles during slow mandibular closure from MR until the moment when the upper and lower teeth make contact.[2] Factors, including tissue elasticity, low level of *muscle tone* or *tonus* and differences in intra- vs. extra-oral air pressure when lips are closed, are enough to keep the mandible in the resting position.[2] The definition of *tone* includes both the passive stiffness of muscular and fibrous tissues. The reaction of the nervous system to stimuli is a muscular contraction. A skeletal muscle can be completely at rest without detectable neuromuscular EMG activity and without losing its *tone* or *tonus*,[3] which explains why no jaw muscle EMG has been recorded with needle electrodes during MR.[4-6]

The medical term *hyperactivity* is defined as "General restlessness or excessive movement such as that characterising children with attention deficit disorder or hyperkinesis".[7] The term "*muscular hyperactivity*" is used in *research diagnostic criteria* (RDC)[8] in a section about movement disorders under the subheading Orofacial Dyskinesia. However, *hyperactivity* is used in many dental papers as a label for low-level surface EMG (SEMG) activity recorded in the masseter and/or temporalis areas during MR[9-12] despite the absence of distinct jaw movements. This is still the practice, even if no movements of the mandible have been observed beyond small changes of a few millimetres in the *free-way space* (the interocclusal distance between the occlusal surfaces of the teeth). Thus, *hyperactivity* has been defined and used in significantly different ways in the research literature, by some for strong involuntary activity[8] and by some for small increases of μV levels with or without observable jaw movements.[9-11,13,14] For small increases, a more appropriate term, *elevated activity*, has been used.[11]

To obtain the true amount of muscle activity, the portions of artefact activity should be estimated and subtracted. Activity in neighbouring muscles is an artefact if the aim was to record the activity of a specific muscle. The main parts of the recorded energy are as follows: (a) electronic noise,[15] (b) biological noise [16] and (c) EMG activity in groups of muscles.[3,5,15,16] The size of the contribution from an individual muscle cannot be calculated based on SEMG recordings.[3] The parts of the electrical activity that come from jaw muscles during MR are zero or very close to zero.[3,5] To the best of our knowledge, no proponents of the hyperactivity theory have taken all three (a, b and c) parts into consideration by reducing the figures of total electrical activity when presenting normative values for *jaw muscle activity* during MR. Figure 1 illustrates the problem with electronic noise. It may not be of consequence when comparing clench levels, but our experience is that the noise level, after filtering (Figure 1), is at least about 0.40 μV or −0.40 log (μV), which is significant when recording low SEMG levels during MR position (MRP). This might explain why we do not have any reports that suggest the normative value for jaw muscle activity during MR to be above zero.

Debates about the diagnostic value of SEMG in diagnosis of masseter muscle hyperactivity during mandibular rest and related topics have been ongoing for decades.[9-11,17-22] The risk that artefact activity is recorded from facial muscles and other neighbouring muscles was pointed out in old texts already in the early years of EMG use in dental clinics and research.[4-6,17,23,24] SEMG is not acknowledged as being of value in the diagnosis of temporomandibular disorders (TMD) by groups responsible for publicising the diagnostic criteria for temporomandibular disorders.[8,25] The Royal College of Dental Surgeons of Ontario recently published a position paper[18] supporting negative opinions about the use of SEMG in dental clinics by stating that there are insufficient data to support any diagnostic value of SEMG in TMD clinics. However, large groups of authors still advocate that SEMG can be useful in diagnosing TMD.[9-12] Their view is to us best represented by a position paper[11] endorsed by the Board of Regents of the International College of Cranio-Mandibular Orthopedics (ICCMO) and by information given on the ICCMO website,[10] where it is claimed that voltage levels of SEMG, recorded in the masseter and temporalis areas during MR, are higher in TMD patients than in healthy controls. The position paper states that a significant body of scientific literature published in peer-reviewed journals during the past 50 years concludes that the TMD patient population has elevated resting EMG muscle activity and that SEMG can be used to measure such electrical activity in masticatory muscles at rest. It should be noted that it is presented as a sign of TMD in general, with no exceptions for subgroups. This study is focused on one TMD group, patients with disc displacement with or without reduction. If it is not a valid sign for a subgroup, it should not be accepted as a universal TMD sign. For more references, the readers are referred to lists in texts by Cooper[11] and Jankelson.[9]

The *aim* of this study was to compare SEMG levels in the masseter and anterior temporalis areas during MR between patients with disc displacement (DD) and subjects identified as healthy. The *hypothesis* was that average SEMG levels would be higher in the patients during MR before and after repeated clenches with maximal effort.

The term *healthy* was defined as being without signs, symptoms, history of TMD or other health problems.[8,25,26] Specifically, the study compared SEMG levels in the temporal and masseter areas on the right and left sides of the face between patients with TMJ disc displacement and healthy subjects, during MR before clenching and during MR after repeated voluntary clenches with maximal effort.

The study also allowed a comparison of the difference in average SEMG levels during MR before clenching and after repeated voluntary clenching with maximal effort and a comparison of average SEMG levels during clenching, between TMD patients and healthy subjects.

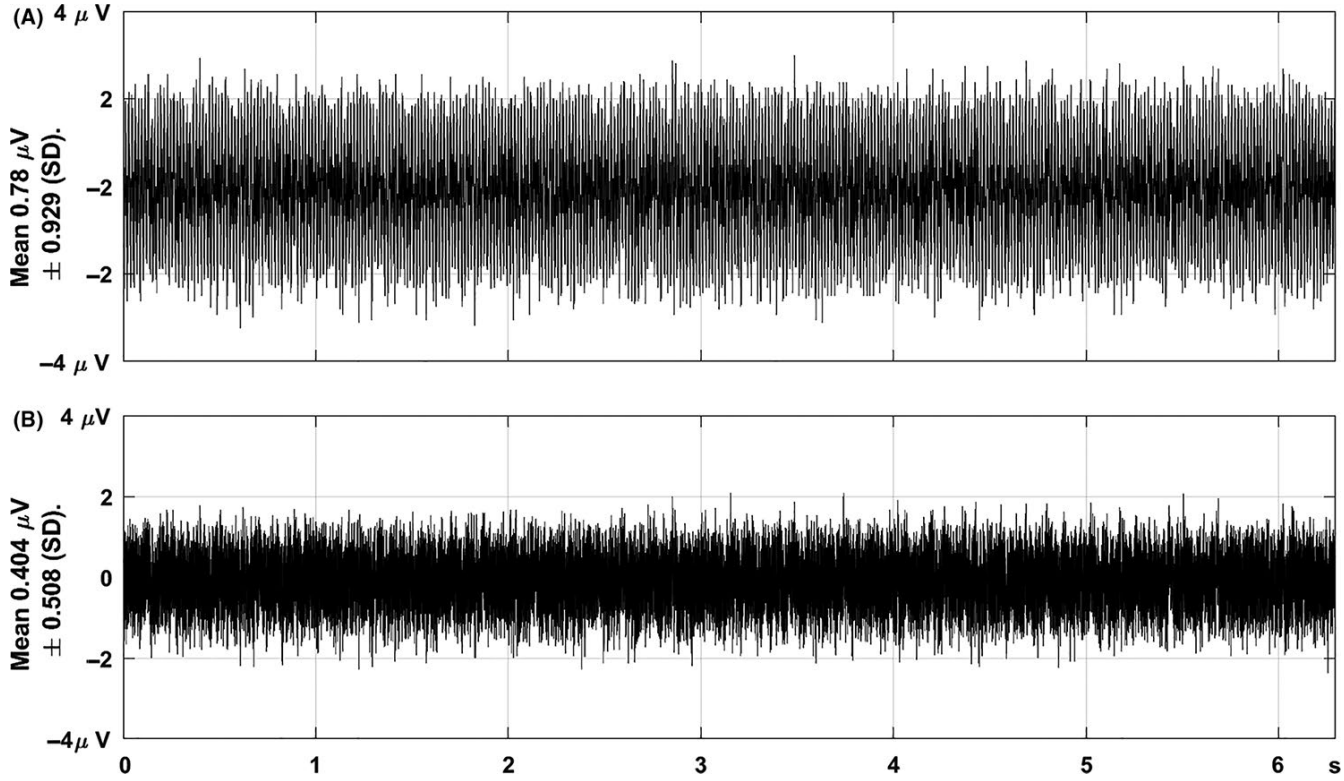

FIGURE 1 The main parts of the recorded energy are as follows: A, electronic noise,[15] B, biological noise [16] and C, EMG activity in groups of muscles.[3,5,15,16] This figure illustrates a typical level of unavoidable electronic noise. The signal is the output from an amplifier channel when the corresponding input contact was shut off from EMG input. That is, the output signal contains no EMG energy. The not filtered noise, mean level 0.78 μV or −0.11 log(μV), is displayed in the upper window. In the lower row is the same signal filtered using the same programme that was used for filtering the SEMG signals. The mean level was 0.41 μV or −0.39 log (μV)

2 | METHODS

2.1 | Subjects

All subjects gave informed consent. The experimental protocols were approved by the Zhejiang University Ethical Committee. During the time the study was performed, all patients coming to the TMD Clinic at the College of Medicine, Second Affiliated Hospital, Zhejiang University were asked to volunteer for SEMG examination. Those who did, and were diagnosed as having disc displacement, were included in this study. Healthy volunteers were recruited from staff and students at the Dental School at the College of Medicine, Second Affiliated Hospital, Zhejiang University.

Group 1 (control group) consisted of 36 healthy subjects. There were 12 males with age 26.9 ± 7.04 and 24 females with age 24.6 ± 4.68 years (P = .251). The age figures are given as mean ± standard deviation (SD).

Group 2 consisted of 42 patients diagnosed as having disc displacement without reduction (DD) and/or disc displacement with reduction (DDR). There were 10 males with age 23.3 ± 11.73 and 32 females with age 29.4 ± 12.79 years (P = .185). Sixteen patients had the diagnosis of DD in one or both joints. Seventeen patients had the diagnosis of DDR in one or both joints, and 9 had DD in one and DDR in the other joint. There were no significant differences in mean age between the two main groups of subjects. None of the patients had acute pain in the TMJ at the EMG recording. Patients with DD were not divided into subgroups.

2.2 | Clinical examinations

None of the subjects had acute pain or felt pain during the SEMG recordings. It is our understanding that clenching may cause or increase injury in patients with TMJ disc displacement. Therefore, pain caused by clenching should be avoided. We consider discomfort without pain as acceptable when recording SEMG. The discomfort and pain levels were recorded based on a visual analogue scale (VAS). Zero means no pain or discomfort. Subjects specified the severity of discomfort without pain by marking position one meaning slight to moderate discomfort or position two meaning strong discomfort. No subjects felt pain during the EMG recording but positions three to ten will in further studies be used for marking degree of pain from three meaning tiny pain to ten meaning the most severe pain that the subject can imagine. We assume that pain also may cause a feeling of discomfort but will not try to differentiate between pain with and pain without discomfort. Each patient self-administered the questionnaire, filling out the form after the recording process. Two of the investigators individually examined all subjects.

The subjects were excluded in the cases where a difference in diagnosis existed without establishing consensus. Clinical diagnoses of disc position were based on examination according to RDC standards[25] and bilateral MR imaging of the TMJs.[27,28] All joints had one of the research diagnostic criteria (RDC) diagnoses in group II, that is DDR and/or DD in one or both TMJs. Some patients also had diagnoses in groups I and III. Regarding the individual RDC diagnoses, the numbers of joints within each diagnosis subgroup[25] were Ia 2, Ib 6, IIa18, IIb 20, IIc 9, IIIa 10, IIIb 7 and IIIc 0. Some of the patients had a history of acute TMJ or muscle pain, but none had acute pain during mandibular rest at the time of examination for diagnosis, treatment planning and SEMG recording. The chief complaints for coming to the clinic were the presence of TMJ sounds during jaw movements, TMJ pain and/or jaw muscle pain during wide opening and jaw opening limitation. Some patients had displacements in both joints but with different group II diagnoses. Therefore, the sum of joint diagnoses is larger than the number of patients.

MRI diagnoses were made by a radiologist who knew the subject was a patient in the TMJ clinic but without knowing the clinical diagnosis. One author, the director of the TMD clinic, from where patient subjects were recruited, examined all patient MRI images and discussed her interpretation with the other clinicians (JH, BL and ML). If differences in diagnoses existed and consensus could not be reached, the patient was excluded.

2.3 | SEMG recordings

Recordings were made using the BioPAK system version 7.2 (Bio Research Associates Inc Milwaukee, WI, USA).[29] The BioPAK EMG system has optically isolated differential amplifiers. The input impedance of the amplifiers was 10^{11} Ohms. The common mode (CM) rejection ratio (CMRR) of the amplifiers was guaranteed at >130 decibel (dB) at 50/60 hertz (Hz) and remaining at 120 dB at the low-pass (LP) cut-off frequency. The CM voltage range for rejecting any direct current (dc) offsets was ± 3.0 volts. The amplifiers included a 12 dB/octave high-pass (HP) proprietary linear filter with a HP cut-off frequency of 10 Hz and a 6 dB/octave low-pass (LP) proprietary linear filter, included in the BioPAK system, with an LP cut-off frequency of 1000 Hz in the amplifiers. The signal-to-noise ratio (SNR) was 54 dB.[29] The input signals were digitised with a 16-bit analog-to-digital (A/D) converter card. The theoretical 16-bit resolution was 0.03 μV, but the BioPAK program rounds off to the nearest 0.1 μV. Due to the very high CM rejection ratio, the maximum signal-to-noise ratio was 106:1. All recordings were made with the sampling rate (SR) 4000 Hz.

The electrodes used were BioFLEX; Bioresearch Associates, Inc, Milwaukee, WI, USA, with 2 conductive polyester adhesive rectangular contacts of 144 square millimetres with 20 mm centre-to-centre spacing. They were placed after cleaning the skin with 95% alcohol, according to generally accepted standards[29,30] in the middle of each jaw muscle area. Lines through the centres of electrodes on each muscle side were parallel to the jaw muscles' anterior borders. The ground reference electrode was placed on the wrist.

The subjects were sitting in a chair with their backs and heads upright. After the electrodes were placed, the subjects were resting for about 5 minutes before recording started. The subjects were instructed to clench with maximal force, as hard as possible without causing pain, for about 5 seconds 6 times, with the mandible back in resting position for about 5 seconds between each clench. The recordings started about 10 seconds before the first clench and lasted until about 10 seconds. after the last clench. It was believed that one clench would be insufficient to get a reliable reading of SEMG. At the same time, we did not want the subjects to make too many clenches, causing fatigue or discomfort. No subjects found the experience painful.

Bilateral SEMG recordings were made in the anterior temporalis and the masseter areas. The subjects were told to not swallow, to avoid mimics and to not move the head or the mandible during mandibular rest. The subjects were visually observed during the recordings, and if facial mimics or other movements were noticed, the recording was discarded. They were not told to close their eyes, only to look straight forward.

2.4 | SEMG analysis

BioPAK files were stored in Track Row Column (TRC) format, converted to American Standard Code for Information Interchange format (ASCII) inside BioPAK and imported into MATLAB, a software program tuned for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly (MATLAB, version R2018a, MathWorks, Inc, Natick, Massachusetts). All SEMG recordings were checked by spectral analysis, and noise was removed by a proprietary filter written by one of the authors (ZT).[31] Calculations of mean and standard deviation (SD) of SEMG levels in sections with clench and MR activity were made using scripts written in MATLAB.

2.5 | Statistical analysis

SEMG recordings were made at four areas on the face: right masseter (RM), left masseter (LM), right temporalis (RT) and left temporalis (LT) areas. The comparison in mean SEMG levels between healthy subjects and TMD patients was based on three quantities measured in the four areas (a) MR of about 10 seconds before the first clench (VMRb), (b) the mean values of six MR periods, each measured for about 3-5 seconds after the six clenching contractions (VMR6), and (c) the mean values of the six clenching contractions, each lasting about 3-5 seconds (VCle). All analyses were performed using SPSS, a software platform that offers advanced statistical analysis (version 24, SPSS Inc Chicago, Ill, USA).

The distributions of the data in each of the 12 series for each group were examined, and they were generally skewed to the right.

For statistical analysis logarithmic, to the base 10, transformation of the data was therefore considered appropriate for all 12 series.

The selection of the appropriate statistical model to compare groups (healthy/TMD) for each quantity measured at the four areas was based on the following consideration. The recordings on the four areas of the face for each of the three quantities are correlated since these are measurements for a single subject. There are many ways of analysing our set of data. Some possible models are a one-way multivariate analysis of variance (MANOVA), analysis of variance (ANOVA) and the linear mixed model (LMM). One-way MANOVA compares means for measurements for the four areas between groups, modelling the error terms for the four areas as correlated. The mixed ANOVA analysis has one between-subject factor (groups) and four within-subject factors (areas). The four areas are considered repeated measurements, and the analysis tests the interaction between groups and areas. An LMM also views the data as repeated across the four areas for each subject. One possible regression model can be specified to have group as a fixed effect and random effects for subjects and the two within-factors and their interaction to describe the four areas, left/ right and masseter/ temporalis. Now, activity measured by SEMG in the four areas may differ because muscles in these four areas are different. The measurements in the four areas for each quantity are therefore more appropriately viewed as four correlated responses and not as repeated measurements of the same activity. The hypothesis of no difference between groups was therefore carried out using one-way MANOVA and assessed using Pillai's trace based on the significance level of 0.05. If there was evidence to reject the null hypothesis of no difference, the hypothesis of interest (that average SEMG levels are higher for TMD patients than healthy subjects) was assessed by examining the means. When comparing one variable between groups, the two independent populations t test was used to test the one-sided hypothesis that average SEMG levels were higher in TMD patients than in healthy subjects.[32-34]

3 | RESULTS

The means of the four responses for each subject, RM, LM, RT and LT (in logarithms with base 10), were compared between healthy subjects and TMD patients for each of the three quantities VMRb, VMR6 and VCle. In addition, the difference between the means of VMRb and VMR6 was also examined. The mean resting SEMG levels were not significantly different between healthy subjects and patients ($P > .05$). The mean clenching SEMG levels were significantly different ($P = .003 < .05$), with the mean for healthy subjects being greater than that for TMD patients (Table 1).

The assumptions for using MANOVA were satisfied for the four responses, RM, LM, RT and LT, for each of the three quantities VMRb, VMR6 and VCle. For the four responses for each quantity, the test for common covariances was not rejected. There was no evidence to reject the null hypothesis of common means for the four responses, RM, LM, RT and LT, for VMRb (Pillai trace = 0.119, $P = .052 > .05$) or VMR6 (Pillai Trace = 0.110, $P = .072 > .05$). However, because the p-value for Pillai's trace was just greater than the significance level, the differences between groups were examined for each of the four areas. Only the mean for RT was significantly different, and from Table S1, we see that the mean was larger for healthy subjects than for patients. The ranges of mean values of SEMG, in the masseter and the anterior temporalis muscle areas, and on the right and left side of the face, during mandibular rest, were larger in healthy subjects than in TMD patients (Tables 2 and S1).

TABLE 1 Means and standard errors for LmVMRb, LmVMR6, LmVCle and LmVMR6-LmVMRb

	Patient (n = 42)		Healthy (n = 36)	
	Mean	SE	Mean	SE
LmVMRb ($P = .979$)	0.24	0.03	0.35	0.04
LmVMR6 ($P = .835$)	0.32	0.04	0.39	0.04
LmVCle ($P = .003$)	1.78	0.04	1.95	0.04
LmVMR6-LmVmRb ($P = .085$)	0.08	0.02	0.03	0.02

Note: LmVMRb = means of the four areas, right anterior temporalis (RT), left anterior temporalis LT, right masseter (RM), and left masseter (LM) log μV levels during MR before the first clench for each subject. *LmVMR6* = means of the RT, LT, RM and LM (means of six values) log μV levels during MR after the first clench for each subject. *LmVCle* = means of the RT, LT, RM and LM (means of six values) log μV level during clenching with maximal force for each subject. *LmVMR6-LmVmRb* = difference between mean log μV level during MR before the first clench and mean log μV levels during MR after the first clench, for each subject.

Hypothesis tests for LmVMRb and LmVMR6 are for the alternative that mean for TMD patients is higher than that for healthy subjects. Hypothesis tests for LmVCle and for LmVMR6-LmVmRb are for the alternative that means for TMD patients and healthy subjects are different.

The term *log* refers to *logarithmic with base 10*.

TABLE 2 Means, standard deviations and ranges for VMRb, logarithmic (base 10) μV levels for mandibular rest before clenching, measured at the four areas, right anterior temporalis (RT), left anterior temporalis LT, right masseter (RM) and left masseter (LM)

	Group	Mean	SD	Range
RM VMRb	Healthy	0.24	0.28	−0.21 to 0.89
	Disc dysfunction	0.19	0.27	−0.27 to 0.75
LM VMRb	Healthy	0.28	0.30	−0.21 to 1.04
	Disc dysfunction	0.20	0.24	−0.32 to 0.61
RT VMRb	Healthy	0.43	0.30	−0.30 to 1.18
	Disc dysfunction	0.24	0.26	−0.22 to 0.86
LT VMRb	Healthy	0.46	0.28	−0.19 to 1.20
	Disc dysfunction	0.35	0.29	−0.20 to 0.96

Note: The MANOVA test for differences between healthy subject and patients for all four variables was not significant at the 5% significance level (Pillai trace = 0.119, $P = .052$)

There was evidence to reject the null hypothesis of common means for the four responses, RM, LM, RT and LT, for VCle (Pillai's Trace = 0.147, $P = .019$). The mean right temporalis and mean left temporalis clench levels were significantly different between healthy subjects and patients ($P < .05$). The means were significantly greater for healthy subjects than for patients (Table S2).

4 | DISCUSSION

The results do not support that the mean SEMG voltage levels in anterior temporalis and masseter areas during mandibular rest, on the right side and left side of the face, are higher in patients with TMJ disc displacement than in healthy subjects. Instead, mostly, the estimated means were greater for healthy than for TMD subjects (Tables 2 and S1).

The results support that elevated SEMG levels occur in recordings during mandibular rest in healthy subjects as well as in TMD patients without causing movements. Elevated SEMG levels would most probably cause mandibular movements if reflecting jaw muscle activity. The results therefore support that increased SEMG levels during MR cannot be labelled as jaw muscle activity but are composed of activity from various sources where the size of the input from each source is not known. Because no mandibular movements were observed, it is not likely that jaw-closing muscles contributed. This means that SEMG during MR, without observed movements, has no value as a sign of TMD in general.

So far, increased activity levels during MR have not been found in jaw muscles when needle electrodes were used for control of muscle sources.[4-6] A probable reason for higher levels of SEMG activity during mandibular rest was caused by artefact activity. The most likely reason for high MR levels is, as pointed out in many old texts, that the SEMG electrodes also record artefact activity from neighbouring muscles.[3-5,9,17,23,24] The results support that needle recordings must be used, as a complement to the SEMG recording, if one specific muscle is named as the activity source.[4-6,24,30-32]

If only SEMG is used during MR, such recordings should in EMG classification be labelled as SEMG recorded in a *muscle area*, not from a specific *muscle*. Lower SEMG levels may well indicate improved muscle relaxation in an area during MR but not which specific muscle's activity levels that were changed. The dangers of taking high values as signs of TMD or jaw muscle dysfunction, or low values as indication of freedom from such diseases or disorders, are illustrated in Figures 2 and 3.

None of the patients in this study had chronic pain or acute pain during MR. The results do not demonstrate whether acute or chronic muscle pain can or cannot cause increased EMG activity levels. The inference is only that SEMG cannot be used to diagnose an individual jaw muscle as the source of increased activity level during MR.

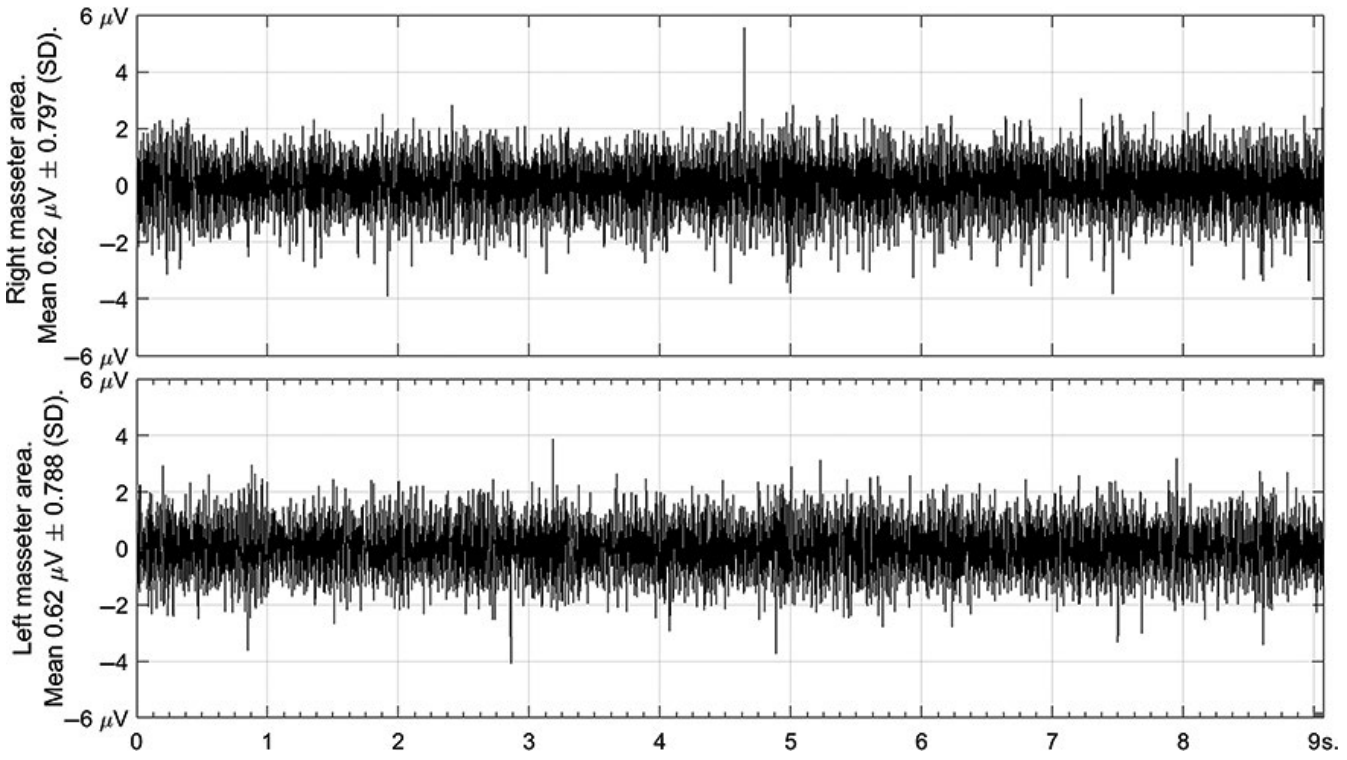

FIGURE 2 Female patient with the diagnosis disc displacement without reduction (DD). This figure, showing SEMG during mandibular rest before first clench, illustrates the observations of frequent cases of patients with well relaxed SEMG levels. The mean energy values were here 0.62 μV or −0.21 log(μV). This means that only about 0.20 μV or −0.70 log(μV) may have been from active muscles, which may or may not have been jaw muscles. Compare the levels in this figure with those in Figure 1

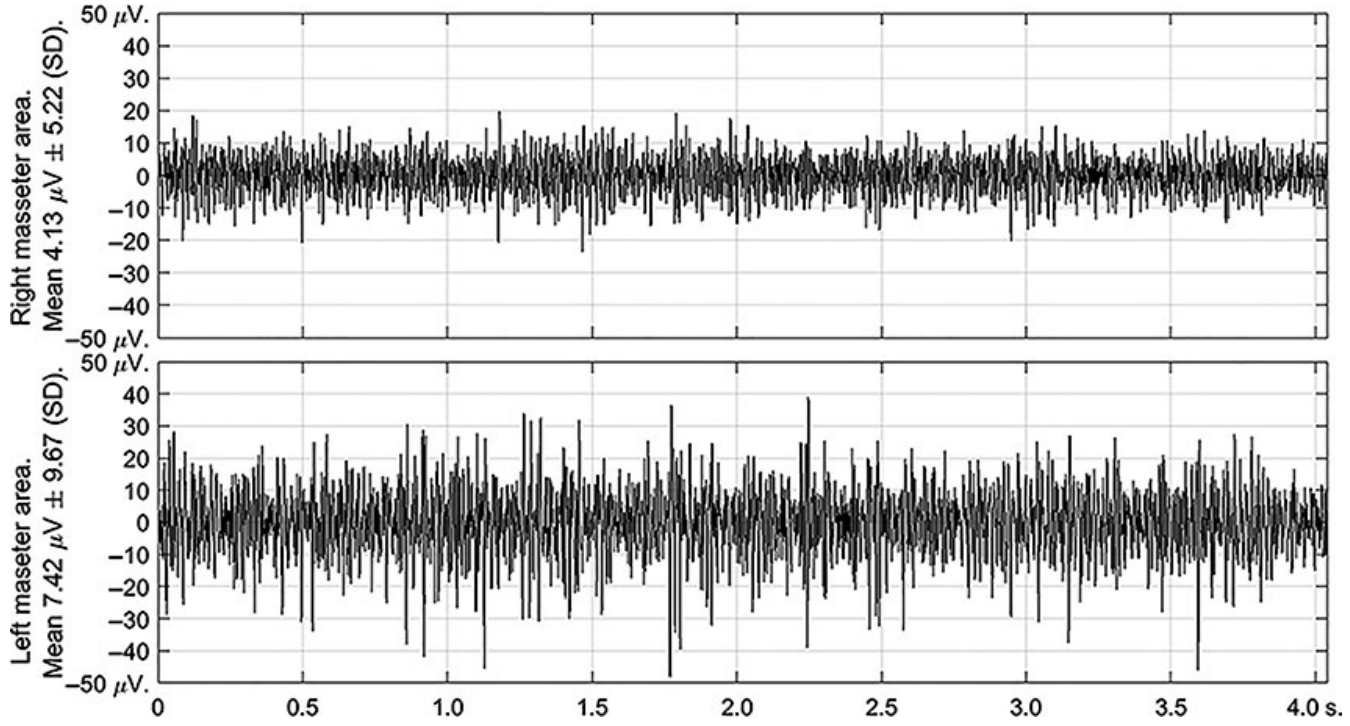

FIGURE 3 SEMG recordings from the left and right masseter areas during mandibular rest in a female healthy control subject. The figure illustrates the result that the SEMG levels were often high without moving the mandible into tooth contact position. Mean log10 values were in the upper window 0.62 μV and in the lower window 0.87 μV

The conclusion that intra-muscular electrodes are needed for *localisation* of SEMG source does not mean that MR *activity degree* can be calculated using single needle electrode recordings for individual muscles and compared between sessions, such as before and after treatment. It is well known that needle electrodes are not suitable for calculations of mean activity levels in whole or sections of muscles. Rather, they are only suitable for measuring characteristics of motor units close to the needle tip.[26,35-37] Estimates of *activity degree* in the whole muscle or portions of the muscle can be made by repeated recordings from several sites in the same muscle,[26] but that is most probably not a suitable method for calculation of activity degree during MR in TMD Clinics.

The theory that the mandible can stay in a resting position without contact between opposing teeth might be explained by opposing forces in antagonists despite EMG activity in the jaw-closing muscles. However, simultaneous recordings from these cannot be made using

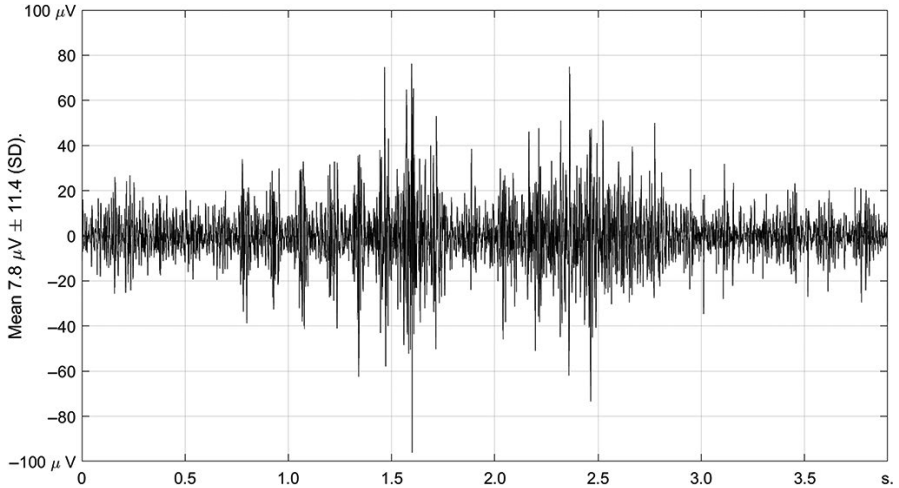

FIGURE 4 This SEMG figure is from the right anterior temporalis area in a patient with mandibular tremor. This patient was not included in the study. The tremor was not voluntary and indicates a neurological muscle disorder. The patient was referred to a Department of Clinical Neurology. It is shown here because it illustrates that the mean activity level can be well under the highest MR levels in the healthy subjects and be observed together with mandibular distinct movements. It indicates that SEMG can be useful in dental clinics and help in early detection of neuromuscular disorders. Mean log10 value was 0.89 μV

surface electrodes, and therefore, such a hypothesis needs confirmation by recording with intra-muscular electrodes. Such recordings have been made in healthy subjects. One study used monopolar needles[38] and found rather high levels, 14 ± 11.4 μV in the lower belly of the lateral pterygoid muscle. Another older study, performed before digitised recordings became common and based on visual evaluation, used a concentric needle (CN)[39] and reported lateral pterygoid activity during mandibular rest as negligible. The difference may be because monopolar needles have a wide uptake area, but a CN has a rather small uptake area within the muscle close to the needle's endpoint.[26,35-37]

The implications are not that EMG cannot be useful in clinical diagnoses. On the contrary, regular use of SEMG can be of value by helping to detect signs of neuromuscular disorders, as illustrated in Figure 4. Clinical cases, where SEMG combined with needle EMG were of value, have been published.[6,22] The inference is that clinical EMG research should not always be performed only with SEMG, but also with an option for using intra-muscular electrodes.

It is generally acknowledged that pain in jaw muscles is an important TMD factor.[8,25,40] However, pain did not occur during the EMG recordings in this study and no differences in SEMG levels were found between groups. Therefore, the possible effect of pain on SEMG cannot be discussed based on the results of this study.

It was not the aim to compare bite-force between subjects and patients. It was still considered to be of interest to show to what degree the subjects were clenching (Table 1). Differences could not be used to test for strength differences, because the subjects were told to not bite harder if that caused pain to avoid damaging TMJ tissues as explained in Methods.

Occlusion was not included as a factor because it was beyond the resources to do such an evaluation. However, it should be mentioned that none of the controls, and only one patient, had malocclusion motivating referral for orthodontic treatment.

5 | LIMITATIONS

The effect of electronic noise is a significant source of artefact activity. There are variations between filters used in the branded hardware and software. A manufacturer may have its own proprietary filter for noise removal, and the hardware settings for HP and LP limits can vary significantly between different brands and versions. Details about how the filter programmes are seldom given, which makes comparisons between studies difficult.

Surface electrodes may differ in size of the detection surface. Distance between the poles in a bipolar surface electrode is not always the same in different brands. The anatomy of muscles and the thickness of non-muscular tissues between the skin, where the electrodes are placed, can have large variations between subjects.

The subjects were observed visually during the recordings, and no facial or other movements were noticed. It is possible that blinking or mimics occurred undetected. Future similar recordings could use simultaneous video recordings, not available in this study, for control of such artefact sources.

It is possible that some control subjects had asymptomatic disc displacement.[41] The patients' MRI recordings were covered by national healthcare insurance. Ideally, the healthy subjects should also have been examined with MRI imaging, but no funding was available for such recordings. To the best of our knowledge, MRI examination of healthy controls has not been made in similar studies.

The number of patients was too low for dividing those with DD into subgroups, and future studies are desirable with larger patient groups, making such a design possible.

If possible, the EMG recordings should be analysed by several examiners without knowing from which group the subjects belong to. SEMG examinations have, to the best of our knowledge, not been blinded in similar published researches. However, it is desirable that EMG analysis is blinded in future studies.

6 | CONCLUSIONS

The hypothesis that average SEMG levels would be higher in the patients during MR, before and after repeated clenches with maximal effort, was not supported by the data. High levels of SEMG recorded activity during mandibular rest were as common in healthy controls without signs of TMD as in patients with disc displacement disorders, which means that they are not reliable signs of TMD. SEMG recordings during efforts of voluntary mandibular rest are not a valid general diagnostic tool in TMD patients unless distinct jaw movements are observed. If such movements are observed, intra-muscular electrodes should be used to localise the EMG source.

A possible explanation for the differences in opinions about the origin of hyperactivity is that SEMG activity in scalp, facial mimic and neck muscles was in critical references mislabelled as jaw muscle hyperactivity.

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CONFLICT OF INTEREST

All authors (both the corresponding author and co-authors) confirmed that we do not have a conflict of interest to declare.

AUTHOR CONTRIBUTION

Jianlai Hu and Yan Dong was a guarantor of integrity of entire study. Jianlai Hu, Sven E Widmalm and Yan Dong conceptualized and designed the study. Jianlai Hu, Boxiu Li, and Min Lin* involved in literature research, clinical studies, experimental studies and data acquisition. Jianlai Hu, Sven E Widmalm, Tongsheng Zhang and Dong Zhou analysed/interpreted the data and involved in statistical analysis. Jianlai Hu, Sven E Widmalm, Anders Buvarp and Yan Dong prepared, edited and revised/reviewed the manuscript. Jianlai Hu, Sven

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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