

# Research Articles Using the BioPAK System

(as of Feb. 2003)

## Electromyography

1. Buzinelli RV, Berzin F. Electromyographic analysis of fatigue in temporalis and masseter muscles during continuous chewing. *J Oral Rehabil* 2001 Dec;28(12):1165-7.

The aim of this study was to evaluate the electromyographic changes in the anterior temporalis and masseter muscles after fatigue induced by continuous chewing. Surface electrodes were placed bilaterally over the anterior temporalis and masseter muscles of 31 subjects with normal dentition. Recordings were taken every minute from the beginning of chewing to the exact moment the volunteer reported subjective sensation of fatigue in the jaw muscles. The length of endurance period (fatigue threshold) was measured to each subject, as well as the average amplitude and duration of activation phase and duration of relaxation phase through electromyographic recording of each muscle. The average endurance period was about 500 s. No significant change occurred on the average amplitude of activation phase meanwhile the duration of both the activation and relaxation phase diminished after fatigue.

2. Kamyszek G, Ketcham R, Garcia R Jr, Radke J. Electromyographic evidence of reduced muscle activity when ULF-TENS is applied to the Vth and VIth cranial nerves. *Cranio* 2001 Jul;19(3):162-8

The object of this study was to determine if the resting muscle activity of TMD patients with measured hyperactivity (EMGave > 2.0 microvolts) could be reduced by the application of ULF-TENS (Ultra-Low-Frequency-Transcutaneous Electrical Neural Stimulation) [(BioTENS) BioResearch, Inc. Milwaukee, WI]. Twenty-nine patients with resting muscle hyperactivity and ten without resting muscle hyperactivity were selected from a series of 124 consecutively diagnosed TMD patients. Electromyographic records were taken bilaterally (with the mandible at rest) from the superficial masseter, anterior temporalis, anterior digastric, and posterior temporalis muscles before and after the application of ULF-TENS. The EMG data were averaged. For the 85 muscles that were found initially to exceed the usual cutoff of 2.0 microvolts, means and standard deviations were calculated. The "before TENS" levels were: mean = 3.353 +/- 1.44227 and the "after TENS" values were: mean = 1.844 +/- 0.92421. Using a student t-test, we found the difference between the before and after levels significant ( $p < .0005$ ). Additionally, means and standard deviations were calculated for each muscle (Ta, Mm, etc.) separately and also found to be significantly different (before Vs after TENS). In these "hyperactive" patients, the nonhyperactive muscles were also pooled, the means calculated before (mean = 1.21 +/- 0.456) and after (mean = 1.00 +/- 0.345) TENS and found to be significantly different ( $p < 0.01$ ). For the ten patients exhibiting no muscle exceeding the 2.0 microvolt cutoff (mean = 1.08 +/- 0.415), no significant change (in levels) was observed after ULF-TENS (mean = 0.96 +/- 0.359;  $p > 0.88$ ); however, when we calculated the "paired difference," we found a significant reduction, albeit very slight, in these patients' muscles, too. We conclude that ULF-TENS has an activity-reducing effect on the resting EMG levels of both hyperactive and relaxed muscles. It also appears that while the > 2.0 microvolt cutoff is useful for identifying patients that are hyperactive at rest, it does not identify complete relaxation of masticatory muscles.

3. Tosello DO, Vitti M, Berzin F. EMG activity of the orbicularis oris and mentalis muscles in children with malocclusion, incompetent lips and atypical swallowing--part II. *J Oral Rehabil* 1999 Aug;26(8):644-9.

The EMG activity of the orbicularis oris (upper and lower), and of the mentalis muscles was verified during several movements of the lips, in 18 children ageing from 8 to 12 years, divided into three groups: one with normal occlusion, and two with class II division 1, with atypical swallowing and/or incompetent lips and who had received no orthodontic treatment. In blowing through a straw the muscular activity of the orbicularis oris and the mentalis was significantly greater in the incompetent lips group. The mentalis presented moderate activity in the competent lips group and negligible in normal occlusion. In puffing out of the cheeks, the malocclusion groups developed marked activity of the orbicularis oris and very marked activity of the mentalis, while the normal occlusion presented moderate and negligible activities, respectively. In pursing of the lips, only the incompetent lips group presented a very marked activity of the lower segment. The compression of the lips against the teeth revealed a marked activity of the upper segment of the orbicularis oris in the groups of malocclusion and the mentalis presented greater activity in the competent lips group. The reciprocal compression of the lips presented a hyperactivity of the three muscles.

4. Schievano D, Rontani RM, Berzin F. Influence of myofunctional therapy on the perioral muscles. Clinical and electromyographic evaluations. *J Oral Rehabil* 1999 Jul;26(7):564-9.

The purpose of this study was to evaluate the influence of oral myofunctional therapy on the superior and inferior orbicularis oris (OOS and OOI) and mentalis (MT) muscles at rest and with lips closed in mouth breathing patients with no nasal airway obstruction. The sample consisted of 13 children aged 5-10 years. Clinical and electromyographic evaluations were performed before and after treatment. The results showed that muscles ( $P < 0.05$ ) and functions ( $P < 0.01$ ) improved after therapy, which can be observed by clinical evaluations. The electrical activity increase between rest and closed lip positions was statistically significant for the muscles studied. Before therapy the significant minimal level (s.m.l.) was  $P < 0.01$  and after therapy it was  $P < 0.05$ . When the difference between the rest and closed lip positions before and after therapy was compared, a statistically significant decrease ( $P < 0.05$ ) in the electrical activity of the OOI and MT muscles was observed. There was no correlation between the root-mean-square (RMS) of the OOI and MT muscles with the morphological and functional evaluations. The therapy can improve morphology and function of the muscles in mouth breathing patients with no nasal airway obstruction.

5. Tosello DO, Vitti M, Berzin F. EMG activity of the orbicularis oris and mentalis muscles in children with malocclusion, incompetent lips and atypical swallowing--part I. *J Oral Rehabil* 1998 Nov;25(11):838-46.

The function and the level of activity of the orbicularis oris (upper and lower), and of the mentalis muscles were verified electromyographically in resting position and in several movements and carried out in 18 children aged 8-12 years, divided into three groups: one with normal occlusion, and two with Class II division 1, with atypical swallowing and/or incompetent lips, who had received no orthodontic treatment. It was observed that, in a resting position with the lips separated, there was no activity in any of the muscles. When there was a contact of the lips, action potentials were recorded in the muscles studied, in those individuals with incompetent lips. In the movements of sucking either through a straw or a pacifier and the

thumb, there were no differences among the groups. The incompetent lips group presented very marked muscle activity of the lower orbicularis oris and mentalis in the movement of sucking a lollipop. In deglutition of saliva, the orbicularis oris presented slight activity, and the mentalis, moderate. In deglutition of water, the mentalis presented very marked activity, whereas, the upper and lower orbicularis oris presented moderate and marked activities, respectively.

6. Sgobbi de Faria CR, Berzin F. Electromyographic study of the temporal, masseter and suprahyoid muscles in the mandibular rest position. *J Oral Rehabil* 1998 Oct;25(10):776-80.

The temporal muscles (anterior position), and the masseter and suprahyoid muscles were studied electromyographically in 15 subjects with ages ranging from 18 to 35 years, showing normal occlusion (Class I of angle), complete dentition and no dysfunction of the stomatognathic system. The volunteers sat comfortably in a chair, keeping the Frankfurt plane parallel to the floor; the muscles were analysed in the mandibular resting position through a number of stages: with minimum exteroceptive stimuli, relaxation with soft music, abolition of the intrabuccal negative pressure through a plastic tube, stress provoked by an electronic game, disocclusion of posterior teeth using the occlusal splint and finally withdrawal of this device. The electromyographic results were analysed statistically. The samples, were analysed for all of the frequencies of motor units, in a 1-min period. It was found that there were statistically significant difference between the relaxation stages as compared with the withdrawal of negative intraoral pressure and mainly with the stress phase, being this only on the suprahyoid muscles, with 5% significance.

7. Christensen LV, Mohamed SE. Bilateral masseteric contractile activity in unilateral gum chewing: differential calculus. *J Oral Rehabil* 1996 Sep;23(9):638-47.

Twelve healthy subjects performed 10 s, 15 s, 20 s, and 25 s of right-sided and, subsequently, left-sided gum chewing. The contractile activities of the ipsilateral (chewing side) and contralateral (non-chewing side) masseter muscles, mainly the concentric contractions of the phase of jaw closing and the isometric contractions of the phase of dental occlusion, were recorded through cumulative surface electromyography (EMG). A linear function ( $y = ax + b$ ) described the association between an increase in the duration ( $x$ ) of unilateral gum chewing and the cumulative EMG ( $y$ ) of both the ipsilateral and the contralateral masseter muscle, and because of different slopes ( $a$ ) of the two straight lines a geometric function ( $y = aqx$ ) described the progressively larger differences between the paired and straight lines. When differential calculus was applied to the exponential functions, it became evident that the chewing forces generated by the ipsilateral masseter muscle continually exceeded those generated by the contralateral masseter muscle, and that the positive work (force  $\times$  distance) produced by the concentric contractions of the ipsilateral masseter muscle continually exceeded that produced by the concentric contractions of the contralateral masseter muscle. It was inferred that mechano-physical work plays a major role if clinical muscle fatigue develops during prolonged unilateral gum chewing.

8. Christensen LV, Tran KT, Mohamed SE. Gum chewing and jaw muscle fatigue and pains. *J Oral Rehabil* 1996 Jun;23(6):424-37.

To study possible associations between gum chewing and fatigue and pains in the jaw muscles, eight healthy adults performed prolonged idling, prolonged unilateral chewing of gum, and brief vigorous clenching of the teeth (MVC). Through surface electromyography (EMG), the

authors monitored the cumulative (microV.s) as well as the average rates (microV.s-1) of contractile activities in the right and left masseter muscles. During 10 min of idling there was an absence of muscle fatigue and muscle pains when the EMG rates of the right and left masseter muscles were 2% and 3%, respectively, of those required to elicit isometric muscle pains through MVC. During 10 min of right-sided gum chewing at a rate of 1.2 Hz, the majority of subjects (75%) experienced weak jaw muscle fatigue-not jaw muscle pains-when the EMG rates of the right and left masseter muscles were 38% and 19%, respectively, of those required to elicit isometric pains through MVC. In comparison with 10 min of idling, the weak muscle fatigue of 10 min of unilateral gum chewing appeared when the total contractile activities of the right and left masseter muscles were increased by 1664% and 519%, respectively. It seemed as if prolonged unilateral gum chewing and previous pain-releasing MVC caused some sensitization of muscle nociceptors which, in turn, aggravated subsequent isometric jaw muscle pains elicited through MVC. Even though the right masseter muscle was the most frequent site of clinical fatigue and pains, the authors found no evidence supporting the theoretical foundation of the myofascial pain/dysfunction syndrome.

9. Christensen LV, Tran KT. Predictability of jaw muscle pains from surface electromyograms. *J Oral Rehabil* 1996 Apr;23(4):283-8.

In seven (88%) of eight healthy subjects, weak to moderate pains were elicited in the masseter muscles through the isometric contractions of maximum voluntary teeth clenching. Integrated surface electromyograms of the right and left masseter muscles were used to quantify the absolute and relative contractile activities of the two muscles. The risk (relative probability) of inducing pain onset in the single masseter muscle generating the larger amount of isometric activity was 2.5 times the risk of eliciting pain onset in the single masseter muscle generating the lesser amount of isometric activity. However, as an aid in the diagnosis of pain onset, the method of masseteric surface electromyography had a false diagnostic ratio of 0.67.

10. Berzin F. Electromyographic analysis of the sternohyoid muscle and anterior belly of the digastric muscle in head and tongue movements. *J Oral Rehabil* 1995 Nov;22(11):825-9.

The sternohyoid muscle and anterior belly of the left digastric muscle were electromyographically studied in 20 young adult volunteer individuals. A surface monopolar electrode and a needle monopolar electrode, inserted into the muscle mass 1.0 cm apart were employed. The muscles acted during the following movements of the tongue; protraction, lateral movements to either side, and placement of the tip of the tongue on the hard and soft palate. It was in the latter movement that the most significant action potentials of the sternohyoid muscle were observed, which coincided with a major displacement of the hyoid bone. Both muscles studied do not take part in the kinesiology of the head.

11. Berzin F. Electromyographic analysis of the sternohyoid muscle and anterior belly of the digastric muscle in jaw movements. *J Oral Rehabil* 1995 Jun;22(6):463-7.

The sternohyoid muscle and the anterior belly of the left digastric muscle were studied electromyographically in 20 young adult volunteer individuals. A surface monopolar electrode and a needle monopolar electrode, inserted into the muscle mass 1.0 cm apart were employed. The most significant action of the two muscles was found in the opening of the jaw, during which the sternohyoid muscle presented an isotonic contraction, allowing for displacements of the hyoid bone. They also acted on those movements that included one of the jaw depression

components, such as protrusion, lateral movements to either side, and retrusion. They were inactive when the jaw was in the resting position. Both muscles operated simultaneously most of the time, but a synchronization of their actions could not be demonstrated.

12. Christensen LV. Effects of electrode movements on masseteric electromyograms of teeth clenching in humans. *J Oral Rehabil* 1995 Mar;22(3):191-5.

In six healthy subjects, the integrated electromyographic (IEMG) activity of the right masseter muscle was recorded during 10 s of maximum voluntary teeth clenching, without and with manual movements (at a rate of 1.6 Hz, with a force of approximately 3N) of the bipolar surface electrodes affixed to the cheek. All IEMG recordings were undertaken at discrimination thresholds of 1 microV and 30 microV. Electrode movements were the likely source of some distortion (artefact) of the IEMG readings. An increase in the discrimination threshold (30 microV vs. 1 microV) seemed to decrease the artefactual effects of electrode movements, possibly because the movements exerted their major distorting effects on the smaller (low voltages) masseteric motor units.

13. Ferrario VF, Sforza C, Miani A Jr, D'Addona A, Barbini E. Electromyographic activity of human masticatory muscles in normal young people. Statistical evaluation of reference values for clinical applications. *J Oral Rehabil.* 1993 May;20(3):271-80.

Electromyographic activity of anterior temporal and masseter muscles was measured in 92 young healthy men and women with sound dentitions during rest position, contact in centric occlusion and clench. Male and female mean potentials were similar except in clench, where males had higher electromyographic levels. Mean pooled electromyographic potentials were 1.9 microV (TA) and 1.4 microV (MM) during rest position, 6.5 microV (TA) and 2.8 microV (MM) during contact in centric occlusion. Mean maximum voluntary clench potentials were 181.9 microV (TA) and 216.2 microV (MM) in men, 161.7 microV (TA) and 156.8 microV (MM) in women. Examined muscles were more asymmetric at low electromyographic activity (rest and centric occlusion) with the temporal muscle less asymmetrical than the masseter. In females temporal muscle activity tended to dominate at every contraction level, while in males masseter activity was stronger in clench, and temporal activity in centric occlusion and in rest position.

14. Donegan SJ, Christensen LV, Kaltenbrunner AM. Surface electromyographic estimates of recruitment/rate coding of masseteric motor units. *J Oral Rehabil* 1992 Mar;19(2):129-36.

Surface electromyographic (EMG) recordings were obtained from the masseter muscles in healthy subjects performing brisk maximum voluntary teeth clenching (MVC) for about 1 s. During the onset (0-600 ms) of ballistic MVC activity, the peak amplitude of the EMG interference patterns showed a consistent and significant increase, on examination for 0-200 ms, 200-400 ms, and 400-600 ms of MVC activity. The peak (maximum) and median (centroid) frequencies of power spectrum density functions of the raw surface EMGs (interference patterns) showed an absence of consistent and significant changes during 0-600 ms of ballistic MVC activity. However, the estimated total energy contents (peak amplitude x peak frequency) of the surface interference patterns showed a consistent and significant increase from 0 to 600 ms of ballistic MVC activity, and this was interpreted as global recruitment/rate coding of masseteric motor units.

15. Ferrario VF, Sforza C, D'Addona A, Miani A Jr. Reproducibility of electromyographic measures: a statistical analysis. *J Oral Rehabil.* 1991 Nov;18(6):513-21.

The masseter, temporalis anterior and digastric anterior muscles of five volunteers have been investigated by means of surface electromyography. Each muscle was tested by three operators at different times and under three distinct conditions of intermaxillary relationship: resting, with no occlusal contact (physiological rest position); occlusion in centric occlusion (C.O.) without clenching force; and maximum voluntary clench. In all the trials the BIO-PAK system (Bio-Research Associates Inc., Milwaukee, WI, USA) was used. Measurements were made in two consecutive experimental trials separated by an interval of about 15 days. In the first trial the operators had minimal instrumental experience, while in the second trial the same operators had performed at least 30 measurements each. The data have been analysed by a factorial variance analysis, particularly with a view to comparing the variability between operators for each volunteer subject. The analysis revealed statistically significant differences only in the first experimental trial, due to the operators' lack of experience. The study demonstrates that the electromyographic system and protocol used allow good reproducibility of measurements. Furthermore, they have potential applications in both clinics and research.

16. Christensen LV, Kundinger KK. Activity index and isometric contraction velocity of human jaw muscles. *J Oral Rehabil* 1991 Nov;18(6):555-61.

To determine the relative contribution of the masseter and anterior temporalis muscles to global isometric bite force, activity indices were constructed on the basis of the peak mean voltage (microV) and the integrated voltage (microV.s) of bipolar surface electromyograms obtained during brief maximum voluntary teeth clenching (MVC). The index that was based on integrated myoelectrical activity showed that the masseter muscle contributed the major part of the isometric MVC force. The index that was based on instantaneous peak myoelectrical activity also showed that activity in the masseter muscle predominated over that in the anterior temporalis muscle. In addition, the latter index showed a negative linear association with the initial (0-50% MVC) isometric contraction velocities of the masseter and anterior temporalis muscles. Both indices appear to be promising clinical diagnostic tools.

17. Kundinger KK, Austin BP, Christensen LV, Donegan SJ, Ferguson DJ. An evaluation of temporomandibular joints and jaw muscles after orthodontic treatment involving premolar extractions. *Am J Orthod Dentofacial Orthop* 1991 Aug;100(2):110-5.

Experimental subjects (n = 29) were patients who had undergone orthodontic treatment in combination with extraction of maxillary or mandibular premolar teeth, or both. Control subjects (n = 29) were healthy dental students with no orthodontic or extraction experience. Sagittal (corrected axis) tomograms of the TMJs were used to determine the narrowest linear distances between the anterior and posterior outlines of the TMJ condyle and the TMJ fossa, expressed as the joint space ratio. There were no significant (p greater than 0.05) differences between the control and experimental ratios. Bipolar surface electromyograms of the masseter and anterior temporalis muscles were used to determine the isometric contraction velocities of these muscles until 50% and 100% voluntary isometric contraction effort (teeth clenching) was achieved. There were no significant (p greater than 0.05) differences between the control and

experimental subjects. Electromyograms were also used to determine the relative contribution of the masseter and anterior temporalis muscles to the bite force developed during brief maximum voluntary tooth clenching, expressed as the activity index. There were no significant ( $p$  greater than 0.05) differences between the control and experimental subjects.

18. Carr AB, Christensen LV, Donegan SJ, Ziebert GJ. Postural contractile activities of human jaw muscles following use of an occlusal splint. *J Oral Rehabil* 1991 Mar;18(2):185-91.

As induced by an occlusal splint over a period of 1 week, this study monitored surface electromyographic changes in the postural contractile activities of jaw elevator and depressor muscles in six healthy adults. The immediate effect of the occlusal splint was to increase the postural contractile activities of the suprahyoid muscles. All postural muscle activities showed wide-ranging biological variation, but the activities induced by the splint tended to stabilize within 1 week, with decreased postural activities in the masseter and anterior temporalis muscles, and increased postural activities in the suprahyoid muscles.

19. Christensen LV, Carr AB, Donegan SJ, Ziebert GJ. Observations on the motor control of brief teeth clenching in man. *J Oral Rehabil* 1991 Jan;18(1):15-29.

Without artificial feedback control, maximum voluntary isometric contractions were performed for about 1 s by six subjects. Randomly selected surface electromyograms of the anterior temporalis and masseter muscles suggested that, in some cases, the motor control of the entire isometric contraction might have been preprogrammed through the phenomenon of anticipation. In the majority of cases, the control of the initial contraction phase might have been preprogrammed, followed by a phase of servo-controlled motor activity. As a functional basis for the servo-control of isometric force generation, it was suggested that compartmentalized 'extrafusil and intrafusil motor units' were recruited and de-recruited in an orderly manner, and periods of alpha-motor inhibition were interpreted as signs of switching from one control scheme to another, possibly via a transcortical loop.

20. Donegan SJ, Carr AB, Christensen LV, Ziebert GJ. An electromyographic study of aspects of 'deprogramming' of human jaw muscles. *J Oral Rehabil* 1990 Nov;17(6):509-18.

Surface electromyograms from the right and left masseter and anterior temporalis muscles were used to detect peripheral correlates of deprogramming, also known as programming and reprogramming, of jaw elevator muscles. Putative deprogramming was attempted through the clinically recommended use of a leaf gauge, placed for 15 min between the maxillary and mandibular anterior teeth and disoccluding the posterior teeth by about 2 mm. Studied contractile activities were those of postural activity (subconscious, semi-isometric, minimal activity) and intercuspate teeth clenching (conscious, isometric, maximal activity). Use of the leaf gauge did not affect normalized postural activity (about 4%), the duration (about 900 ms) and static work efforts of clenching (about 1200 microV.s), the time to peak mean voltage of clenching (about 400 ms), and the peak mean voltage of clenching (about 300 microV). Activity and asymmetry indices showed that the studied motor innervation patterns were not changed by the leaf gauge.

21. Christensen LV, Donegan SJ. Observations in the time and frequency domains of surface electromyograms of experimental brief teeth clenching in man. *J Oral Rehabil* 1990 Sep;17(5):473-86.

Maximum voluntary teeth clenching was performed for about 1 s to study the interactions between subjective sensory-motor events and changes in the time and frequency domains of surface electromyograms of the masseter and anterior temporalis muscle. Isometric jaw muscle contractions were examined for their speeds of contraction, the total energy content and median frequency of their power density spectra, and for the specific rate of change and the efficiency of their voluntary and involuntary activation efforts. The observations suggested that, in general, brief maximum isometric contractions were not preprogrammed, but rather were regulated by a subconscious proprioceptive feedback mechanism; the mechanism, possibly a transcortical loop, appeared to have a low gain and to be based on recruitment/derecruitment of motor units.

22. Widmalm SE, Ash MM Jr. Method for identification and classification of single motor unit potentials in diagnostic electromyography. *J Oral Rehabil.* 1990 Jan;17(1):49-59.

It is important to have an objective method for recording jaw muscle capacity such as EMG before, during and after treatment of muscle dysfunction and also for oral rehabilitation with dentures, implants or other types of restorations. Because measurements of motor unit potentials (MUPs) are needed in several areas of EMG analysis, algorithms have been developed in our laboratory for use in a small computer-aided system for semi-automatic detection and pattern recognition of MUPs. Based upon the test recordings it is suggested that a characteristic 'maximal voltage increase per microsecond during the spike-phase' can be used as a supplement to the more generally used parameter 'rise-time'. Examples are given of how the programs can be useful in the study of the functional anatomy of jaw muscles by recording normative values for MUPs and their recruitment patterns.

23. Nielsen IL; McNeill C; Danzig W; Goldman S; Levy J; Miller AJ. Adaptation of craniofacial muscles in subjects with craniomandibular disorders. *Am J Orthod Dentofacial Orthop* 1990 Jan;97(1):20-34.

The purpose of this study was to examine muscle function in subjects with muscle pain. Forty-three subjects with pain in the craniomandibular muscles, clinically determined by manual palpation, were studied for alteration in recruitment of temporalis, masseter, and suprahyoid muscles during a series of phasic movements. Seventeen normal subjects were used as controls. The subjects with muscle pain were divided into three subgroups: (1) those with pain in both mandibular and neck muscles; (2) those with pain in these two muscle groups with joint degeneration; and (3) those subjects with pain only in mandibular muscles. Surface electromyographic (EMG) recordings were taken as each subject performed 16 different responses in which mandibular incisor movement was tracked simultaneously. The results show that the subjects with muscle pain use their anterior temporalis muscles with less frequency (i.e., probability) and with less intensity in several responses than normal subjects. These responses include rapid vertical closing movements, retrusion, ipsilateral laterotrusion, and natural as well as contralateral mastication. The masseter muscle is impaired much less in its function, and the recruitment of the suprahyoid muscles is not affected in the patients with muscle pain. Comparison of the bilateral activity in the anterior temporalis muscles during intercuspal clenching shows that the subjects with muscle pain often demonstrate a more severe asymmetrical recruitment of these muscles than the more symmetrical recruitment seen in normal subjects. Similar observations were made for the masseter muscle. These studies demonstrate that subjects with muscle pain in craniomandibular muscles alter the recruitment

of their jaw muscles, thus supporting the concept that the neuromuscular system is altered in patients with craniomandibular disorders.

24. Christensen LV. Reliability of maximum static work efforts by the human masseter muscle. *Am J Orthod Dentofacial Orthop* 1989 Jan;95(1):42-5.

To study the reliability of nonfatiguing maximum voluntary static work efforts by the masseter muscle, six healthy subjects exercised teeth clenching in centric occlusion. Maximum voluntary teeth clenching was performed for 10 seconds on 2 different days, each with two trials, and maximum static work efforts (without artificial feedback-control) were quantified by integrated surface electromyography. Reliability was determined by factorial analyses of variance and intraclass correlations. Data reduction showed that maximum voluntary static work efforts were reproduced reliably during the four different trials.

25. Christensen LV. Experimental teeth clenching in man. *Swed Dent J Suppl* 1989;60:1-66.

The thesis develops an electromyographic (EMG) method to quantify maximum voluntary teeth clenching (MVC), studies the onset and endurance of jaw muscle fatigue and pain from MVC, and explores the prevention of the discomforts through pharmacological and physical means. MVC, or maximum voluntary static work efforts by the elevator muscles of the mandible, was quantified by continuous (integral) functions of variations in both time and recruitment/rate coding of motor units in the masseter muscle. Fatigue was felt in the masseter muscle after about 30 seconds of MVC; differential calculus suggested that the appearance and disappearance of fatigue was associated with primarily recruitment and decruitment of masseteric motor units, respectively. About 60 seconds of MVC elicited a mild pain in the masseter and temporalis muscles; about 120 seconds of MVC induced a moderate pain and complete exhaustion of the isometrically contracting muscles. Although pain releasing maximum static work efforts are stable variables they cannot predict the pain magnitude of brief and prolonged MVC, probably because of modulations (recruitment/decruitment/rate coding) of masseteric motor units. It is suggested that the modulations begin with the onset of fatigue, are practically complete with the onset of pain, and are absent or negligible with an experience of exhaustion. A single oral dose of 1000 mg of ibuprofen did not affect the onset, endurance, and magnitude of pain from MVC. By contrast, 30 minutes of cooling (ice) of the masseter muscle effectively prevented the onset of pain; it also increased the masseteric EMG, credibly because of modulations of myoelectrical signals and, possibly, increased MVC efforts in the absence of pain.

26. Christensen LV. Quantitative observations on maximum static work efforts and associated pain of the human masseter muscle. *J Oral Rehabil* 1988 Nov;15(6):561-73.

The single case experimental design was used to study day-to-day variations in the onset (PL), tolerance (PT), and intensity (VAS) of masseter muscle pain. Pain was induced by maximum voluntary teeth clenching, with no artificial feedback-control of the level of isometric activity, and static work efforts were quantified by cumulative electromyography. A continual effort to produce maximum static work, about 40% increase from baseline work, elicited in 30-40 s an initial sensation of muscular pain that had an intensity of about 25% of maximum possible score. A further increase in maximum static work effort, about 60% increase from baseline work, caused in about 2 min an intolerable increase in the intensity of muscular pain, about 50% of maximum possible score. Whereas PL showed day-to-day variation, PT and the ratio

PL:PT did not. Intensity (VAS) scores and maximum static work efforts showed no day-to-day variations. Onset (PL) and tolerance (PT) showed no linear associations with VAS scores, and VAS scores showed no linear associations with maximum static work efforts; if anything, the latter associations tended to resemble a cubic parabola. Two different central neural processes, not associated with maximum static work efforts in a simple linear manner, might have been instrumental in: (i) the establishment of criteria for onset and tolerance of pain, and (ii) the discrimination of variable levels of pain intensity.

27. Christensen LV, Robbins DM. Effect of topical cheek surface anesthesia on isometric contractions of the human masseter muscle. *Am J Orthod Dentofacial Orthop* 1988 Feb;93(2):99-102.

To study the possibility of interactions between buccal cutaneous sensory receptors and voluntary maximum isometric contractions of the masseter muscles, six adult subjects exercised maximum teeth clenching before and after spraying the right cheek surface with aerosol containing 20% benzocaine. The right cheek and masseter muscle served as the experimental side, the left cheek and masseter muscle as the control side. Isometric motor outputs, on the right and left sides, were monitored by integrated surface electromyography over periods of 10 seconds. Topical surface anesthesia provided no evidence of motor modulation by cutaneous tactile receptors. Before and after anesthesia, the two muscles showed nearly identical and well-coordinated motor innervation patterns. It is suggested that the cortical motor commands of maximum isometric contractions, with recruitment of practically all available motor units, overrule all modulatory inputs except those of fatigue.

28. Christensen LV. Effect of ibuprofen on isometric contractions and associated pain of the human masseter muscle. *Am J Orthod Dentofacial Orthop* 1987 Aug;92(2):144-50.

A randomized, single-blind crossover trial tested the effect of 1,000 mg of ibuprofen on jaw muscle pain induced by maximum voluntary teeth clenching (MVC). Subjects exercised MVC until there was onset of pain in the masseter muscles (pain latency in seconds), and until pain and exhaustion of the masseter and anterior temporalis muscles could no longer be endured (pain tolerance in seconds). Pain intensity was quantified by visual analogue scores, and pain sensitivity by the pain sensitivity range and the pain sensitivity ratio. During MVC the mean voltage of the left masseter muscle was recorded by cumulative surface electromyography. Ibuprofen had no significant effect on the pain latency and the pain tolerance. Neither did ibuprofen significantly decrease the pain intensity nor significantly affect the pain sensitivity range and the pain sensitivity ratio. After intake of ibuprofen, the number of electromyograms with a decrease in mean voltage was significantly increased--credibly, an expression of increased central fatigue with voluntary decruitment of motor units, and possibly the result of increased contraction times because of an undisclosed effect of ibuprofen. There was no circumstantial evidence of impaired motor activity that could be attributed to biosynthesis of prostaglandins.