The clinical usefulness of surface electromyography in the diagnosis and treatment of temporomandibular disorders

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ABSTRACT

Background. This article presents a comprehensive review of the recent literature regarding the scientific support for the use of surface electromyography (SEMG) in diagnosing and treating temporomandibular disorders (TMDs).

Types of Studies Reviewed. The authors conducted a Medline search involving human studies using the key words "surface electromyography or electromyography" and "masticatory muscles or temporomandibular disorders or craniomandibular disorders." They also reviewed relevant articles regarding the clinical usefulness of SEMG based on reliability, validity, sensitivity and specificity, as well as additional references included in some of the articles.

Results. The clinical use of SEMG in the diagnosis and treatment of TMD is of limited value when one considers reliability, validity, sensitivity and specificity as measurement standards. SEMG does not appear to contribute any additional information beyond what can be obtained from the patient history, clinical examination and, if needed, appropriate imaging.

Conclusions. Clinically, the determination of the presence or absence of TMD does not appear to be enhanced by the use of SEMG. However, the modality may be useful in a meticulously controlled research setting.

Clinical Implications. SEMG has limited value in the detection or management of TMD and in some instances may lead to unnecessary dental therapy as a solution for those disorders.

Key Words. Surface electromyography; reliability; validity; sensitivity; specificity; biological factors; technical factors.

JADA 2006;137:763-71.

JADA CONTINUING EDUCATION ARTICLE 2

The first reports describing the use of surface electromyography (SEMG) in dentistry were published in the 1950s.[1-7] Since then, interest in this subject has ebbed and flowed over the years. While the usefulness of SEMG has been debated, few studies offer data that help the clinician understand the role of SEMG in the practice of dentistry. In fact, SEMG's diagnostic reliability and validity, as well as its therapeutic value, have been questioned.[8-10]

In this article, we review the recent literature regarding SEMG to determine scientifically the clinical usefulness of SEMG in the diagnosis and treatment of temporomandibular disorders (TMDs).

METHODS AND MATERIALS

We conducted a MEDLINE search limited to human clinical and experimental studies using the key words "surface electromyography or electromyography" and "masticatory muscles or temporomandibular disorders or craniomandibular disorders." We also reviewed additional references included in some of the articles. We also included in this review any relevant articles regarding the clinical usefulness of SEMG on

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TABLE 1

Diagnostic tests and applications.*

TEST CATEGORY	APPLICATIONS
Predictive	To identify people at risk/not at risk of developing a specific disease
Screening	To identify people who have/do not have a disease or category of disease
Discriminatory	To facilitate a differential diagnosis
Monitoring	To describe changes in the disease process, effects of therapy or both

* Based on information from Lund and colleagues.[32]

TABLE 2

Efficacy of a diagnostic test.*

TERM	DEFINITION
Reliability	Measurement of a phenomenon that can be repeated
Validity	Measurement of the truthfulness of the phenomenon being tested
Technical validity	The procedure or device measures what it claims to measure
Diagnostic validity	The information actually can help diagnose what it claims to be able to diagnose
Sensitivity	The ability to correctly detect the presence of a condition in patients who actually have the condition
Specificity	The ability to detect correctly the absence of a condition in patients who actually do not have the condition

* Based on information from Glazer,[33] Hulley and Cummings[34] and Portney and Watkins.[35]

the basis of reliability, validity, sensitivity and specificity.

THE PURPOSED USEFULNESS OF SURFACE ELECTROMYOGRAPHY

A clincial use of SEMG has been proposed for the diagnosis and treatment of TMD.[11-14] This is based on the assumption that various pathological or dysfunctional conditions can be discerned from SEMG recordings of masticatory muscle activity, activity including postural hyperactivity,[15-19] abnormal occlusal positions,[20-23] functional hyperactivity and hypoactivity,[16,24,25] muscle spasms,[24,26,27] fatigue[28,29] and muscle imbalance.[20,30] SEMG activity has been suggested to be useful in documenting changes in muscle function before and after therapeutic interventions as evidence of successful treatment.[11,13] SEMG also has been used in biofeedback concerning the awareness and control of nocturnal and diurnal parafunctional habits.[8,31]

USEFULNESS OF SURFACE ELECTROMYOGRAPHY IN DIAGNOSIS

According to Lund and colleagues,[32] several types of diagnostic tests can be useful in clinical practice. Four major types have been described: predictive, screening, discriminatory and monitoring (Table 1). The parameters used in the assessment of the efficacy of a diagnostic test are reliability, validity, sensitivity and specificity[33-35] (Table 2). It is with these tools that one can determine the clinical usefulness of SEMG in the diagnosis and treatment of TMD.

Reliability. Pretty and Maupome[36] described reliability as being equivalent to repeatability or reproducibility, whereby a reliable procedure is one that is consistent, stable and dependable with minimal systematic or random error. A reliable diagnostic procedure is one that gives the same result, within accepted ranges, on repeated measurement of the same variable. In essence, reliability is linked to the precision of a procedure. They concluded that some of the possible sources of error are bias; the variation inherent among different observers; variation related to the measurement tools, broadly referred to as their "precision" or "accuracy"; and the variation caused by changes occurring in the object being measured.

Validity. Ideally, a diagnostic procedure should be both accurate and valid. Accuracy is defined as the degree to which a measurement is free from error or bias, and validity is defined as a measurement of the truthfulness of the phenomenon being tested. Pehling and colleagues[37] and Pretty and Maupome[36] stated that a procedure can be accurate without being valid; however, it cannot be valid without being accurate. In essence, the validity of the diagnosis is limited by the reliability of the diagnostic methods used to obtain the clinical diagnosis. Reliability of measurement is at the core of valid or useful diagnostic procedures; if an instrument's reliability is low, its validity cannot be determined.[38]

Sensitivity and specificity. Several authors[36,39,40] reported that sensitivity and specificity are two of the operating characteristics that indicate the accuracy of a diagnostic procedure. Therefore, a typical diagnostic situation allows for either of two outcomes: the person either has or does not have the disease. When life is threatened, overidentifying a disease is appropriate since it is critical not to overlook the disease. Widmer and colleagues[41] determined that as TMD does not place the patient's life at risk, the clinician can risk using a test that has the potential to underdiagnose someone with the disease. Therefore, it is recommended that the specificity required for a diagnostic TMD test be high so as not to overdiagnose the condition. The incorrect interpretation of the presence of TMD could lead to unnecessary or inappropriate treatment, which may have unfavorable biological, psychological and economic consequences.[42,43]

Gold standard. The gold standard is the proven diagnostic procedure, finding or criterion accepted as the best currently known evidence or indicator of the problem.[33,34] The current gold standard that can be used to identify the presence or absence of TMD, or one of its subcategories, is a comprehensive evaluation of the patient's history and clinical examination supplemented, when deemed appropriate, with imaging.[10,44-47]

FACTORS THAT INFLUENCE USE OF SURFACE ELECTROMYOGRAPHY

Several biological and technical factors influence the reliability, validity, sensitivity and specificity for the use of SEMG as a diagnostic and treatment procedure.

Biological factors. The biological factors that influence information provided by SEMG are physiological variability, age, sex, skeletal morphology, psychological factors, and skin thickness and weight. Each of these factors is discussed below.

Physiological variability. Physiological variability exists in all humans. In general population samples, researchers have found that normal subjects have a certain degree of physiological variability in terms of muscle activity asymmetry,[48,49] postural position,[50,51] silent period after chin taps[52] and spectral analysis,[53-55] resulting in confusion between symptomatic and asymptomatic groups. The presence of variability between people, in addition to the existence of considerable overlap among these so-called "normal" and "abnormal" groups, makes it difficult to ascertain any diagnostic conclusions in any specific patient.[45]

Age. In a healthy population, electromyographic (EMG) activity recorded during isometric contraction decreases with increasing age, probably because of gradual muscle atrophy and increased fatty infiltration.[56,57] It also was found, in populations with and without TMD, that EMG amplitudes and frequency levels of the temporal muscle and, to a lesser degree, the frontal muscle decreased with increasing age. This may be due to a decrease in the number of motor units activated during this voluntary contraction.[57-60] A further explanation for this decrease in EMG activity in the temporal muscles with increasing age may be a combination of impaired chewing ability and decreased muscle force.[61,62] It also has been reported that with increasing age, the latency of the masseteric jaw jerk reflex is increased while the amplitude is decreased.[63] Therefore, the usefulness of any diagnostic test that uses muscle strength must account for age.

Sex. Differences in SEMG recordings have been attributed to differences between males and females. In normal subjects without TMD, it has been reported that female subjects generated higher EMG amplitudes during the exercise of lifting the same weight[57] and also displayed significantly and consistently higher fatigue and recovery ratios during experimentally induced loading compared with male subjects.[64] It also has been reported that in a general population sample, male subjects showed higher masticatory EMG levels than did female subjects during maximal voluntary contractions.[58,60] Sex also influences the masseter jaw jerk reflex in a healthy population; female subjects in one study displayed a shorter latency while the amplitude of the reflex was significantly higher than in the male sample.[65] The hypotheses for these findings may be explained by differences in the diameter and number of muscle fibers, differences in distribution of fiber type within the muscles, and differences in head and body size between males and females.[59,60,66] Therefore, the usefulness of any diagnostic test using SEMG must define and adjust for the difference in parameters between males and females.

Skeletal morphology. Differences in skeletal facial types in subjects without TMD also influence SEMG measurements. Ueda and colleagues[67] found a longer duration of masseter and digastric muscle activities in people with a decreased vertical skeletal facial type. Other researchers found the amount of postural activity for both masseter and anterior temporal muscles to be higher in Class III subjects than in Class I and Class II subjects.[68] Therefore, to be useful, any diagnostic test employing SEMG must define and adjust for skeletal facial type.

Psychological factors. Psychological factors can influence SEMG recordings significantly. In a healthy population, experimental stressors induce an increase in masticatory EMG muscle activity, with different masticatory muscles demonstrating different patterns of increase.[69,70] Ruf and colleagues[71] found that in healthy dental students, a nonexperimental emotional stress increased EMG activity during both rest and functional muscle activity. However, not all subjects followed this pattern. A few people in this study actually displayed a decrease in EMG activity. This difference may be explained by interindividual variance in the manner in which different people or different muscles of certain people respond to specific stimuli. Cecere and colleagues[70] compared bilateral SEMG recording from the masseter and anterior temporalis muscles of healthy people after performing functional activities at three times during the same day (before work activities in the morning and one hour and seven hours after the initial recordings). Their results indicated that there was a statistically significant difference in SEMG recordings between the initial recordings and the recordings made seven hours later. They reasoned that this discrepancy was related to the interval between the sessions due to changes of the psychological conditions resulting in physiological variations of muscular activity or skin impedance within the subjects. Therefore, to be useful, any diagnostic test employing SEMG must define and adjust for these psychological factors.

Skin thickness and weight. SEMG activity is greatly influenced by the thickness of the soft tissues overlying the muscles that are being measured. De la Barrera and Milner[72] and Lobbezoo and colleagues[73] described the mechanism of this phenomenon as being the process whereby electrical signals are low-pass–filtered and attenuated as they pass through media such as muscle tissue and subcutaneous fat. They stated that the greater the conduction distance, the greater the filtering and attenuation. Additional filtering occurs owing to the anisotropy of electrical conductivity in muscle tissue and as a result of refraction and redirection of electrical signals at tissue boundaries, such as those between muscle and subcutaneous fat. They concluded that SEMG signals cannot be interpreted in the same manner for all subjects and that selectivity of SEMG measurements increases as the thickness of the layer of subcutaneous fat interposed between the skin and the muscle surfaces decreases.

Surface electromyography is inherently problematic, with many shortcomings, and thus has questionable value.

It also has been reported that female skinfold was found to be significantly thicker than that of male subjects, thus resulting in more attenuation of the EMG signal for females, as well as yielding the finding that the thickness of certain muscles (including different areas within the same muscle) varies, thus accounting for a reduced signal.[74] A lower-amplitude signal in obese people could be interpreted inaccurately as evidence of reduced muscle activity because there is a reduced uptake of the signal (adipose tissue contains fewer muscle fibers) and the fibers are further away from the electrode than they are in people with lesser skin thickness.[75] Therefore, any diagnostic test using SEMG must define and adjust for the thickness of the soft tissues overlying the muscles that are being measured.

Summary. In summary, after critically reviewing these biological variables, we conclude that measuring SEMG is inherently problematic, with many shortcomings, and thus has questionable value. These biological variables certainly reduce the reliability of the instrument and greatly negate, if not totally eliminate, the validity of its measurements, thus denying sensitivity and specificity.

Technical factors. The technical factors that influence SEMG recordings are electrode placement, position and interelectrode distance (IED); cross talk; head or body movement; existing pain conditions; facial expressions; history of bruxism; and statistical methodology. We discuss each of these factors below.

Placement, position and IED of electrodes. The ability of surface electrodes to detect the activity of a particular muscle accurately relies on at least three factors: the proper placement of the electrodes over the muscle, their position in relation to muscle fiber orientation and the IED.

Placement of the surface electrode in an area other than the anteroinferior portion of the masseter muscle belly in healthy people resulted in erroneous results.[76] It also was found that recording of accurate muscle fiber conduction velocity depends on the proper orientation of the surface electrodes.[72,77,78] Other studies demonstrated that for optimal pickup of SEMG signals, surface electrodes are best aligned parallel with the fiber orientation of the underlying muscle, thus allowing the detection of stronger signals.[79,80] This implies that users of SEMG must have a sound knowledge of muscle fiber orientation for proper positioning and placement of the surface electrodes.

The IED is considered to be the distance between the electrodes at the time of placement. Zedka and colleagues[80] determined that the IED rarely remains the same when the underlying muscle changes its length. As the skin stretches or folds, the electrodes placed in the direction of the muscle fibers move considerably. Displacement of the surface electrodes is more noticeable during functional activities of the muscles. This displacement depends on the initial distance between the electrodes and also on their orientation in regard to the course of the muscle fibers. It is possible that the displacement could alter the SEMG recordings significantly, thus resulting in different conclusions about the muscle activity. Burdette and Gale[81] found that SEMG recordings were altered significantly with changes to IED, even though they tried to reliably relocate the surface electrodes with a custom-made template. Other researchers found that alteration to the IED created a greater variation in surface recordings from the deeper layers of the muscle fibers (masseter) than from the superficial layers (anterior temporal),[82,83] implying that for accurate measurement of different muscles, IED must be individualized depending on the depth of the fibers. This finding suggests that attempting to compare SEMG recordings from the same patient during two different sessions without marking the exact electrode placement is instilled with inherent errors.

Cross talk. Another source of error is the phenomenon of cross talk, whereby activity of muscles not purposely being recorded by SEMG influences the measurements of those muscles that are being studied. This creates contamination of the measurements on which the clinician is relying to produce an accurate diagnosis.[70,74,81,84-86]

Head or body movement. Another potential source of artifacts leading to inaccurate measurements is the extraneous contraction of neighboring muscles that are not being studied. Such activities include eye blinking, swallowing or coughing during SEMG monitoring.[81,84]

Existing pain conditions, other than those directly involving the masticatory muscles, have been shown to have an effect on masticatory muscle activity.

It also has been well-documented that body position (standing, seated, supine and lateral decubitus) influences the EMG activity of masticatory and cervical muscles. Hence, any movement by the subject during recording of muscle activity can influence the final results.[87-90]

Existing pain conditions. Existing pain conditions, other than those directly involving the masticatory muscles, have been shown to have an effect on masticatory muscle activity. Goldreich and colleagues[91] found that while subjects performed a functional activity, their masseter EMG activity decreased after two days of postorthodontic arch wire adjustment. This study showed that the pain in subjects receiving the treatment did not arise from the masseter muscle but rather from the paradental tissues. Schroeder and colleagues[92] found that chronic pain conditions other than those originating from the masticatory muscles elicited an increase in masticatory muscle SEMG activity. Maillou and Cadden[93] found that remote deep somatic noxious stimuli could increase activity in the masticatory muscles. Wang and colleagues[94] determined that pain emanating from internal derangements caused an increase in SEMG activity in masticatory muscles. Jensen[59] determined that there was an increase in SEMG activity in both masticatory and cervical muscles when subjects had a tension-type headache. Several studies reported that pain in the cervical musculature can increase masticatory muscle activity.[95,96] Lund and colleagues,[8,97-99] using their "pain adaptation model," proposed that the pain arising from nonmuscular tissues sometimes can cause the same signs of dysfunction as muscle pain. It also has been shown that internal derangements and pain in the jaw muscles caused a decrease in the amplitude of movement[100] and that tonic pain from outside muscles and joints altered movement.[101]

The implications of these studies are that a person with an existing nonmasticatory pain complaint may provide misleading SEMG measurements of the masticatory muscles at the time of examination.

Facial expressions. People in pain, regardless of the source of the discomfort, express their pain in the form of facial expressions. This was evidenced by LeResche and Dworkin,[102] who monitored facial expressions of patients with chronic TMD after a standardized clinical examination involving palpation of the masticatory and cervical muscles and the temporomandibular joint. In another study, LeResche and colleagues[103] videotaped 36 women with chronic TMD and compared them with 35 female patients who had recent-onset TMD and subjected them to a standardized experimental pain stimulus (cold pressor test) and digital palpation of the masticatory muscles and temporomandibular joint. They found that levels of pain-induced facial expressions were significantly higher in subjects with chronic TMD under all experimental conditions, including baseline. The facial expressions of people experiencing pain resulted in an increase of the EMG signal coming from the facial muscles.[86,97,99] This contamination can lead to confusion regarding the true source of the increased muscle activity.

History of bruxism. The level of physical training of the masticatory muscle must be considered because hypertrophic muscles due to exercise in asymptomatic people have increased masticatory muscle activity.[104] This is an important consideration in the case of TMD, because chronic bruxism often is associated with hypertrophy of jaw elevator muscles that results in elevated resting EMG activity. This higher level actually is a normal value for such a person.[41] It also has been reported that patients with TMD demonstrated a higher prevalence of bruxism and, as expected, a greater resting activity of the elevator muscles.[105-108] Sherman,[109] in a study of a sample of bruxers (with and without pain), found there were significant differences in the resting masseter EMG activity of bruxers and nonbruxers. However, there were no significant differences between resting EMG values of the patients who had pain and those of the patients who did not have pain. This study emphasizes the need to choose the proper control for each group of patients before assignment of a person can be made to either a symptomatic or asymptomatic group.

Statistical methodology. In statistical terminology, "normal" refers to a specific type of bell-shaped distribution in which most of the scores fall in the middle of the scale with progressively fewer falling at the extremes.[35] The problem with TMD is that this straightforward distribution does not exist. Rather, there is a lack of an accurate description of the normal population, thus making it difficult to distinguish what is normal from what is abnormal.[9] Therefore, the use of an instrument that tries to delineate between health and disease, with subsequent treatment decisions based on its findings, may not be appropriate if these conditions have a degree of overlap.

It would seem that reproducibility and validity would be difficult, if not impossible, for surface electromyograhy to achieve.

Summary. Because of the confounding variables presented by the technical factors described here, it would seem that reproducibility and validity would be difficult, if not impossible, for SEMG to achieve. Therefore, attaining clinically acceptable sensitivity and specificity in the diagnosis and treatment of TMD also is highly unlikely.

CONCLUSIONS

Clinicians constantly seek better ways to manage their patients' needs. Certainly, improved measurability of clinical signs and symptoms associated with TMD is desirable. Although SEMG initially would appear to have great usefulness in this area, the efforts needed to standardize the data are extremely difficult and, in most cases, clinically impractical.[70,85] A review of the literature suggests that the established standards of scientific merit (reliability, validity, sensitivity and specificity) are most difficult to attain, thereby placing the diagnostic and treatment utility of SEMG in doubt. There also is question as to whether SEMG can accurately separate people with facial pain from those without pain,[32,110] distinguish between different TMD conditions[32] and predict which asymptomatic people will develop TMD.[32] At this time, the use of a comprehensive history and examination, a millimeter ruler, palpation of the temporomandibular joint and muscles and, when necessary, imaging techniques remain the standard measures by which to diagnose TMD. These measures also provide the best cost-benefit ratio and, one hopes, help the patient avoid unnecessary and inappropriate therapy.[46,47,111,112]

However, it is important to state that the use of SEMG for the purpose of research does have scientific merit. It is only under meticulously and adequately controlled conditions that the researcher may enhance our knowledge regarding muscle activity and contribute to the diagnosis and treatment of TMD.[113-116] It does not appear, however, that at this time SEMG either enhances or improves our diagnostic or treatment capabilities in a clinical setting. The only exception may be in the area of biofeedback training, and even in that area care must be taken to avoid an inappropriate conclusion. ■

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