Surface electromyographic assessment of patients with long lasting temporomandibular joint disorder pain

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Abstract
The normalized electromyographic characteristics of masticatory muscles in patients with temporomandibular joint disorders (TMD) and healthy controls were compared.

Thirty TMD patients (15 men, 15 women, mean age 23 years) with long lasting pain (more than 6 months), and 20 control subjects matched for sex and age were examined. All patients had arthrogenous TMD according to the Research Diagnostic Criteria for TMD (RDC/TMD). Surface electromyography of masseter and temporal muscles was performed during maximum teeth clenching either on cotton rolls or in intercuspal position. Standardized EMG indices and the median power frequency were obtained, and compared between the two groups and sexes using ANOVAs.

During clenching, the TMD patients had larger asymmetry in their temporalis muscles, larger temporalis activity relative to masseter, and reduced mean power frequencies than the control subjects (p < 0.05, ANOVA). In both groups, the mean power frequencies of the temporalis muscles were larger than those of the masseter muscles (p < 0.001). No sex related differences, and no sex × group interactions were found.

In conclusion, young adult patients with long lasting TMD have an increased and more asymmetric standardized activity of their temporalis anterior muscle, and reduced mean power frequencies, relative to healthy controls.

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1. Introduction

Patients with temporomandibular joint disorders (TMD) are becoming a considerable part of the patients referred to dental clinics (Epker et al., 1999; Iwasaki et al., 2010; Murray and Peck, 2007; Santana-Mora et al., 2009). In these patients, pain and disability are not confined to the stomatognathic system, negatively influencing the global quality of life (De Felício et al., 2009; Dworkin and LeResche, 1992; Epker et al., 1999; Iwasaki et al., 2010; Santana-Mora et al., 2009).

TMD is a complex disorder, and its nature has not been completely understood yet (Cairns, 2010; Douglas et al., 2010; Epker et al., 1999; Ferrario et al., 2007; Murray and Peck, 2007; Santana-Mora et al., 2009). Patients often present with multiple alterations, where muscular and articular symptoms and signs intermingle (Cairns, 2010; Douglas et al., 2010; Epker et al., 1999; Dworkin and LeResche, 1992; Ferrario et al., 2007; Murray and Peck, 2007; Koh et al., 2009; Manfredini and Guarda-Nardini, 2008; Robinson de Senna et al., 2009). In an effort to make diagnosis as objective as possible, several protocols for history taking and clinical assessment have been proposed (De Felício et al., 2009); among the most used there are the Research Diagnostic Criteria for temporomandibular disorders (RDC/TMD) (De Felício et al., 2009; Dworkin and LeResche, 1992; Epker et al., 1999; Tartaglia et al., 2008). Recently, some attempts to relate these diagnostic criteria to image findings provided by magnetic resonance, a technique currently considered to supply the most accurate information about joint morphology and alteration, have been made, but with contrasting results (Koh et al., 2009; Manfredini and Guarda-Nardini, 2008; Robinson de Senna et al., 2009).

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The current gold standard to identify the presence or absence of TMD still remains mainly based on clinical examination supplemented, when deemed appropriate, with imaging (Klasser and Okeson, 2006).

Therefore, other objective, quantitative methods are currently used to supplement the diagnosis of TMD, and to monitor the effectiveness of the relevant treatments. Surface electromyography (EMG) can make an objective recording of the masticatory muscle function and dysfunction (Castroflorio et al., 2005, 2008; De Felício et al., 2009; Ferrario et al., 2007; Forrester et al., 2010; Gay et al., 1994; Grünheid et al., 2009; Koyano et al., 1995; Santana-Mora et al., 2009; Sato et al., 1998; Suvinen et al., 2003, 2009; Tartaglia et al., 2008). Indeed, recent studies proposed that the principal disorders in TMD patients are not joint problems, but motor problems (Douglas et al., 2010), with alteration in muscular activity (Santana-Mora et al., 2009). Therefore, functional records become essential for a better comprehension of the disease (Santana-Mora et al., 2009). Surface standardized EMG is not invasive, low cost, and it can be made directly in the dental office, without the necessity of sending the patient to specialized diagnostic centres (Castroflorio et al., 2005, 2008; Cecílio et al., 2010; Ferrario et al., 2006, 2007; Forrester et al., 2010; Santana-Mora et al., 2009; Sato et al., 1998; Tartaglia et al., 2008).

Most of the previous EMG investigations made on symptomatic TMD patients analyzed acute pain conditions, finding that their masticatory muscles were more asymmetric and more easily fatigued, less efficient and coordinated, and produced reduced electric potentials and bite forces when compared to those of healthy subjects (Ferrario et al., 2007; Kogawa et al., 2006; Santana-Mora et al., 2009; Suvinen et al., 2003; Tartaglia et al., 2008). In contrast, scanty studies analyzed TMD patients with long lasting pain (duration longer than 6 months), a condition where an acutely altered neuromuscular condition should modify to permit some (even limited) functions of the stomatognathic system (Epker et al., 1999; Santana-Mora et al., 2009). The muscular activity in these patients, both in single muscles and in pairs (e.g., right-left symmetry, torque) may be different to that found both in healthy subjects and in TMD patients with acute pain, showing some adaptation of their condition.

The aim of the current study was to assess the normalized EMG characteristics of masticatory muscles of a group of young adult patients with long lasting TMD during the performance of standardized static tasks. The null hypothesis was that the painful situation did not induce modifications in the normalized EMG characteristics of their masticatory muscles as compared to those of normal subjects.

### 2. Materials and methods

#### 2.1. Subjects

Thirty TMD patients, aged 17–30 years (mean 23.2 years, SD 3.5), and 20 healthy subjects without signs or symptoms of TMD (control group, age range 19–31 years, mean 22.6 years, SD 2.8), equally divided into men and women, were examined. TMD patients were referred to a private dental clinic located in São Paulo (Brazil) for the treatment of craniofacial pain, reporting subjective symptoms of pain in the orofacial region. In all patients pain duration was longer than 6 months. The control subjects were students of normal permanent dentition (28 teeth at least), absence of periodontal hemiarch, and without dental pain or periodontal problems.

The inclusion criterion for the control group was to present arthrogenous TMD on the Research Diagnostic Criteria for TMD (RDC/TMD), Axis I, groups II and III. All the TMD patients had a permanent dentition, with at least one molar maxillary-mandibular contact per dental hemiarch, and without dental pain or periodontal problems.

The inclusion criteria for the control group were to present full natural permanent dentition (28 teeth at least), absence of periodontal problems, and no TMD based on the RDC/TMD.

The exclusion criteria, for both groups, were: neurological or cognitive deficit, previous or current tumors or traumas in the head and neck region, current orthodontic or TMD treatment, current use of analgesic, anti-inflammatory and psychiatric drugs. All women declared to be not pregnant.

All subjects gave their informed consent to all the clinical and EMG procedures that were a part of the treatment currently offered. Consent was also obtained from the parents/legal guardians of the patients younger than 18 years. The study protocol was approved by the local ethic committee. All procedures were not invasive, not dangerous, and did not provoke pain or discomfort to the subjects, who were free to stop their examination in any moment.

#### 2.2. Experimental design

In all subjects, surface EMG of the right and left masseter and anterior temporal muscles was performed during maximum voluntary teeth clenching (MVC) (Ferrario et al., 2006; Sforza et al., 2010). All subjects underwent two sets of tests: a standardization recording (clench on cotton rolls) and a test recording (clench in intercuspal position) (Ferrario et al., 2000).

To standardize the EMG potentials of the analyzed muscles with tooth contact, two 10 mm thick cotton rolls were positioned on the mandibular second premolars/first molars of each subject, and a 5 s MVC was recorded.

EMG activity was then recorded during a MVC in intercuspal position. For both recordings, the subject was invited to clench as hard as possible, and to maintain the same level of contraction for 5 s; during tests performance, the subjects were verbally encouraged to perform at their best. All subjects repeated the MVC test three times. The tests were explained and shown to the subjects, who practiced before actual data acquisition.

For all tests, the subjects sat with their head unsupported and were asked to maintain a natural erect position. To avoid any fatigue’s effect, a rest period of at least 3 min was allowed between each test. Clenching did not provoke additional muscular/articular pain in both conditions (MVC on cotton rolls/occlusal surfaces).

#### 2.3. Experimental protocol

Disposable, pre-gelled, silver/silver chloride bipolar surface electrodes (diameter 10 mm, interelectrode distance 21 ± 1 mm) were positioned on the muscular bellies parallel to muscular fibers: anterior temporal: vertically along the anterior margin of the muscle (about on the coronal suture); masseter: parallel to the muscular fibers, with the upper pole of the electrode at the intersection between the tragus-labial commissura and the exo-canthion–gonion lines.

A disposable reference electrode was applied to the forehead. The electrodes were located according to the recommendations of SENIAM (Surface EMG for Non-Invasive Assessment of Muscles Hermens et al., 2000).

EMG activity was recorded using a computerized instrument (Freely, De Götzen srl; Legnano, Milano, Italy). The analog EMG signal was amplified (gain 150, peak-to-peak input range from 0 to 2000 μV) using a differential amplifier with a high common mode rejection ratio (CMRR = 105 dB in the range 0–60 Hz, input imped-
For all tests, the 3 s period with the most constant RMS EMG signal was automatically selected by the software and used for all subsequent analyses, that were automatically performed by the computer software.

For each subject, the EMG potentials of the analyzed muscles recorded during the MVC tests were expressed as percent of the mean potential recorded during the standardization test (MVC on the cotton rolls) (Ferrario et al., 2000), unit: µV/µV × 100. All following calculations were made with the standardized potentials. For each subject, the values obtained in the three MVC tests were averaged.

A set of standardized EMG indices were then computed (Ferrario et al., 2006). In brief, to assess muscle symmetry, within each subject the EMG waves of paired (left and right, masseter and temporalis) muscles were compared by computing a percentage overlapping coefficient (POC, unit%). POC is an index of the symmetric distribution of muscular activity as determined by occlusion; it ranges between 0% and 100%: when two paired muscles contract with perfect symmetry, a POC of 100% is obtained.

To individuate the most prevalent pair of masticatory muscles, the activity index (Ac, unit%) was computed as the percentage ratio of the difference between the mean masseter and temporalis standardized potentials, and the sum of the same standardized potentials (Sforza et al., 2010; Tartaglia et al., 2008). Ac is positive (up to 100%) when the masseter muscle standardized potentials are larger than the temporalis muscles ones, negative (up to −100%) when the temporalis muscles potentials are larger, and null when they are equal.

The mean (masseter and temporalis) total standardized muscle activities (unit: µV/µV %) were computed as the integrated areas of the EMG potentials over time (Ferrario et al., 2006).

Reproducibility of surface EMG measurements was tested both within the same session and after 6 months, finding no systematic differences and limited random errors (De Felicio et al., 2009).

### 2.5. Data analysis – EMG power spectrum

From the EMG recordings, the same 3 s time window used for the analysis in the amplitude domain was selected. For each muscle and test (MVC on cotton rolls and occlusal surfaces), a fast Fourier transform (FFT) was carried out using the software of the electromyograph, and the median power frequency (MPF, unit: Hz) computed (DeLuca, 1997; Sforza et al., 2007).

### 2.6. Statistical analysis

Descriptive statistics were computed for all variables within sex and group (patients and controls). Mean values were compared by two-way factorial analyses of variance (EMG indices obtained in the amplitude domain; between subjects factors: group and sex) and a mixed-model analysis of variance (median power frequency; between subjects factors: group and sex; within subjects factors: muscle, masseter and temporalis anterior; side, right and left; test, MVC on cotton rolls and MVC on occlusal surfaces).

The level of significance was set at p < 0.05 for all statistical analyses.

### 3. Results

No significant sex or inter-group differences were found for age (Table 1). Significant inter-group differences were found for temporalis muscle POC and activity index (p < 0.05, analysis of variance). Overall, the TMD patients had larger asymmetry in their temporalis muscles (smaller POC), and larger activity indices, than the control subjects.

The POC index of the masseter muscle, the torque coefficient and the standardized muscular activity did not differ between groups (p > 0.05). No sex related differences, and no sex x group interactions were found.

On average, the MPFs of the masticatory muscles of the TMD patients were significantly lower than those recorded in the con-

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Control</th>
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<th>ANOVA</th>
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<td></td>
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<td>Women</td>
<td>Men</td>
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<td>21.5</td>
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<tr>
<td></td>
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<td>POC Temporalis</td>
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<td>−0.06</td>
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<td>Standardized activity</td>
<td>µV/µV s</td>
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<td>113.90</td>
<td>99.13</td>
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</table>

POC, percentage overlapping coefficient (index of left–right muscular symmetry); TC, torque coefficient (potential lateral displacing component); Activity index, tempolaris muscle activity relative to masseter muscle activity. Comparisons were made by 2 × 2 factorial analyses of variance (1,46 degrees of freedom for both factors and interaction). NS: not significant (p > 0.05).
4. Discussion

Surface EMG is not a widespread method for diagnosis and monitoring of TMD yet (Castroflorio et al., 2008; Klasser and Oke-son, 2006; Suvinen and Kemppainen, 2007). Several problems in the clinical application of this technique still limit its use to help clinicians in their daily practice. One of the principal problems is normalization/standardization of surface EMG recording, a practice currently used for the assessment of other body muscles (DeLuca, 1997; Hagg et al., 2004). Indeed, to compare EMG recordings among different subjects it is necessary to relate all measurements to the electrical muscle activity detected during some standardization recording, like a maximum voluntary contraction (MVC) (Castroflorio et al., 2005, 2008; Cecilio et al., 2010; Forrester et al., 2010; Santana-Mora et al., 2009). EMG potentials collected in MVC have been reported to have the best repeatability (Forrester et al., 2010; Suvinen et al., 2009). Among the various protocols, an MVC on cotton rolls has been reported to have the lowest in-ter-individual variability (De Felicio et al., 2009; Ferrario et al., 2006; Forrester et al., 2010), and a method based on this standardization has been in use in the last 10 years (Ferrario et al., 2000; Tecco et al., 2011).

According to this protocol, normalized EMG data will inform on control subjects, without sex-, side- or test-related differences (Tables 2 and 3). Additionally, the MPF recorded from the temporalis muscles were larger than those recorded from the masseter muscles. No significant interactions between the analyzed and between within subject factors were found (p > 0.05).

4. Discussion

Surface EMG is not a widespread method for diagnosis and monitoring of TMD yet (Castroflorio et al., 2008; Klasser and Oke-son, 2006; Suvinen and Kemppainen, 2007). Several problems in the clinical application of this technique still limit its use to help clinicians in their daily practice. One of the principal problems is normalization/standardization of surface EMG recording, a practice currently used for the assessment of other body muscles (DeLuca, 1997; Hagg et al., 2004). Indeed, to compare EMG recordings among different subjects it is necessary to relate all measurements to the electrical muscle activity detected during some standardization recording, like a maximum voluntary contraction (MVC) (Castroflorio et al., 2005, 2008; Cecilio et al., 2010; Forrester et al., 2010; Santana-Mora et al., 2009). EMG potentials collected in MVC have been reported to have the best repeatability (Forrester et al., 2010; Suvinen et al., 2009). Among the various protocols, an MVC on cotton rolls has been reported to have the lowest in-ter-individual variability (De Felicio et al., 2009; Ferrario et al., 2006; Forrester et al., 2010), and a method based on this standardization has been in use in the last 10 years (Ferrario et al., 2000; Tecco et al., 2011).

According to this protocol, normalized EMG data will inform on the influence of occlusion (teeth contact) on the neuromuscular activity, avoiding individual variability (anatomical variations, physiological and psychological status, etc.) and technical varia-tions (muscle cross-talk, electrode position, etc.). In patients with acute pain (duration less than 6 months), the method allowed an objective differentiation among different diagnostic categories defined according to the RDC/TMD (Tartaglia et al., 2008), and to discriminate between patients with TMD and patients with a “neck pain” problem with a 0.86 sensitivity, and a 0.92 specificity (Ferra-rio et al., 2007).

Even if TMD is more frequent in women than in men (Cairns, 2010), in the current study the same numbers of male and female patients were analyzed, thus allowing to extend the results to a wider patient group. As found in previous studies on both healthy controls and patients, no significant sex-related differences were found (De Felicio et al., 2009; Ferrario et al., 2006, 2007; Tartaglia et al., 2008). To limit inter-individual variability (Cecilio et al., 2010), only young adult patients were selected, according to San-tana-Mora et al. (2009).

Two kinds of evaluations were made: analysis of the standard-ized amplitudes of EMG potentials, and analysis of the median power frequencies. Overall, during teeth clenching, TMD patients had reduced mean power frequencies, and a more asymmetric standardized contraction of their temporalis anterior muscles than healthy controls (POC temporalis index). Also, the standardized activity of their temporalis muscles was larger than that recorded from their masseter muscles (negative Activity index), in contrast with the nearly equivalent activity recorded in normal subjects (Activity index next to zero). In both groups, the mean power frequencies of the temporalis muscles were larger than those of the masseter muscles.

The reduced MPF in TMD patients has already been reported for fatigue studies (Gay et al., 1994; Koyano et al., 1995), but in the current study we did not make fatigue assessments. Indeed, Grün-heid et al. (2009) reported that chronic jaw-muscle pain can be characterized by a reduced frequency and intensity of voluntary jaw-muscle activity, thus resulting in modifications of the myoglo-bin composition and cross-sectional area of jaw-muscle fibers, with an increase in the percentage of fibers expressing fast myoglobin types and a decrease in the cross-sectional area of slow-type fibers.

Both findings obtained from the standardized amplitudes of EMG potentials (temporal muscle asymmetry and larger relative activity) are in accord with literature data collected on TMD pa-tients. In a previous investigation made on patients with acute TMD, POC temporalis together with the standardized total muscle activity (EMG potentials over time) significantly differed from those recorded in healthy controls (Tartaglia et al., 2008). While the current findings on the temporalis muscle well parallel the previous data, the lack of significant differences on total muscle activity may be related to the different composition of the patient group. In the study by Tartaglia et al. (2008), patients had an acute
pain, and were older (age range 15–74 years, mean 42) than the current ones. Also, patients from both RDC/TMD Axis I (groups I, II and III) and Axis II were included in that study. Indeed, at a closer inspection, the current values for standardized total muscle activity are very similar to those previously reported for patients who had a diagnosis according to the RDC/TMD Axis I, groups II and III (Tartaglia et al., 2008).

A larger muscular asymmetry also characterized the TMD patients analyzed by Ferrario et al. (2007), together with a lower total muscle activity and a larger muscular torque. This group of patients was older (age range 21–66 years, mean 35) than the current group, and had an acute disorder according to the RDC/TMD Axis I, groups II and III.

Therefore, according to the current and previous experimental findings, in differentiating between patients and healthy persons, the temporalis muscle asymmetry seems to be more useful than the masseter muscle asymmetry (Tartaglia et al., 2008). A possible explanation may be the postural action performed by the temporalis anterior muscle, and the relationship between increased anterior tooth contacts and increased relative temporals muscle activity (Ferrario and Sforza, 1994), making this muscle either more sensible for small occlusal modifications, or more responsible for them after an increment in its activity.

Additionally, in both the analyzed MVC tasks (on cotton rolls and on occlusal surfaces) and in both groups, the temporalis anterior muscle had a higher mean power frequency than the masseter muscle, as previously reported (Farella et al. 2003; Koyano et al., 1995). According to previous reports, the differences between the masseter and temporalis anterior muscles may be explained by the heterogeneous composition in fibers of the human masticatory muscles (Farella et al., 2002; Mao et al., 1992; Rowlerson et al., 2005; Scioti et al., 2003), and they have also been reported to have a different behavior during fatigue tests: the masseter has faster reductions of its MPF than the temporalis anterior (Koyano et al., 1995).

Santana-Mora et al. (2009) found that a group of young adult women with long lasting TMD had a significantly larger muscular asymmetry during clenching than their healthy controls, in good accord with the current findings. Additionally, the activity of the temporalis muscles was larger than that of the masseter muscle. They also found a reduction in the total muscular activity, but no standardized values were reported, thus making the comparison with the present findings difficult.

Significant modifications of the activity indices were reported by Ferrario et al. (2002) who analyzed the immediate effect of a stabilization splint in a group of TMD patients, finding a larger equilibrium both between the left and right sides, and between the temporal and masseter muscles, in the with splint condition as compared to the without splint one.

Overall, summarizing all this information, it seems that in TMD patients there is an altered relationship between the temporals and masseter muscles, with a relatively increased temporals activity (or relatively reduced masseter one); also, the contraction of the right and left side temporals muscles are not balanced (Ferrario et al., 2002, 2007; Santana-Mora et al., 2009; Tartaglia et al., 2008). According to Santana-Mora et al. (2009), the increase in temporals activity may be the effect of a protective adjustment aimed at reducing articular loads, in accord with the hypotheses of the “Pain Adaptation Model” (Cairns, 2010; Murray and Peck, 2007).

The hypothesis of Santana-Mora et al. (2009) contrasts with other biomechanical models: according to Ferrario and Sforza (1994), a relatively increased temporals muscle activity results in a larger joint load. In normal conditions, when clenching on the anterior teeth, inhibitory reflexes reduce muscular activity and bite force, thus preventing articular damage (Ferrario et al., 2004; Forrester et al., 2010). In TMD patients, occlusal splints made with posterior contacts can reduce relative temporals muscle activity together with TMD symptoms (Ferrario et al., 2002).

In conclusion, young adult patients with long lasting TMD have an increased and more asymmetric standardized activity of their temporals anterior muscle relative to healthy controls, and a reduced mean power frequency. Surface EMG of masticatory muscles allowed a fast and simple assessment of the functional and dysfunctional characteristics of the analyzed TMD patients, adding an objective datum to the clinical findings and personal symptoms. This evaluation could assist the conventional clinical assessments, helping in the measurement of the physical parameters of a patient’s masticatory system (Cooper, 2006). Further investigations should also assess dynamic activities (chewing and swallowing), thus assessing the actual performance of physiological motor tasks.

Nevertheless, the analyzed individual results represent a convenience sample, and the extrapolation of the present results to a wider population, as well as to different TMD diagnostic groups, should be done with caution.

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