ELECTROMYOGRAPHY AND BITE FORCE STUDIES OF MUSCULAR FUNCTION AND DYSFUNCTION IN MASTICATORY MUSCLES

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som med vederbörligt tillstånd av Odontologiska fakulteten vid Umeå universitet för avläggande av odontologie doktorsexamen kommer att offentligen försvaras i föreläsningssal B, Odontologiska kliniken, 9 tr, Umeå, fredagen den 17 oktober 1986, kl 09.00

av

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Leg. tandläkare
ABSTRACT. Electromyographic (EMG) activity versus bite force was studied during a gradually increased isometric contraction up to maximal effort for patients with painful masseter muscles and referents. The masseter muscle, the anterior temporal muscle and the descending part of the trapezius muscle were chosen for the recordings. Bite force was registered with a bite force sensor placed between the first molars. The effects of double blind intramuscular injections of lidocaine and saline in the patients' masseter muscle were evaluated by EMG versus bite force and by assessments of discomfort. EMG activity during unilateral chewing was compared in terms of relative masticatory force between referents and patients by amplitude probability distribution analysis. Regression analyses showed intra-individually steeper slopes for high force levels than for low force levels for the masseter muscle. This was not observed for the anterior temporal muscle. These differences in slopes of the EMG versus force regressions for the masseter muscle and the anterior temporal muscle could be due to differences in recruitment pattern. The same intra-individual relationship between low and high force levels was found for referents and patients. An increased activity, especially among the patients, was found for the descending part of the trapezius muscle during stronger activity of the mandibular elevators. The EMG versus force relationship for low force levels of the masseter muscle was less steep after an intramuscular injection of lidocaine but not after saline. Both solutions for injection had a positive effect on the patients' assessments of discomfort one week after the injection. Three days after injection the patients who received lidocaine experienced a reduction in muscular discomfort. This reduction was not found among patients receiving saline. The amplitude probability distribution analysis revealed that the patients used greater relative masticatory forces than the referents during the chewing of an almond for all probability levels analysed below the peak load of the masseter muscles. Rough estimates of the peak masticatory forces in Newton (N) were for chewing an almond 364 N (referents); 373 N (patients) and for gum-chewing 239 N (referents); 238 N (patients) as regards the masseter muscle. The values were similar for the anterior temporal muscle.

Key words: Electromyography; bite force; contraction, isometric; masticatory muscles; mastication; injections, intramuscular.

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PREFACE
This thesis is based on the following publications and manuscripts, which will be referred to in the text by their Roman numerals:


DEFINITIONS AND ABBREVIATIONS

α  A specified level of significance set for a statistical test.

Amplitude  The maximum absolute value attained by the disturbance of a wave or by any quantity that varies periodically.

A/D converter  A device which translates continuous analogue signals into proportional discrete digital signals.

APDF  Amplitude probability distribution function.

Dynamic contraction  The muscle length is either shortening (concentric) or lengthening (eccentric) during the contraction.

EMG  Electromyography.

ESR  Erythrocyte sedimentation rate.

Hz  Unit of frequency. A periodic oscillation has a frequency of n hertz if in 1 second it goes through n cycles (formerly cycle per second).

kHz  1000 Hz.

Isometric contraction  The muscle length does not change during the contraction.

Load  Force applied to a body.

mg  Milligram.

ml  Millilitre.

mm  Millimeter.

MPF  Mean power frequency. A single estimate of the myoelectric power spectrum. The MPF is the frequency where there is equal energy (power) in the frequencies lower and higher than MPF. The power spectrum describes the content of different frequencies in a signal.

ms  Millisecond.

MuAP  Motor unit Action Potential.
MVC: Maximal voluntary contraction. The maximal (bite) force exerted in a voluntary contraction.

N: Newton. The unit of force in the meter-kilogram-second system, equal to the force which will impart an acceleration of 1 meter/second² to the International Prototype Kilogram mass.

P: Probability level.

p: The probability value calculated in a statistical test.

PC: Personal computer.

%: Percentage.

Positive work: The work done by a concentrically contracting muscle. The time integral of mechanical power over a specified time is positive. Contrary negative work is the work done by an eccentrically contracting muscle. The time integral of mechanical power over a specified time is negative.

Referents: Synonymous with controls.

RMS: Root mean square value. The square root of the time average of the square of the EMG signal.

RVC: Reference voluntary contraction. The maximal (bite) force exerted in a voluntary reference contraction.

s: Seconds.

SD: Standard deviation.

SPSS: Statistical package for the social sciences.

Static contraction: Synonymous with isometric contraction.

Time constant: The time required for a signal to fall to 1/e (36.8%) of the initial value of the signal or to rise from zero to 1-1/e (63.2%) of the final value.

TMJ: Temporomandibular joint.
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\[ \mu V \]  \( 10^{-6} \) V. Volt is the unit of potential difference or electromotive force in the meter-kilogram-second system, equal to the potential difference between two points for which 1 coulomb of electricity will do 1 joule of work in going from one point to the other.

**Voltage**

Potential difference or electromotive force measured in volts.

**VAS**

Visual Analogue Scale.
INTRODUCTION
Background
Pain and tenderness in the masticatory muscles is one of the main characteristic signs and symptoms of disturbances in the masticatory system (Agerberg and Carlsson, 1975; Rugh and Solberg, 1979; Möller, 1981). Evaluation of the muscular function or dysfunction is important for an understanding of etiological factors and for successful treatment based on correct diagnoses. One way to study muscular function and dysfunction objectively is by electromyography. Motor units (a single motor neuron and the muscle fibres it innervates) are activated in order to develop tension in a muscle. Movements of ions along the muscle fibre membrane result in a motor unit action potential (MuAP) which is measurable by electromyographic (EMG) recordings (Basmajian, 1978). One of the pioneers in the use of EMG for studying the activity of masticatory muscles is Carlsöö (1952). The first studies concern action during basic mandibular movements. Extensive research and development of methods for EMG analyses of the masticatory system have followed (Ahlgren, 1966; Möller, 1966, 1974; Yemm, 1977; Christensen, 1980; Sheikholeslam, 1985).

Tender muscles in the neck and shoulders are frequently reported by patients at the Department of Stomatognathic Physiology, Umeå. Clenching the teeth is common among these patients. There is no difference in the prevalence of temporomandibular joint (TMJ) dysfunction between a group exposed to cervicobrachial stress and a non-exposed group (Alanen and Kirveskari, 1985). However, in the exposed group a significant association is found between symptoms of cervicobrachial disorder and TMJ dysfunction (Alanen and Kirveskari, 1985).

EMG versus bite force
The relationship between EMG and muscular performance measured as force has been studied for various human muscles (Bigland and Lippold, 1954; Ahlgren, 1966; Möller, 1966; Milner-Brown
and Stein, 1975; Lawrence and De Luca, 1983; Haraldson et al., 1985). This relationship is reported as being both linear and nonlinear. There is a close correlation between surface recorded EMG activity and isometric muscular force despite differences which may be due to the type of muscle studied, the contraction performed and the analysis method (Bigland and Lip-pold, 1954; Ahlgren, 1966; Möller, 1966; Milner-Brown and Stein, 1975; Lawrence and De Luca, 1983).

In this investigation one approach was to study the EMG activity of mandibular elevators versus bite force during a gradually increased isometric contraction up to maximal effort. Low and high contraction (force) levels were separately analysed following an experimental model described by Chaffin, Lee and Freivalds (1980). Using this model differences in muscular activity for varying force levels could be studied for force-producing masticatory muscles during normal function (referents) and dysfunction (patients).

An increased EMG activity in the descending part of the trapezius muscle during increased activity of the mandibular elevator muscles would indicate a possibility of interplay between these muscles.

A clinical application of EMG versus bite force
Intramuscular injections are used for the management of muscular pain in patients with a myofascial pain dysfunction syndrome (Travell, 1960; Bonica, 1984; Travell and Simons, 1984). Bonica (1984) also describes infiltration anaesthesia as effective in relieving pain such as that caused by lumbago. The results concerning the effects of different injection solutions on muscular pain are controversial. The pain-relieving effect of saline is equivalent to that of lidocaine (Tfelt-Hansen, Lous and Olesen, 1981) and better than mepivacaine (Frost, Jes sen and Siggaard-Andersen, 1980). Insertion of a needle at a trigger point is also effective against muscular pain (Lewit, 1979). An injection also has a strong placebo effect (Doongaji,
Vahia and Bharucha, 1978). The physician's interest in the treatment of the patient is associated with a more successful outcome (Doongaji et al., 1978). Many clinicians favour both the use of local anaesthetics and combinations with corticosteroids (Brown, 1978; Marbach and Varoscak, 1980). EMG versus bite force analysis could be complementary to clinical information in a study on injection solutions. There is a marked decrease in EMG activity of the anterior temporal muscle during maximal bite 5 minutes after an injection of mepivacaine (Bakke, Möller and Rasmussen, 1980).

Masticatory force estimated by the use of EMG versus bite force

Chewing consists of vigorous, alternating contractions, about one third of a second long, in which the elevator muscles produce both force and movement while the depressor muscles contract mainly to move the mandible (Möller, 1974). Patients with functional disorders and pain in the masticatory system have a chewing pattern that differs from that of referents (Möller, Sheikholeslam and Lous, 1984). The patients chew with greater relative strength, longer relative contraction times and stronger intermediary activity between strokes (Möller et al., 1984). The mean voltages of EMG activity (Möller, 1966) and integration of the amplitude of the EMG pattern (Mohamed, Christensen and Harrison, 1983) are used to quantify the muscular performance during chewing.

By using the amplitude probability distribution analysis a measure of the distribution of contraction levels (muscular load levels) during dynamic or intermittent isometric contractions can be obtained (Ericson and Hagberg, 1978; Jonsson, 1978 a). Winter (1979) states that with our present knowledge an isometric contraction can be used to predict muscle tension in a dynamic contraction if the length of the muscle is not
changed rapidly. The EMG versus force relationship from a gradually increased isometric reference contraction could therefore be used for an estimation of the relative force used during a dynamic contraction (Ericson and Hagberg, 1978). Whether the amplitude distributions of EMG activity could be used for chewing analyses has not previously been studied. The use of APDF in chewing analysis might accomplish an alternative method for estimating masticatory forces during chewing differentiated in varying muscular load levels.
AIMS OF THE PRESENT INVESTIGATION
- to evaluate the relationship between on one hand the EMG activity from the masseter muscle and the anterior temporal muscle and on the other hand the bite force during a gradually increased isometric contraction (I,II).

- to investigate whether there is any difference in the EMG versus bite force relationship between patients with painful and tender masseter muscles and referents (II).

- to investigate a possible interplay between the descending part of the trapezius muscle and the mandibular elevator muscles during a gradually increased isometric contraction up to maximal bite force (I,II).

- to investigate whether the EMG versus bite force relationship for patients differs before and after the administration of intramuscular anaesthetics and saline injections in painful masseter muscles (II) and to compare the different injection solutions concerning discomfort and bite force (III).

- to investigate whether the amplitude distribution of EMG activity obtained by computing the amplitude probability distribution functions can be used for chewing analysis by studying the unilateral chewing of an almond and chewing-gum (IV).

- to compare the amplitude distribution of EMG activity in terms of relative masticatory force between patients with painful masseter muscles and referents. Furthermore to estimate the size of the maximal masticatory force in Newton (V).
MATERIALS
Prior to consenting to participate all subjects were informed in detail about the experimental procedures. The selection of subjects and the methods used were approved by the ethical committee of the University of Umeå. All subjects were interviewed and clinically examined before participation in the studies.

Referents
Ten females were selected from among dental students and assistants. They had no symptoms or signs of muscular tenderness from their masticatory muscles nor did they have any pain in their temporomandibular joints or any facial pain. They had complete dentitions and "normal" morphologic occlusion.

Patients
Thirty females were selected from among patients referred to the Department of Stomatognathic Physiology, School of Dentistry, Umeå. When the experiment was carried out the participants were suffering daily pain in the superficial masseter muscle which was also tender on palpation. During palpation a "jump sign" (Travell and Simons, 1984) in terms of a "palpebral reflex" or withdrawal movement during palpation was the accepted clinical sign of muscle tenderness. The muscular pain was chronic i.e. defined as being observed by the patient for more than three months. There was no current diagnosis of any systemic disease or pain of neurological origin. No participant had pain in the temporomandibular joints during both posterior and lateral palpation when resting or during opening movements which could be regarded as a sign of affections of the joints (Carlsson and Helkimo, 1972). All participants had a normal ESR and a negative test for the rheumatology factor. They had complete dentitions and "normal" morphologic occlusion. Twenty-six out of 30 patients were aware that they had a habit of clenching and/or grinding their teeth. During the time (April-May 1985) of the experiments approximately 250 patients were visiting the Department of
Stomatognathic Physiology, Umeå. The inclusion criteria meant that the 30 patients selected comprised nearly all those who were eligible. None of the patients refused to participate. Before start of the experiments all the masticatory muscles were reexamined. During the examinations the normal stomatognathic routines for patients at the Department of Stomatognathic Physiology, Umeå (Wänman and Agerberg, 1986) were followed. No attempt was made to evaluate clinically the severity of tenderness in the trapezius muscle which was reported by seven patients.

Number of participants and age distribution in the different reports are presented in Table 1.

Table 1. Number of participants and age (years; mean, SD and range) in the different reports. All participants were females.

<table>
<thead>
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<th>SD</th>
<th>Range</th>
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<td>24</td>
<td>2</td>
<td>20-26</td>
</tr>
<tr>
<td>II</td>
<td>28</td>
<td>27</td>
<td>7</td>
<td>18-43</td>
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<td>III</td>
<td>30</td>
<td>27</td>
<td>7</td>
<td>18-43</td>
</tr>
<tr>
<td>IV</td>
<td>9</td>
<td>24</td>
<td>2</td>
<td>20-26</td>
</tr>
<tr>
<td>V</td>
<td>23</td>
<td>27</td>
<td>8</td>
<td>18-43</td>
</tr>
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</table>

Footnote: The experiments for Reports I and IV, and II, III and V respectively were performed on the same samples of referents and patients. However, the number of participants varies for the different reports.

Selection of participants according to age and sex
Only fairly young and premenopausal females (range 18-43 years) were chosen because age and sex have effects on EMG recordings (Visser and de Rijke, 1974; Carlson, Alston and Feldman, 1964). Women require a higher amplitude and a larger number of peak
potentials than men to produce a given tension during isometric contractions of a thumb muscle (Visser and De Rijke, 1974). Carlson, Alston and Feldman (1964) report a decrease in amplitude during maximal contraction in an elderly age group compared to a younger age group.

Females were also chosen since they have a higher incidence of disturbances of the masticatory system in patient materials than men (Agerberg and Helkimo, 1986). They also represent a larger group of patients at the Department of Stomatognathic Physiology, Umeå.

Maximal bite force values are reported to be higher for males than for females (Helkimo, Carlsson and Helkimo, 1977). Bite force is reduced with increasing age probably due to an age-dependent deterioration of the dentition (Helkimo et al., 1977). Furthermore morphologic variation can affect the EMG activity of the masticatory muscles (Möller, 1966). The inclusion criteria: "complete dentition and normal morphologic occlusion" were established in order to keep the effects of these factors constant.
METHODS
In this section it is the methods of the EMG recordings that are mainly discussed. The experimental design for each report and the statistical analyses can be studied in detail in the original reports.

Muscles selected for EMG recordings
The superficial masseter muscle and the anterior temporal muscle were chosen for the investigation. Both muscles are known to be active when the mandible is elevated (Möller, 1966). During maximal bite in the intercuspal position the anterior temporal muscle, the masseter muscle and the medial pterygoid muscle exhibit strong EMG activity (Möller, 1966). The anterior temporal muscle also contracts vigorously on both sides during chewing and the activity of the masseter muscle during chewing is related to the placement and hardness of the bolus (Möller, 1966, 1974). The term superficial masseter muscle in Report I was used to emphasize the location of the electrodes on the masseter muscle. However, differentiation of EMG activity between the superficial and deep portion of the masseter muscle was not attempted. The descending part of the trapezius muscle was chosen for EMG recordings (I,II) because it is commonly reported as being tender in combination with the habit of clenching the teeth.

The muscular pain in the masseter muscles was probably due to muscular stress, a "hyperfunctional myalgia", since 26 out of 30 patients had the habit of clenching and/or grinding their teeth. The side with the most painful masseter muscle was recorded for the patients. It was chosen by evaluating the strongest pain response during palpation. The preferred chewing side was recorded for the referents. If the subject had the habit of chewing unilaterally recordings from the most exercised and presumably strongest muscle were those that were required.
Electrodes
Beckman miniature bipolar surface electrodes were used in all EMG recordings. Surface electrodes are reported to record from a greater population of motor units than intramuscular electrodes (Basmajian, 1978). The Beckman miniature electrodes have been recommended for small muscles and fulfill the rather strict requirements regarding freedom of motion artifacts (Hof, 1984). The use of closely spaced bipolar electrodes minimizes the risk of crosstalk between muscles (Zipp, 1982).

Efforts were made to place the electrodes at a distance of 25 mm apart on the skin overlying each muscle in the direction of the muscle fibres. Before application of the electrodes the skin was rubbed vigorously with an alcohol-ether gauze pad in order to reduce skin resistance. Electrode paste was used to enhance the signals.

High test-retest reliability coefficients of EMG activity obtained with surface electrodes are reported for the biceps brachii muscle (Komi and Buskirk, 1970). However, the reproducibility of the signals from the relatively small masticatory muscles varies unless conditions are carefully standardized (Nouri, Rothwell and Duxbury, 1976). In the reports in this investigation all recordings were made without changing the electrode positions and the main results were based on intra-individual analyses. During the recordings the subject sat with a straight head on an upright chair without head support.

Normalization of EMG activity
The myoelectric signals picked up from a muscle contain information about the demanded force exerted. Generally a high amplitude means a high muscular contraction and a low amplitude means a low muscular contraction. However, the amplitude varies between different individuals due to factors such as the electrode skin impedance, varying depths of the skin and subcutaneous tissue (Basmajian, 1978). The amplitude should
preferably be normalized before any comparisons between individuals are made (Jonsson, 1978 b). There are several ways to normalize EMG activity. The muscular contraction could be expressed as a percentage of maximum voluntary signal amplitude (Möller, 1966). One or more fixed reference loads could be used (Hagberg, 1979; Jonsson, 1982) or, as in this investigation, signal amplitude as a percentage of that during a maximal voluntary contraction.

The normalization also includes a correction for variation in postural activity, including base line noise of the EMG recordings, by a subtraction of this value. One advantage of measuring EMG amplitude versus a gradually increased force is the continuous number of measurable points obtained giving an individual but not necessarily linear calibration curve.

Amplification of EMG signals
The EMG signals were amplified linearly 2 Hz to 2 kHz. An oscilloscope and a Mingograph ink jet recorder* (DC-1 kHz) (paper speed 10 mm/s) were used to check the quality of the signals. The amplified signals were recorded on a Tandberg FM tape recorder ** (DC - 1 kHz).

Amplitude analysis of EMG signals
The EMG signals were RMS (root mean square) detected and A/D converted before analysis by a PC. The RMS detector gives an output voltage directly proportional to the energy content of the original signal. The formula for the definition is:

\[ \text{RMS} = \sqrt{\frac{1}{T} \int_{0}^{T} x^2(t) dt} \]

where \( x(t) \) is the EMG signal analysed and \( 0-T \) is the part of the time that the signal is analysed.

* Siemens-Elema AB, Solna, Sweden.
For the gradually increased isometric contraction up to maximal effort the time constants for RMS-detection were 100 ms (I,II) and 50 ms (IV,V). The signals were A/D converted before being fed into a PC at a rate of 7 Hz (I,II) and 14 Hz (IV,V).

The signals from the EMG activity recorded during chewing were RMS detected with a time constant of 50 ms and A/D converted. The sampling rate was 30 Hz and the EMG signals were stored on discs before the APDF analysis by the PC. The increased sampling rate of the EMG signals during chewing was used since the duration of each chewing cycle is short. Each burst of activity during chewing has been reported to last for approximately 1/3 of a second (Möller, 1974).

The time constant for RMS-detection is also important because of the delay between the EMG signal and the initial build-up of tension in the muscle and the delay in reaching maximum tension (IV). If the time constant in chewing analyses is too long parts of the myoelectric burst can be missed. The delay between the onset of the EMG signal and the initial build-up tension, the electromechanical delay, can be approximately 50 ms (Cavanagh and Komi, 1979). Möller (1966) suggests that the delay between maximal electrical activity and peak tension in the anterior temporal muscles is 100 ms. Hagberg (1979) suggests that a suitable time constant for kinesiologic studies is 50-100 ms.

**Bite force**

The bite force was registered with a miniature bite force sensor (Fløystrand, Kleven and Öilo, 1982) placed between the first molars on the same side as the attached electrodes. The sensory unit is a semiconductor with planar resistors diffused on both sides mounted in a metal housing constructed in the shape of a fork. The size of the housing is 8*23 mm and the height of the bite-fork is 3.4 mm (Fløystrand et al., 1982) (Fig.1).
Fig. 1 The bite-fork (Flöystrand et al., 1982).

The bite-fork was calibrated with weights before start of the experiments. Thin (1 mm thick) acrylic splints were used during all registrations with the bite force sensor in order to protect the teeth against enamel fractures and to stabilize the bite-fork. Apart from the contact between the splints and the bite-fork no parts of the splints came into contact with each other during the bite force recordings. Stabilization of the bite-fork is advantageous in bite force recordings. The maximal bite force increases significantly if eccentric load on the upper premolar is made centric and axial with respect to the bite force sensor (Widmalm and Ericsson, 1982). In the study referred to the correct placement was obtained by covering the whole occlusal surface of the tooth with a plastic filling. High test-retest correlation coefficients (r) are reported for maximal bite force values on one test occasion for both patients with muscular pain dysfunction syndrome (r = 0.97) and controls (r = 0.96) (Molin, 1972). Repeated tests at an interval of one week also show a high test-retest correlation (molars r = 0.88) (Helkimo, Carlsson and Carmeli, 1975).

EMG versus bite force

EMG activity versus bite force was recorded during a gradually increased isometric contraction from zero to maximal effort in 10-15 s. Maximal voluntary contraction (MVC) was defined as the maximal force exerted in a voluntary contraction by each subject at the time of the experiment. The highest bite force
value in Newton out of 2 or mostly 3 trials corresponded to 100% MVC (I,II). A transformation of bite force values in Newton to % MVC was made to define the contraction levels and avoid arbitrary variations among subjects.

The bite force signals were recorded on the four channel tape recorder simultaneously with the EMG signals and analysed with the same sampling frequencies as previously presented. Regression analysis was used to evaluate the reference contraction. Following the experimental model of Chaffin et al., (1980) low (0-40% MVC) and high (60-100% MVC) contraction levels were analysed separately (I,II). Linear regression (yV=A+B*% MVC) was used for the regression analysis of the separate low and high contraction levels. B is the regression coefficient that expresses the slope of the regression line (slope B) (Nie et al., 1975) (Fig.2). In this investigation the expressions force level and contraction level were used synonymously since bite "force" in Newton was transformed to percentage of maximal voluntary "contraction" (% MVC).

The main reason for analysing low and high force levels separately was to permit study and comparison of the myoelectric activity during varying degrees of muscular load within referents and patients. However, a comparison of normalized and defined levels of muscular activity between groups was also wanted (II). The relationship was used in the chewing analyses (IV,V) to transform distribution levels of EMG activity (μV) to distribution levels of relative masticatory force.

The correlation coefficients for linear, exponential and power function regressions were also evaluated for the total EMG versus force curve. Correlation coefficients for linear regression were calculated for low and high contraction levels.
Regression analysis for EMG activity recorded from the descending part of the trapezius muscle was used to calculate whether there was a significant increase in EMG activity of this muscle during the contraction of the elevator muscles.

Fig. 2 EMG (µV) versus bite force (0-100% MVC) (recordings from the masseter muscle for one subject). Linear regressions for 0-40% MVC (low force level) and 60-100% MVC (high force level) are plotted. B is the regression coefficient which expresses the slope of the regression line (slope B).

Intramuscular injections
The effects of intramuscular injections of lidocaine 2 ml of 1% without vasoconstrictor (Xylocain (R) 10 mg/ml) were compared with a corresponding injection of 2 ml saline administered double blind into the painful belly of the patients' superficial masseter muscle. In the EMG study on injection solutions (II) 13 patients received a lidocaine injection and 15 received a saline injection. Postural activity and EMG versus bite force were recorded and compared intra-individually before and 10 minutes after injection (II). Postural activity was recorded after an instruction to rest with closed eyes, with a relaxed mandible and shoulders.
A clinical evaluation was made regarding the maximal bite force values (N) and the subjective assessments of discomfort in the masseter muscle, also compared before and 10 minutes after injection. Each person was followed up in making a corresponding assessment on days 1, 3 and 7 after the injection. Fifteen patients received lidocaine and 15 saline in this study (III).

Discomfort
Borg's new rating scale constructed as a category scale with ratio properties (Borg, 1982 b) was used for the assessments of discomfort in the masseter muscle (Table 2).

Table 2. Borg's new rating scale (a category scale with ratio properties).

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>Nothing at all</td>
</tr>
<tr>
<td>0.5</td>
<td>Very, very weak (just noticeable)</td>
</tr>
<tr>
<td>1</td>
<td>Very weak</td>
</tr>
<tr>
<td>2</td>
<td>Weak (light)</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Somewhat strong</td>
</tr>
<tr>
<td>5</td>
<td>Strong (heavy)</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Very strong</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Very, very strong (almost max)</td>
</tr>
<tr>
<td>10</td>
<td></td>
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<tr>
<td>*</td>
<td>Maximal</td>
</tr>
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</table>

Borg's new rating scale has previously been used for assessment of discomfort and pain from loaded passive joint structures (Harms-Ringdahl et al., 1983). The scale is documented in a comparison with the Visual Analogue Scale (VAS) in order to, in conformity with the VAS scale, reliably assess the intensity levels of perceived pain elicited by loading the joint structures (Harms-Ringdahl et al., 1986). Borg's new rating scale
has also been documented as useful for perceived chest pain during angina pectoris (Borg, Holmgren and Lindblad, 1981). One advantage of the scale which has ratio properties is the possibility it affords of obtaining quantitative information that can be used for inter-individual comparisons (Borg, 1982 a,b).

**Amplitude probability distribution analysis of EMG during chewing**

Amplitude probability distribution analysis of muscular load levels of EMG activity during the unilateral chewing of a blanched almond until swallowing and the corresponding time for chewing half a stick of chewing-gum (prechewed for 30 s) were made for the masseter muscle and the anterior temporal muscle (IV, V). Unilateral chewing has been recommended for studying basic mechanisms (Möller, 1974).

APDF:s were calculated for RMS-detected EMG activity during chewing of the almond and the chewing-gum. The amplitude probability at a certain level can be expressed as a fraction of the total duration for which the signal is lower than or equal to this level. When a large number of levels are used the APDF provides a good estimate of variation in muscular performance (Hagberg, 1979). The probability levels 0.01, 0.1, 0.2, 0.3,.....0.9, 0.99 were calculated. A probability level close to zero represents static loading of a muscle, probability level 0.5 the median activity and probabilities close to one the maximal loading of the muscle (Jonsson, 1978 a). The APDF analysis method (Fig.3) is described in detail in Reports IV and V.
Fig. 3 The analysis system of the experimental set-up presented in a simplified layout. Bite force and EMG activity were simultaneously amplified and recorded on the four channel tape recorder. RMS-detection and A/D-convertion preceded the analysis by the personal computer (PC). Values for chewing analyses were stored on discs. The PC was used for regression analyses and APDF analyses of the signals.

Since the duration of a burst of activity of the elevator muscles is short, followed by a period of lower intermediary activity when the antagonising suprahyoidal muscles contract, there is low EMG activity recorded from the mandibular elevator muscles during at least half the duration of the EMG recordings analysed. If the duration of a chewing stroke lasts at the most for 380 ms during unilateral chewing (Möller, 1966) approximately the probability levels below 0.7 concerned intermediary activity of the elevator muscles. The duration of the amplitude levels (µV) as a percentage of the total time (100%) of the recording could be used to describe the meaning of probability levels (P) (Fig. 4)
Fig. 4 A. The duration of amplitude levels (μV) as a percentage of the total time of the EMG recording analysed.
B. The cumulative duration of amplitude levels (μV) as a percentage of the total time of the EMG recording analysed.
C. The corresponding APDF curve for different probability levels (P). The EMG activity for each level is equal to or lower than this level. This curve reflects the cumulative duration in B. (Adapted from Jonsson, Ericson and Hagberg, 1981; Jonsson, 1982.)

It was found during the chewing analyses (IV,V) that the maximal bite force value of the reference contraction was often exceeded during peak loading of the muscles. Thus, it being a submaximal level of muscular force, it was found more appropriate to name the gradually increased reference contraction a reference voluntary contraction (RVC) in the reports concerning the chewing analyses (IV,V). A transformation of the muscular load levels of EMG activity (μV) to load levels of relative masticatory force (% RVC) was made by regression in reverse of the isometric reference contraction for EMG versus bite force from 0-100% RVC (IV) (Fig. 5). Power function regression (μV=A*% RVC**B) was used since it provides a good explanation for both linear and non-linear relationships (Hagberg, 1981).
Fig. 5 Power function regression for EMG (μV) versus bite force (% RVC) of the reference voluntary contraction 0-100% RVC. The arrow shows how the transformation is made by regression in reverse.

Rough estimates of maximal masticatory forces in Newton (N) were obtained by a transformation of the estimated peaks of relative masticatory forces in % RVC. The reason being that Newton is the unit most commonly used for measurements of bite force and masticatory force. The peak value in % RVC (probability level 0.99) for each muscle and subject during chewing was multiplied by the individual maximal bite force value (N) from the reference contraction. The same calculation was made for probability level 0.9, that is close to the peak level. The values were transformed for patients and referents during gum-chewing and chewing an almond (V).

Furthermore the time for chewing the almond until swallowing and the number of bursts used were counted on ink jet recordings of the raw EMG signal. The number of bursts during gum-chewing were counted on ink jet recordings for a period of 10 s (V).
Statistics

Data concerning the regression analysis of the EMG versus force relationship were calculated directly by the PC during the signal analyses. Further statistical analyses were performed by using nonparametric statistics (Siegel, 1956) and descriptive statistics on a SPSS computer program (Nie et al., 1975; Hull and Nie, 1981). The sign test and Wilcoxon matched-pairs signed-ranks test were used for intra-individual comparisons. The Mann-Whitney U test was used for unpaired observations for inter-individual comparisons. The probability values presented were two-tailed and p<0.05 was regarded as significant, except for study IV where one-tailed p-values were used when the almond chewed was presumed to be harder than the chewing-gum.

Siegel (1956) describes the differences between the sign test and the Wilcoxon test. "The sign test utilizes information simply about the direction of the differences within pairs. If both the relative magnitude and the direction of the differences is considered a more powerful test can be used. The Wilcoxon matched-pairs signed-ranks test gives more weight to a pair which shows a large difference between two conditions than to a pair exhibiting a small difference. Both tests could be used for ordinal measurements or higher scale levels. However, the Wilcoxon test requires ordinal information not only within pairs but also as regards the differences between pairs" (Siegel, 1956).

The Mann-Whitney U test requires at least ordinal measurements and is one of the most powerful of the nonparametric tests (Siegel, 1956). Mainly nonparametric tests for the statistical analyses were used because of the small number of participants and the uncertainty of constancy of variance and the existence of a normal distribution.
RESULTS

EMG versus bite force in referents and patients (I,II)
Low and high force (contraction) levels of the EMG versus bite force curves for the referents' (I) and patients' (II) masseter muscle were analysed intra-individually. For both groups steeper slopes were found for high force levels (60-100% MVC) than for low force levels (0-40% MVC). No significant intra-individual differences between the regression coefficients of high and low force levels were found for the anterior temporal muscle of either the referents or the patients.

When slopes for low and high force levels were compared separately as unrelated samples between referents and patients there were no significant differences concerning the masseter muscle. However, for the anterior temporal muscle there were less steep slopes among patients for both levels of the EMG versus bite force curve compared to referents (II).

The correlation coefficients (r) for the total regression curve (0-100% MVC) for linear, exponential and power functions were high (range of r = 0.70 to 0.99) (I).

The descending part of the trapezius muscle (I,II)
Five out of 10 referents showed a significantly increased EMG activity of the descending part of the trapezius muscle during the registration of EMG versus bite force. When the same analyses were made for the patients with painful masseter muscles the EMG activity of the descending part of the trapezius muscle was significantly increased for 21 out of 28 patients during the strongest bite (II).

EMG versus bite force after intramuscular injections of the patients' painful masseter muscles (II)
After the superficial masseter muscle was injected with lidocaine there was a significant decrease in the regression coefficient (slope) B of the EMG versus bite force relationship concerning the low force level (0-40% MVC). The slopes were
compared intra-individually before and 10 minutes after injection. The decrease in the regression coefficient was not found when the same comparison was made for saline injections. No significant differences were observed for high force levels of the EMG versus bite force curve for the masseter muscle after injections of either of the two solutions.

The anterior temporal muscle was not injected and no significant differences were found for either low or high force levels of the EMG versus bite force curve after lidocaine or saline injections in the superficial masseter muscle.

Intra-individual analysis revealed that after the lidocaine injection the RMS value of postural activity in the masseter muscle was significantly reduced. There was no significant difference in postural activity in the masseter muscle after the saline injection. During the period of injections into the masseter muscle no significant differences in postural activity of the anterior temporal muscle were found.

Discomfort assessed by patients with painful masseter muscles

Seven days after injection both lidocaine and saline injections had positive effects on the muscular pain in the masseter muscle when the patients assessed their discomfort on Borg's new rating scale. Borg's scale values were intra-individually compared for before and 10 minutes after as well as 1, 3 and 7 days after injection respectively. An inter-group comparison between those patients injected with lidocaine and those with saline showed that they assessed the discomfort similarly except for day 3 when only those who received lidocaine reported significantly less discomfort. Analysed intra-individually a significant decrease in discomfort was found for both patients receiving lidocaine and those receiving saline with the exception of day 1 after lidocaine injection and days 1 and 3 after saline injection (Fig.6).
Fig. 6 The median values for the assessments of discomfort in the masseter muscle using Borg's new rating scale before and after injections of lidocaine and saline respectively. The results after 10 minutes, 1, 3 and 7 days after injection are compared to those prior of the injection.

Comparison of maximal bite force (N) of patients before and after injection (III)
After an intramuscular injection of saline into the superficial masseter muscle the intra-individual maximal bite force values (N) for these patients increased significantly. This was not the case concerning the maximal bite force values for the patients who received lidocaine (III) (Fig. 7).
Maximal bite force (N) compared between referents and patients (I,III)
The mean maximal bite force value for the 10 referents (I) measured between first molars was 396 N (SD ± 85 N). For the 30 patients (III) the mean maximal bite force value was 357 N (SD ± 162 N). There were no significant differences in maximal bite force values when the values were compared between referents and patients.
Amplitude probability distribution analysis of chewing for referents and patients (IV,V)
The estimated relative masticatory force (% RVC) in the masseter muscle and the anterior temporal muscle respectively was higher during chewing an almond than during gum-chewing for both referents and patients (Fig.8). For the referents these differences were found for probability levels (P) close to maximal loading (P= 0.9 and P= 0.99). The patients used higher relative masticatory forces during chewing an almond than during gum-chewing for all probability levels tested (P= 0.1 to 0.99).

No significant differences in relative masticatory forces were found between the masseter muscles and the anterior temporal muscles for either referents or patients when the muscles were compared intra-individually with each other. The tests were made for relative masticatory forces both during chewing an almond and gum-chewing.

When the referents were compared with the patients the peaks of the relative masticatory forces between the two groups were similar. The relative masticatory forces during the chewing of an almond were significantly higher for the patients for all probability levels (P= 0.1 to 0.9) analysed below the peak load of the masseter muscles. As regards the anterior temporal muscles of the patients the relative masticatory forces were higher for probability levels lower than or equal to 0.7 which corresponds to 70% of the total time of the almond-chewing analysed (V).

During gum-chewing the patients used higher forces than the referents as regards the masseter muscle during 70% of the total time (P < 0.7) of chewing analysed. As regards the anterior temporal muscle the patients used higher forces during gum-chewing for probability levels 0.3 and 0.5 compared to the referents (V).
When referents and patients were chewing an almond the median masticatory forces during maximal loading exceeded 100% RVC for both the masseter muscles and the anterior temporal muscles (Fig. 8) (IV, V).

![Graphs showing relative masticatory forces for referents (R) and patients (P) for chewing gum and almonds.](image)

**Fig. 8** The APDF:s for the relative masticatory forces (% RVC) as median values for the different probability levels are presented for referents (R) and patients (P).

The chewing time for the almond was significantly longer for the patients than for the referents. The median time for chewing the almond until swallowing was 15.8 s for the referents and 20.8 s for the patients. During chewing of the almond there was no significant difference in the total number of bursts of activity until swallowing between referents and patients. Nor was there any significant difference in the number of bursts of EMG activity during 10 s of gum-chewing between referents and patients.
Estimation of the peak of the masticatory forces (N) for referents and patients (V)

Higher estimates of maximal masticatory force values in Newton were calculated for chewing an almond than for gum-chewing (probability level $P = 0.99$). This was also the case for $P = 0.9$ (Table 3).

Table 3. The medians of estimated maximal ($P = 0.99$) and close to maximal ($P = 0.9$) masticatory force values in Newton for referents and patients. Separate calculations were made for the masseter muscle and the anterior temporal muscle. $P$ = probability level.

<table>
<thead>
<tr>
<th></th>
<th>Masseter muscle</th>
<th>Anterior temporal muscle</th>
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</thead>
<tbody>
<tr>
<td>P</td>
<td>0.99</td>
<td>0.9</td>
</tr>
<tr>
<td>Almond</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Referents</td>
<td>364</td>
<td>168</td>
</tr>
<tr>
<td>Patients</td>
<td>373</td>
<td>278</td>
</tr>
<tr>
<td>Chewing gum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Referent</td>
<td>239</td>
<td>133</td>
</tr>
<tr>
<td>Patients</td>
<td>238</td>
<td>173</td>
</tr>
</tbody>
</table>
DISCUSSION
EMG versus bite force in patients with painful masseter muscles and referents (I,II)
The muscle fibres are activated differently at low and high force levels (Milner-Brown and Stein, 1975). These investigators state that for the first dorsal interosseous muscle the greatest contribution of motor unit recruitment occurs at low force levels while increased firing rate contributes to the MuAP:s (motor unit action potentials) at higher force levels. Frequency analysis of surface EMG during an increasing contraction also shows that recruitment is most prominent at levels below 30% MVC in the biceps muscle (Hagberg and Ericson, 1982). The slope of the regression line for EMG activity versus force expresses the recruitment pattern and firing rate of motor units (Chaffin et al., 1980). Chaffin et al., (1980) designed the experimental model where linear regression slopes for EMG amplitude versus force during 0-40% of maximal voluntary contraction (MVC) and 60-100% MVC were separately analysed. The section 40-60% MVC was omitted in order to make a clear distinction between the slopes for low and high contraction levels. Chaffin et al. (1980) report steeper slopes for the terminal section of the EMG versus force curve for the biceps brachii muscle; such slopes are related to higher MuAP:s from fast-twitch motor units compared to the slow-twitch motor units recruited at lower tension levels. Recruitment and rate coding seem to play various roles in muscles with separate functions and fibre compositions (Kukulka and Clamann, 1981). Desmedt and Godaux (1981) report that there are exceptions from the recruitment of the alpha motor neurones in order of increasing size (Henneman, 1965, 1981).

The relative frequencies of type I (slow-twitch) and type II (fast-twitch) fibres vary for the muscle fibre composition of different masticatory muscles (Eriksson, 1982). The anterior temporal muscle consists of about equal relative frequencies of type I and type II fibres while the masseter muscle has a predominance of type I fibres in all parts except the posterior
superficial portion (Eriksson, 1982). When activated fast-twitch fibres produce higher MuAP:s than slow-twitch fibres (Chaffin et al., 1980). Following the model of separate analyses of low and high force levels by Chaffin et al. (1980) a difference in recruitment of muscles with different fibre-type composition could be reflected in the steepness of the EMG versus bite force regression curve. The EMG versus bite force curves of the masseter muscles in the present investigation showed intra-individually steeper slopes for high force levels (60-100% MVC) than for low force levels (0-40% MVC) for both referents and patients. The curves of the anterior temporal muscle, however, did not show steeper slopes for the high force levels than for the low force levels. The explanation offered lies in the influence of a fibre-type composition on recruitment pattern. Steeper slopes at low force levels for the anterior temporal muscle could be appropriate if more fast-twitch fibres (high amplitude MuAP:s) as compared to the masseter muscle were recruited at low force levels in the former muscle.

During the recordings of EMG signals from the masseter muscle with surface electrodes the risk of obtaining crosstalk from signals from the medial pterygoid muscle was considered as minimal. Otherwise signals from the medial pterygoid muscle could erroneously have been interpreted as masseter activity and consequently also have influenced the EMG versus bite force curves. Crosstalk signals that have propagated from the biological volume conductor are mainly composed of low frequencies (Zipp, 1982; De Luca, 1985). The aforementioned investigators explain that the high frequencies are cut-off due to the lowpass filtering effects of the tissue. Zipp (1982) also concludes that the bipolar configuration of the surface electrodes exhibit a highpass filter whose cut-off frequency is determined by the inter-electrode distance.

The reason for the same intra-individual relationship between low and high force levels found for the EMG versus bite force
curves of the referents' healthy masseter muscles and the patients' painful masseter muscles respectively could be a similar recruitment pattern. This could also be true concerning the anterior temporal muscles of the referents and the patients.

However, compared inter-individually the EMG versus force curves of the anterior temporal muscles for the patients showed less steep slopes as regards both high and low force levels than the curves of the referents' muscles did. The reason was unclear but the close and complicated interplay between the masticatory muscles could have been changed and thus have affected the slopes (II). Less steep slopes of EMG versus bite force for the patients were unlikely to be an expression of signs of muscular fatigue. Fatigue on the contrary is seen as an increased steepness of the surface EMG versus force curve (Edwards and Lippold, 1956; Vredenbregt and Rau, 1973).

Patients have increased postural activity of mandibular elevators compared to controls (Lous, Sheikholeslam and Möller, 1970; Möller, 1976). No comparison of postural activity between referents and patients was made in the present investigation. The reason was that the EMG recordings for the patients and referents took place in different rooms although the equipment used was the same. However, differences in surrounding electric fields and the placement of the equipment affected the level of base line noise of the EMG signals. As the base line noise will be added to the EMG recordings of postural activity it would be incorrect to compare postural activity between referents and patients. The normalization of EMG activity justified comparisons of EMG versus bite force and APDF analyses between referents and patients.

The sign of interplay between the descending part of the trapezius muscle and the mandibular elevator muscles was evident in the whole group of patients studied. However, it was not possible to quantify the increased activity of the
trapezius muscle since no reference contraction of force concerning the shoulder was used.

Muscular fatigue
It was possible that local muscular fatigue did develop to some extent during the high level of the gradually increased contraction in the EMG-force studies of the present investigation. However, no subjects reported feelings of fatigue. Psychological or central muscular fatigue is defined as a subjective feeling of weakness and discomfort in a skeletal muscle and may appear on the basis of peripheral muscular fatigue (Christensen, 1981). Signs of peripheral muscular fatigue during a sustained, constant force, isometric contraction are that the EMG amplitude increases and the myoelectric power spectrum shifts towards lower frequencies (for review De Luca, 1985). De Luca (1985) discusses that the changes can be attributed to one or more of the factors of decreased conduction velocity in the depolarization wave along the muscle fibres, recruitment of new fibres and synchronization of motor unit firings.

Changes in the power spectrum of the masseter muscle have been studied (Naeije and Zorn, 1981; Palla and Ash Jr, 1981; Lindström and Hellsing, 1983; Naeije, 1984). Lindström and Hellsing (1983) report a decrease of the normalized center frequency (mean power frequency) of the EMG recordings from the masseter muscle during 10 minutes of constant force (30-70 N). Fatigue of masticatory muscles is also observed in terms of an increase in myoelectrical activity and a decrease in myomechanical activity (Christensen, 1984). Analyses of cumulative electromyography in human masseter muscles during 10 s and 20 s of maximum voluntary tooth clenching does not show signs of fatigue. However, 30 s and 40 s of maximum voluntary isometric contractions result in subjective masseter fatigue and changes in myoelectrical activity (Christensen, 1984). In the present investigation the muscular contraction was gradually increased
and maximal bite force and the corresponding EMG amplitudes were only present for a couple of seconds.

An attempt was made to analyse the MPF (mean power frequency) of the EMG activity for six referents. The MPF was plotted against the bite force. Intervals of 5% from 0-100% MVC were used. There was a slight decrease of MPF for high bite force levels for both the masseter muscle and the anterior temporal muscle. However, the decrease in MPF was similar for both muscles. The results can not be interpreted as fatigue without further analyses.

The impression was also that the mean slope (B= 3.92) for the first section of low amplitude EMG activity versus low bite force was steeper for the regression curve of the anterior temporal muscle compared with the first section of the curve of the masseter muscle (B= 1.31). During this period fatigue was unlikely to have developed.

Mechanisms of intramuscular injection solutions
Lidocaine is known to act directly on the excitable cell membrane decreasing its permeability to sodium and therefore also reducing membrane excitability (Guyton, 1981). The pain relief from local anaesthetics outlasts by hours, and sometimes days and weeks, the transient pharmacological action (Bonica, 1984). The muscular mechanism behind this effect is not fully understood. A blockade may interrupt an afferent abnormal reflex mechanism (Bonica, 1984). Melzack (1971) studied phantom limb pain and its implications for treatment of pathologic pain. He suggests that the anaesthetic block of sensory input for several hours stops the self-sustaining activity of neuron loops of the spinal cord (neural pool) that is responsible for some chronic pain. Stimulation after the anesthesia wears off will again trigger sustained activity. However, more time will be needed before stimulation is spread to a sufficiently large number of neurons within the pool. Therefore there will be pain relief (Melzack, 1971). Other mechanisms suggested are that
lidocaine increases microcirculation and specifically inter­rupts feedback mechanisms between a trigger point and the central nervous system (Travell and Simons, 1984).

Normal saline was used for comparison with lidocaine regarding the effects of intramuscular injections on masseter muscles (II,III). No reports describing the pharmacological effects of normal saline per se have been found. Hyper- or hypotonic saline solutions can elicit pain (Wolff, 1977). However, relief of pain can follow after local injections of hypertonic saline solution. This is reported for phantom limb pain (Feinstein, Luce and Langton, 1954). Melzack (1971) suggests that, in contrast to anaesthetics, hypertonic saline solution opens the spinal gate and might initially elicit severe pain. Because the input projects to central biasing mechanisms the level of inhibition will be raised. The spinal gate will then be closed to subsequent inputs (Melzack, 1971). The injection of normal saline in painful masseter muscles did not evoke any pain response in the patients.

Other mechanisms can be due to effects of the injection needle and the amount of solution injected. The injection needle itself can mechanically disrupt abnormally functioning contractile elements or nerve endings (Travell and Simons, 1984). These investigators also suggest a dilating or "washing out" of nerve-sensitizing substances. The use of a relatively large amount of injection solution may produce a separation of pathologically contracted muscular tissue (Carlsson, 1979).

An evaluation of intramuscular injections by EMG versus bite force (II)
The stabilizing effects of lidocaine on excitable cell membranes (Guyton, 1981) lead to the suggestion that the motor units of the masseter muscle have lower MuAP:s after an injection of lidocaine. This could be reflected in an intra-individually less steep EMG versus bite force curve after injection. Less steep curves were found for the low force
(contraction) levels concerning the masseter muscles after lidocaine injections. This was not found after saline injections. Both the injection needle and the amount of solution injected were the same in the lidocaine and saline groups. The difference found between lidocaine and saline could be regarded as a difference between the solutions injected. The results would suggest a pharmacological action of lidocaine that could be observed by EMG versus bite force analyses. No earlier reports were found where injection solutions had been studied by using the EMG versus force relationship.

The high force level of the EMG versus bite force curve for the masseter muscle did not show any significant changes after the lidocaine injection. The reason for this is not known. One possible explanation, although it has not been investigated, could be that the stabilizing effects of lidocaine were different for slow-twitch fibres and fast-twitch fibres.

Assessments of discomfort and values for maximal bite force (N) before and after intramuscular injections (III)

All the patients studied had a chronic type of muscular pain but made fairly low assessments of discomfort on Borg's new rating scale (III). The effects of the intramuscular injections on muscular discomfort would probably have been greater if patients with acute muscular pain had been studied.

Stiffness in the masseter muscle during day 1 after injection was reported by some patients. The lack of a decrease in the assessments of muscular discomfort on this day could have been connected with this stiffness. There was only a slight advantage found for lidocaine concerning the assessments of muscular discomfort between the patients who received injections of lidocaine and saline respectively. This result can be related to a report by Tfelt-Hansen et al. (1981) where the pain-relieving effect of saline injected into painful regions of the head and neck was equivalent to that of lidocaine in
migraine patients. However, no reports have been found that deal specifically with injections in painful masseter muscles. The intra-individual inability to increase the maximal bite force value in the lidocaine group 10 minutes after injection indicated a possibly advantageous pharmacological effect of this solution. The administration of the injection solutions was double blind, implying that the placebo effect was the same for all patients. Higher maximal bite force values than those measured could probably be produced by the patients before injections. Since all patients assessed a significant reduction of their muscular discomfort 10 minutes after injection the placebo effect of the injection could have helped to increase the bite force for the patients receiving saline. However, it was not possible for the patients who received lidocaine to significantly increase bite force after the injection and it might have been caused by a neuro-muscular blocking.

Maximal bite force values (N) compared between referents and patients (III)
Referents are reported to have higher bite force values than patients (Molin, 1972; Helkimo et al., 1975). Stronger maximal EMG activity in the mandibular elevators are also reported for referents than for patients (Sheikholeslam, Möller and Lous, 1980, 1982). There were no significant differences in maximal bite force values between referents and patients in this investigation. No patients with affections of the temporomandibular joints (TMJ:s) participated. Other investigators have included affections of TMJ:s in their patient materials (Molin, 1972; Helkimo et al., 1975; Sheikholeslam et al., 1980, 1982). The pain in the temporomandibular joints could have had a more decreasing effect on bite force than muscular pain alone. The gradually increased muscular contraction performed up to maximal bite force in 10-15 s also differed from the intermittent bites at specific force levels, including maximal force, used by the investigators previously referred to. The sample of 10 referents could also have been too small to detect statistically significant differences in maximal bite force values.
The influence of the factors "chronic muscular pain" and "clenching and/or grinding habits" on the maximal bite force values of the patients participating in this investigation were hard to evaluate. These factors could also have been responsible for the lack of difference in maximal bite force values between referents and patients. The patients could have adapted to pain which patients with acute muscular pain were less likely to have done. However, there is no clear differentiation between acute and chronic pain in the reports on maximal bite force previously referred to (Molin, 1972; Helkimo et al., 1975). Helkimo and Ingervall (1978) studied men, who were grinding or clenching their teeth. They had higher bite force values than men without these parafunctions when measurements were taken at the incisors but not when taken at the molars. These investigators suggest that muscular training could have been performed in an eccentric mandibular position which was reflected in increased force only at the incisors.

For patients with manifest mandibular pain dysfunction syndrome there are no significant differences in bite force values registered from the affected side compared to the nonaffected side (Molin, 1972; Helkimo et al., 1975). There were differences between the patients in the present investigation concerning tenderness in masticatory muscles other than the masseter muscle. A suggestion based on the results reported by Molin (1972) and Helkimo et al. (1975) is that variation in muscular tenderness of the total masticatory system did not seriously affect the bite force measurements.

The maximal bite force values in the present investigation were within the range of values presented by other investigators (See Appendix I).
Amplitude probability distribution analysis as a method for studying chewing mechanisms (IV, V)

Ahlgren (1966) reports that the mean maximal EMG amplitudes for the temporal muscles and masseter muscles are higher for peanut-chewing than for gum-chewing. Increased EMG amplitudes during non-fatiguing contractions correspond to increased exerted force (Bigland and Lippold, 1954). The significant increase in relative masticatory force within both the masseter muscle and the anterior temporal muscle during chewing an almond compared to gum-chewing for the referents (IV) was therefore in accordance with the results reported by Ahlgren (1966) and indicated that amplitude probability distribution analysis could be used for chewing analysis. Higher maximal mean voltage of EMG amplitudes of the elevator muscles during the chewing of peanuts than during the chewing of apple and bread are also reported (Haraldson and Ingervall, 1979).

Stronger intermediary mean voltage EMG activity and longer relative contraction times for patients than for referents are reported during unilateral chewing (Möller et al., 1984). These results reported by Möller et al. (1984) are in line with results from the amplitude probability distribution analysis when the chewing patterns of patients and referents were compared (V). This finding also confirms the possibility of using amplitude probability distribution analysis for studying chewing mechanisms.

There is a correlation between experimental hyperactivity of the masseter muscle and muscular pain (Christensen, 1971). Masticatory muscles unfavourably loaded during chewing as regards intensity and duration may contribute negatively to the total muscular overload which is present during hyperactivity of masticatory muscles (Möller et al., 1984). One factor that causes a different pattern of chewing among referents compared to patients with disturbances of the masticatory system is occlusal instability (Möller et al., 1984). Above this the author of the present investigation suggest that the chewing pattern
could also be changed due to protective mechanisms of painful masticatory muscles. In trying to avoid muscular damage by overloading painful muscles while still performing effective chewing, greater relative masticatory forces could be used during lower muscular load levels. The longer bursts of contraction and a longer time for chewing an almond that was found for the patients could be other mechanisms utilised for muscular protection. Amplitude probability distribution analysis could be complementary to mean voltage EMG analyses in giving a detailed information on the distributions of different muscular load levels during chewing.

The normalization of EMG activity versus bite force made a comparison possible between the relative masticatory force for the masseter muscle and the anterior temporal muscle. The normalization implied that different values for maximal EMG activity (µV) for the elevator muscles investigated corresponded to the same 100% RVC. There would be no differences between the masticatory force values for the different muscles due to the normalization if the muscular performance during the isometric reference contraction and the concentric contraction during chewing were equal. However, there could be a difference in force between the muscles if the muscular coordination during the dynamic contraction analysed was very different from that during the reference contraction. The peak values in Newton differed between the masseter muscle and the anterior temporal muscle. The difference was small and could be the result of errors due to the transformation from µV to % RVC. The normalization could explain the non-significance found for both the referents and the patients when relative masticatory forces were tested between the masseter muscles and the anterior temporal muscles during chewing an almond and gum-chewing.
Biases in estimation of masticatory forces
The actual force values of the transformation of EMG activity to relative masticatory force should be regarded as only estimates of the true force. The concentric muscular contraction used during chewing produces higher EMG amplitudes than the isometric contraction used for the reference contraction does (Komi, 1973). Another difference is that during the isometric reference contraction the length of the active muscle fibres remains constant while during the concentric contractions of chewing the muscle fibres of the mandibular elevators become shorter and positive work is performed (Christensen, 1981).
During the chewing all EMG activity recorded from the two mandibular elevators investigated was transformed into relative masticatory force. Parts of the EMG activity were probably related to motor units that were active in functions such as horizontal adjustments of the mandible during the chewing. There could be an overestimation of the relative masticatory force due to the factors described above.

Eriksson, Stålberg and Antoni (1983) describe how EMG activity of single motor units of the masticatory muscles may have different activity patterns for different types of activation. This finding points to the necessity for careful interpretation of results concerning the muscular mechanisms of a complicated masticatory system.

In order to measure EMG activity versus bite force a bite-fork had to be inserted between the molars during the reference voluntary contraction. As previously described this relationship was used during chewing analyses to transform EMG activity (μV) into masticatory force (% RVC) by regression in reverse. The muscle length is affected by the insertion of a bite-fork (Manns, Miralles and Palazzi, 1979). These investigators report that 15 to 20 mm of jaw opening, measured from the distal borders of the canines, during isometric contractions is the optimal masseter muscle length. At this length the highest bite force is produced and the integrated EMG activity is at its
lowest (Manns, Miralles and Palazzi, 1979). In the present investigation there was a bite opening of 5.4 mm between the first molars and the relative masticatory forces could also be overestimated because of this factor.

During the reference contraction the bite force was registered only between two antagonising teeth. The bite force is inhibited by periodontal and/or intradental receptors as described by Van Steenberghe and de Vries (1978). The bite opening leads to an increased activity of the antagonising suprahyoidal muscles (Pruim, Bosch and de Jongh, 1978). The muscular strength could then be inhibited because of the bite opening. These factors could explain the higher force values calculated for the peak muscular load during chewing (without bite-fork) compared to the maximal forces produced during the reference contractions (biting on a bite-fork). The relative masticatory forces might be underestimated because of these factors. Furthermore an extrapolation of values above 100% RVC of the EMG versus bite force curve is hazardous from a statistical point of view. The biases in estimation of relative masticatory forces are also present for transformed values in Newton.

For 10 s of chewing the time that the signal was higher than the peak level (P= 0.99) would be 100 ms. Using a probability level of 0.99 as the value of the peak masticatory force therefore implied that if a very short and high contraction was performed it could be missed. However, it is doubtful if EMG activity shorter than 100 ms would reflect any mechanical muscular activity. The risk of losing information from the EMG signals would be greater if the probability level of 0.9 was used for the peak value. For 10 s of chewing this time would be 1 s.
A comparison with other methods for registrations of masticatory forces

Masticatory (chewing) forces have commonly been measured with built-in force transducers in the teeth (Brudevold, 1951; De Boever et al., 1978; Laurell, 1985) or by an indirect estimation of the force used during chewing reproduced on a bite-fork (Helkimo and Ingervall, 1978; Haraldson, Carlsson and Ingervall, 1979). Masticatory forces reported for different methods, dentitions and for various types of food are presented in Appendix II. The greater masticatory forces calculated in the present investigation as compared to most of the previous investigations (Appendix II) might be a result of the different types of dentitions studied. Laurell (1985) measured masticatory force in patients who were treated for periodontal diseases. He concludes that dentitions restored with cross-arch bridges have a tendency to lead to less chewing and bite force, related to the reduced amount of periodontal support. Complete denture wearers have maximal bite force values of approximately one-third to one-quarter of those for persons with complete dentitions (Carlsson, 1974). In accordance with decreased bite force masticatory forces for denture wearers are also low (Brudevold, 1951; Yurkstas and Curby, 1953). The subjects in the present investigation had complete dentitions and no signs of periodontal disease. Gibbs et al. (1981a, b) studied normal complete dentitions with a sound transmission system. The masticatory force values in Newton of the present investigation were in accordance with values presented by Gibbs et al. (1981b). Masticatory forces are reported as significantly greater for hard food (peanut) than for soft food (cheese) (Gibbs et al., 1981b).
Appendix I. Maximal bite force values in Newton (N). Males = m, females = f, MPD = muscular pain dysfunction syndrome.

<table>
<thead>
<tr>
<th>Investigators</th>
<th>Number of subjects</th>
<th>Age (range)</th>
<th>Dentition (placement of force)</th>
<th>Equipment</th>
<th>Maximal bite force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linderholm &amp; Wennström; 1970</td>
<td>57 m</td>
<td>18-31</td>
<td>natural teeth (molars)</td>
<td>strain gauge dynamometer</td>
<td>490</td>
</tr>
<tr>
<td></td>
<td>14 f</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molin; 1972</td>
<td>31 f MPD</td>
<td>16-45</td>
<td>natural teeth (premolars)</td>
<td>strain gauge dynamometer</td>
<td>196</td>
</tr>
<tr>
<td></td>
<td>30 f healthy</td>
<td>18-28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wennström, Marklund &amp; Eriksson; 1972</td>
<td>2 m</td>
<td>21-60</td>
<td>full upper denture partial lower (molars)</td>
<td>strain gauge dynamometer</td>
<td>73</td>
</tr>
<tr>
<td>Ringqvist; 1973</td>
<td>29 f healthy</td>
<td>19-23</td>
<td>natural teeth (molars)</td>
<td>strain gauge dynamometer</td>
<td>477</td>
</tr>
<tr>
<td>Heikimo, Carlsson &amp; Heikimo; 1977</td>
<td>57 m (Skolt, 68 f Lapps)</td>
<td>15-65</td>
<td>natural teeth (molars) (incisors)</td>
<td>bite fork - strain gauge</td>
<td>m 382 (molars) 176 (incisors) f 216 (molars) 108 (incisors)</td>
</tr>
<tr>
<td>Fløystrand, Kleven &amp; Óiilo; 1982</td>
<td>8 m</td>
<td>20-25</td>
<td>natural teeth (molars)</td>
<td>miniature bite force recorder</td>
<td>500</td>
</tr>
<tr>
<td>Widmalm &amp; Ericsson; 1982</td>
<td>5 healthy</td>
<td>24-27</td>
<td>natural teeth (premolars)</td>
<td>bite fork - strain gauge</td>
<td>range 181-608 (centric load) range 131-500 (eccentric load)</td>
</tr>
<tr>
<td>Hagberg, Agerberg &amp; Hagberg; 1985/86</td>
<td>10 f healthy</td>
<td>20-26</td>
<td>natural teeth (molars)</td>
<td>miniature bite force recorder</td>
<td>396</td>
</tr>
<tr>
<td></td>
<td>30 f MPD</td>
<td>18-43</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Footnote: See Appendix II where maximal bite force values are presented in connection with peak masticatory forces.
Appendix II. Masticatory forces in Newton (N) reported for different methods and types of food.

<table>
<thead>
<tr>
<th>Investigators</th>
<th>Number of subjects</th>
<th>Methods</th>
<th>Type of food</th>
<th>Masticatory force in N (no chewing)</th>
<th>Maximal bite force in N (peak)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brudevold; 1951</td>
<td>1</td>
<td>Strain gauge under artificial teeth - complete dentures</td>
<td>raw celery</td>
<td>85 (peak)</td>
<td>90 (peak) gnathodynamometer</td>
</tr>
<tr>
<td>Yurkstas &amp; Curby; 1953</td>
<td>4</td>
<td>Strain gauge incorporated into a artificial tooth - complete dentures</td>
<td>rolls breads with crust</td>
<td>120 (peak)</td>
<td>120 (peak) total dentures</td>
</tr>
<tr>
<td>Anderson; 1956</td>
<td>2</td>
<td>Strain gauge in a molar natural teeth</td>
<td>biscuit</td>
<td>148 (peak)</td>
<td></td>
</tr>
<tr>
<td>Atkinson &amp; Shepard; 1967</td>
<td>3</td>
<td>Miniature strain gauge - complete maxillary denture opposing natural teeth</td>
<td>selected foods</td>
<td>80 (peak)</td>
<td>130 (peak) occluding on hard rubber</td>
</tr>
<tr>
<td>De Boever et al.; 1978</td>
<td>3</td>
<td>Telemetry transmitter in a posterior pontic - natural teeth</td>
<td>average of many foods</td>
<td>75 (peak)</td>
<td></td>
</tr>
<tr>
<td>Haraldson et al.; 1979</td>
<td>13</td>
<td>Indirect technique - biting as when chewing on a bite force sensor</td>
<td>-</td>
<td>32-52 (range)</td>
<td>144 (median)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- natural pre-molars, canines and incisors</td>
<td></td>
<td>33-52 (median)</td>
<td>169 (median)</td>
</tr>
<tr>
<td>Heikimo &amp; Ingervall; 1978</td>
<td>100</td>
<td>Indirect technique biting as when chewing on a bite force sensor</td>
<td>-</td>
<td>246 (mean)</td>
<td>471 (mean)</td>
</tr>
<tr>
<td>Gibbs et al.; 1981</td>
<td>20</td>
<td>Sound transmission system - natural teeth</td>
<td>peanuts</td>
<td>356 (average)</td>
<td>740 (average) intraoral strain gauge gnathodynamometer</td>
</tr>
<tr>
<td>Laurell; 1985</td>
<td>12</td>
<td>Strain gauge transducers in maxillary pontics - fixed bridges cross arch bilateral end abutments after periodontal treatment</td>
<td>peanuts</td>
<td>109 (mean) total force</td>
<td>320 (mean total force)</td>
</tr>
<tr>
<td>Hagberg; 1986</td>
<td>9 (referents)</td>
<td>Amplitude probability distribution of EMG-activity and force by regression in reverse of reference contraction</td>
<td>almond masseter/temporal</td>
<td>364/382 (median)</td>
<td>379 (median)</td>
</tr>
<tr>
<td></td>
<td>23 (patients)</td>
<td></td>
<td></td>
<td>373/374 (median) of peak loading</td>
<td>315 (median)</td>
</tr>
</tbody>
</table>
CONCLUSIONS AND SUMMARY

- When analysed intra-individually the regression curve for EMG activity from the masseter muscle versus the bite force exerted during a gradually increased isometric contraction showed steeper slopes at high force levels than at low force levels. There was no such finding for the regression curve for EMG activity from the anterior temporal muscle versus the bite force. These variations (in slopes of the EMG versus bite force regression curves) for the two elevator muscles could be due to a different recruitment pattern.

- There was no difference between patients and referents as regards the intra-individual relationship between the slopes of EMG activity from the masseter muscle versus the bite force for both low and high force levels when the gradually increased isometric contraction was studied in both groups. This was also true for the EMG activity recorded from the anterior temporal muscle versus the bite force.

- Signs of interplay between the descending part of the trapezius muscle and the two mandibular elevator muscles investigated were found during the gradually increased isometric contraction. This was most obvious for patients with painful masseter muscles.

- Ten minutes after an intramuscular injection of lidocaine into the patient's painful masseter muscle the regression curve for EMG activity from the masseter muscle versus the bite force during a gradually increased isometric contraction was significantly less steep than before at the low force level. This was not found after an injection of saline. The postural activity of the masseter muscle was reduced 10 minutes after the intramuscular injection of lidocaine. There was no significant change in postural activity after the saline injection. The analyses were made intra-individually.
Both lidocaine and saline injections administered double blind into the patients' painful masseter muscles had positive effects on the assessments of muscular discomfort 10 minutes, as well as 7 days after the injection according to intra-individual before/after injection comparison. Neither lidocaine nor saline produced a significant improvement on day 1 after injection. However, on day 3 after the injection the patients who had received lidocaine experienced a reduction of their muscular discomfort which was not found in the patients who received saline. This was true for both intra-individual and inter-individual analyses.

The patients did not increase the bite force 10 minutes after the lidocaine injection into the painful masseter muscle. When the masseter muscle was injected with saline the bite force values for the patients were significantly increased. There were no significant differences in maximal bite force values when patients with painful masseter muscles and referents were compared.

The results concerning the differences found between the lidocaine and saline injections suggest that the former has specific pharmacological effects.

Amplitude probability distribution analyses produced results that showed a higher masticatory force was used during chewing an almond than during gum-chewing. Patients with painful masseter muscles and referents also had different chewing patterns in terms of relative masticatory forces for different probability levels. This indicates that amplitude probability distribution functions could be useful in chewing analyses when estimations of relative masticatory force and a measure of the distribution of different levels of muscular loading are desired.
The chewing of an almond produced the clearest difference in the chewing pattern found between patients with painful masseter muscles and referents. As regards the masseter muscle the patients used higher relative masticatory forces. This was true for all muscular load levels below the peak (maximal) load. The peak of the muscular load was similar for both patients and referents. In addition there was an increased intermediary activity between chewing strokes for the patients. The time taken to chew the almond until swallowing was longer for the patients than for the referents.
Sammanfattning: Elektromyografisk (EMG) aktivitet och bitkraft studerades vid en gradvis ökad isometrisk muskelkontraktion upp till maximal kraft. Unga kvinnor utan tecken på bettfysiologiska besvär (referenter) samt kvinnor med smärtsamma och palpationsömma massetermuskler (patienter) deltog i studierna. EMG-signalerna registrerades med hud elektroder från m. masseter, m. temporalis anterior och m. trapezius pars descendens. Bitkraften mättes med bitkraftsmätare och bitgaffeln placerades mellan första ök/uk molaren på samma sida som EMG-registerning. EMG/kraft relationen analyserades separat för låg och hög kontraktionsnivå med hjälp av linjär regressionsanalys.

Intramuskulära injektioner av 2 ml lokalbedövning (Xylocain (R) 10 mg/ml) jämfördes dubbel blint med samma mängd koksaltinjektion i de smärtsamma massetermusklerna. EMG/kraft relationen före och efter injektionen utvärderades. Variablerna maximal bitkraft och subjektiv skattning av muskulära obehag på en "smärtskala" jämfördes likaså före och efter injektion. Amplitudfördelningsanalys av EMG-amplituden registrerad vid enkelsidig tuggning utfördes för att jämföra tuggningsmönster hos patienter och referenter.

EMG/kraft sambandet för m. masseter uppvisade vid intraindividuell analys brantare lutning av regressionslinjen vid hög muskelkontraktionsnivå jämfört med låg muskelkontraktionsnivå. Denna skillnad kunde ej ses för m. temporalis anterior. En förklaring kan vara att rekryteringsmönstret av de motoriska enheterna i de två studerade munslutarna är olika. Samma intraindividuella förhållande mellan låga och höga kontraktionsnivåer registerades för referenter och patienter. Under den gradvis ökade isometriska kontraktionen av munslutarna skedde en samtidig ökning av EMG-aktiviteten i m. trapezius pars descendens.

Efter intramuskulär injektion av Xylocain (R) blev regressionslinjens lutning för EMG/kraft sambandet mindre brant vid låg kontraktionsnivå. En motsvarande förändring kunde ej ses efter koksaltinjektionen. En vecka senare upplevde både de patienter som behandlats med Xylocain (R) och de som fått koksaltinjektion en subjektiv minskning av sina muskulära obehag. Den maximala bitkraften var likartad mellan referenter och patienter. Tio minuter efter koksaltinjektionen ökade patienterna intraindividuellt analyserat bitkraften vilket ej skedde efter Xylocain (R) injektionen. Amplitudfördelningsanalys av EMG-amplituden vid enkelsidig tuggning visade på olika tuggningsmönster hos referenter och patienter. Särskilt för m. masseter vid mandeltuggning var tuggkrafterna högre för patienterna förutom vid toppbelastning (maximal tuggkraft). En grov skattning av maximal tuggkraft var för m. masseter vid mandeltuggning 364 Newton (N) (referenter); 373 N (patienter) och vid tuggummituggning 239 N (referenter); 238 N (patienter). Likartade maximala tuggkraftsvärden beräknades för m. temporalis anterior.
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REFERENCES


De Luca C J. Myoelectrical manifestations of localized muscular fatigue in humans. CRC Critical Reviews in Biomedical Engineering 1985. 11. 251-279.


Lawrence J H & De Luca C J. Myoelectric signal versus force relationship in different human muscles. J Appl Physiol; Respirat Environ Exercise Physiol 1983. 54. 1653-1659.


Mohamed S E, Christensen L V & Harrison J D. Tooth contact patterns and contractile activity of the elevator jaw muscles during mastication of two different types of food. J Oral Rehabil 1983. 10. 87-95.


Möller E. Evidence that the rest position is subject to servo-control. In Mastication, eds D J Andersson and B Matthews, J Wright and Sons Limited, Bristol, 1976. pp 72-80.


