Experimental Grinding in Healthy Subjects: A Model for Postexercise Jaw Muscle Soreness?

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Aims: *Pain in some bruxers has been suggested to represent a state of postexercise muscle soreness. This study examined the effect of voluntary, controlled grinding movements on the development of pain and soreness in the masticatory system.* **Methods:** *Twelve healthy men (21 to 42 years old) without signs or symptoms of temporomandibular disorders (TMD) participated. Nine trials of 5 minutes of repeated grinding from the intercuspal position to the right canine-canine position (0.5 Hz) were performed on the first day. During the lateral excursions, the electromyographic (EMG) activity of the right masseter muscle was kept above 50% of maximal voluntary occlusal force (MVOF) with the use of visual feedback. The subjects rated pain intensity, unpleasantness, and soreness on 100-mm visual analogue scales (VAS); other pain measures, including the McGill Pain Questionnaire, were also used. Before and after the exercise trials, the MVOF was determined, and pain detection thresholds (PDT) to pressure stimuli were measured at 9 different sites on the masseter muscles. The subjects returned to the laboratory the 3 following days, where VAS, PDT, and MVOF were measured.* **Results:** *Immediately following the last grinding trial, there was a significant increase in VAS and MPQ scores of pain intensity, unpleasantness, and soreness, as compared to baseline values (analysis of variance, $P < 0.001$). There was still a significant effect from grinding on the VAS score of muscle soreness on the following days, with a peak the first day after the exercise (Tukey test, $P < 0.023$). Pain was frequently (in 7 of 12 subjects) reported in or around the temporomandibular joint. There was a significant effect from grinding on PDT at both masseter muscles (analysis of variance, $P < 0.043$), with significantly lower PDT the first day after the grinding exercise (Tukey test, $P < 0.046$). There were no effects from grinding on MVOF.* **Conclusion:** *These findings suggest that significant but low levels of postexercise muscle soreness can be elicited by standardized grinding movements in the masticatory system of healthy subjects.*

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Key words: masticatory muscles, postexercise muscle soreness, grinding, bruxism, pressure pain thresholds, bite force, electromyography

It is now more widely accepted that the original concept of the vicious cycle, namely that muscle hyperactivity and pain are mutually linked, lacks strong scientific evidence.[1,2] Overloading or overuse of muscles may, however, cause pain, a common experience that has been verified in a large number of studies on postexercise muscle soreness (PEMS) in limb muscles.[3–5] Eccentric contractions, ie, forced lengthening of contracting muscles, are especially effective in producing PEMS.[6] Eccentric contractions of the masticatory muscles in mice have also been shown to elevate the levels of plasma creatine kinase, an indicator of PEMS.[7] Recently, it was hypothesized that nocturnal orofacial motor activity might cause PEMS in the masticatory muscles.[8] A review of the literature seems to support this claim, because many studies with different types of sustained concentric or eccentric contractions have reported significant levels of pain and soreness as an immediate consequence of the exercise. However, it might be more important to examine the subjects in the days following the exercise, which is the typical period for the development of PEMS in limb muscles. Clark et al[9] could not detect any significant effects of a protrusive task in the postexercise period. Svensson and Arendt-Nielsen[10] showed that 5 days of repeated concentric contraction at 50% of the maximal voluntary occlusal force (MVOF) caused a progressive reduction in pain and tenderness scores. This finding contrasts with the prediction from the vicious cycle. Glaros et al[11] reported that symptoms after repeated trials with sustained low-intensity contractions resolved quickly. The study by Christensen[12] is often used as evidence that experimental grinding will cause pain for many days. Bowley and Gale[13] reproduced Christensen's short-term findings but unfortunately did not follow their subjects the days after the exercise. Thus, there is still no appropriate data to indicate the level and duration of pain and soreness produced by experimental daytime grinding in healthy subjects.

The present study was designed to determine whether strong grinding activity in healthy and awake subjects without prior signs or symptoms of temporomandibular disorders (TMD) leads to pain, unpleasantness, or soreness in the post-grinding period.

Materials and Methods

Subjects

Twelve men (mean age 26.0 ± 2.0 years, range 28 to 42 years) volunteered for the study. All subjects were in good health and none had a history or any complaints of TMD. Manual palpation of the masseter muscles and temporalis muscles was performed according to previously published guidelines[14] to verify the absence of muscle disorders. Subjects who had clinical evidence (severe tooth wear or facets) or report of bruxism (self-awareness of bruxism or sleep partner's report of nocturnal grinding noises) were excluded. The subjects were told that the purpose of the study was to examine the effects of repeated grinding movements. Informed consent was obtained prior to beginning the study; the study had been approved by the local ethics committee.

Study Design

On the first experimental day, the subjects performed 9 repeated trials, with standardized tooth grinding for 5 minutes and a 1-minute rest between each trial. Jaw movements and electromyographic (EMG) activity were controlled continuously during the trials. The development of symptoms before the grinding exercise, after all 9 trials, and during the following 3 days was assessed with the use of a McGill Pain Questionnaire (MPQ), 100-mm visual analogue scales (VAS), and pain detection thresholds (PDT) to pressure stimuli on the masseter and temporalis muscles. In addition, the relationship between different levels of MVOF and EMG amplitude (force/EMG curves) was established. Measurements of MPQ, PDT, MVOF, and VAS were obtained before the first grinding trial and after the last grinding trial. In addition, VAS measurements were obtained after each of the grinding trials. All subjects were followed up for the next 3 days with MPQ, PDT, MVOF, and VAS.

Visual Analogue Scales. Subjects were asked to score their pain intensity, unpleasantness, and soreness on 3 separate 100-mm VAS with their jaw at rest and again immediately after a 1-minute chewing task. The chewing task was used as a simple test to measure a possible accentuation of symptoms produced by a functional movement.[15] No EMG measures were obtained during this chewing task. The left end of the VAS was labeled either "no pain," "no unpleasantness," or "no soreness," and the right end was either "most pain," "most unpleasantness," or "most soreness."

McGill Pain Questionnaire. A Danish version of the MPQ was used to calculate the total pain rating index of the sensory, evaluative, affective, and miscellaneous components of pain.[16,17] Furthermore, the subjects were asked to draw the pain distribution on a figure showing the left and right profile of a face.

Pressure Algometry. An electronic pressure algometer (Somedic AB) was used with a probe diameter of 6 mm and a constant application rate of 30 kPa/sec. The probe was held perpendicular to 9 sites on the masseter muscles and 2 sites on

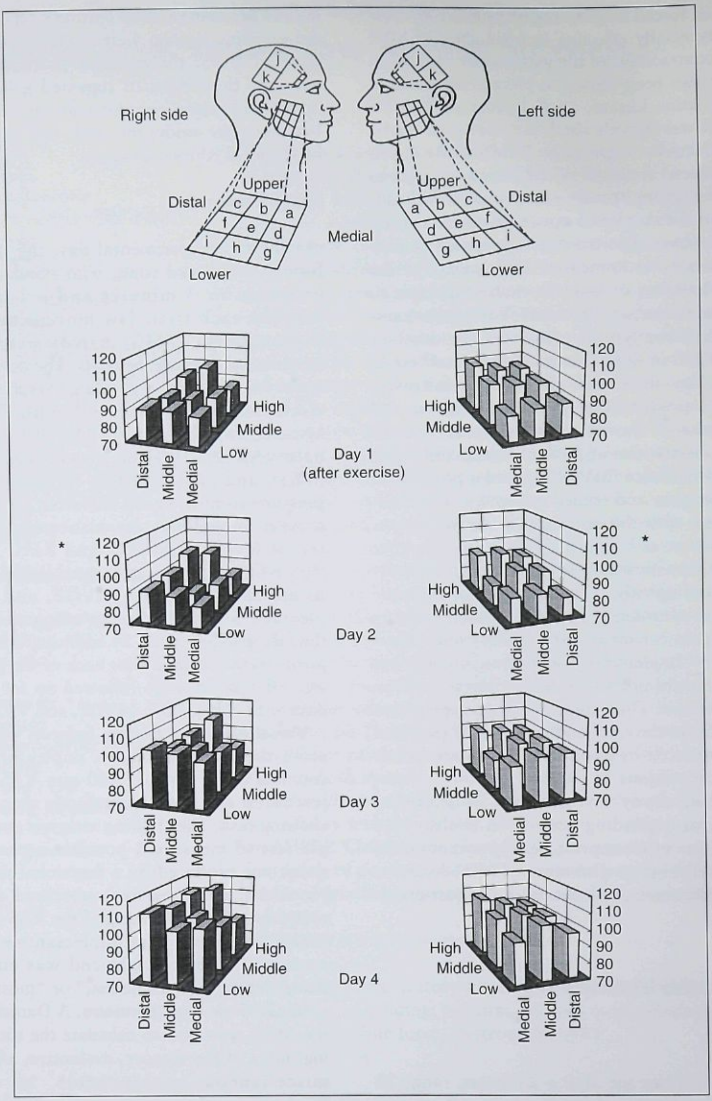

Fig 1 Pain detection thresholds were normalized (as a percentage) to baseline values (day 1). Mean values are shown (n = 12). Pain detection thresholds on the right and left masseter muscles decreased significantly on the first postexercise day (day 2). The PDT were generally lowest at site d. * = significantly different from baseline values (Tukey test, $P < 0.046$).

the temporalis muscles. In accordance with a previous study,[18] the 9 sites on the masseter muscles consisted of 3 sites along the inferior-superior direction (superior, middle, inferior) times 3 sites along the anteroposterior direction (anterior, middle, posterior); 2 sites were defined on the temporalis muscles (upper and lower positions) (Fig 1). The boundaries of the masseter and temporalis muscles were determined by palpation during voluntary contraction. After the anteroposterior and inferior-superior boundaries of the masseter muscle were determined, 4 sites were marked at the corners of the masseter muscle; the other 5 sites were marked at the midpoints of the 4 primary sites. The upper and lower positions on the temporalis muscle were placed according to palpation of the temporalis muscle. A pair (one for each side of the face) of clear pliable plastic templates were indexed to the inferior surface of the earlobes, the lateral angle of the mouth, and the lateral angle of the eyes to reproduce the location of the measurement sites. Subjects were instructed to keep their teeth slightly apart to avoid contraction of the jaw closing muscles during pressure stimulation.[19] The pain detection threshold was defined as the pressure (in kPa) that the subjects first regarded as painful. The subject pushed a small thumb switch that froze the pressure on a digital display when the threshold was reached. Pain detection thresholds were determined in triplicate. The interval between successive pressure stimuli was about 2 minutes. In addition, the PDT were measured on the third finger on the dominant side as an extrasegmental control site.

Electromyographic Activity and Maximal Voluntary Occlusal Force. The skin was cleaned with ethanol, and bipolar disposable surface electrodes (Blue Sensor Type N-10-E, Medicotest) were placed with their long axis transverse to the main direction of the muscle fibers in the central part of the right and left masseter and anterior temporalis muscles. Electrode placement was based on palpation of the muscles during full effort, as previously described by Møller.[20] The interelectrode distance was 10 mm. A saline-soaked grounded electrode was wrapped around the arm. The EMG signals were amplified differentially (5,000 to 20,000 times, Disa 1SC01), filtered (20 to 500 Hz), and sampled (1,000 Hz).

A U-shaped bite force transducer (7 mm high, 1.1 × 1.1 cm area, Aalborg University) was covered with plastic tubes to protect the teeth.[10] The MVOF was measured only on the right side between the first molars, and subjects were instructed to clench their teeth as hard as they

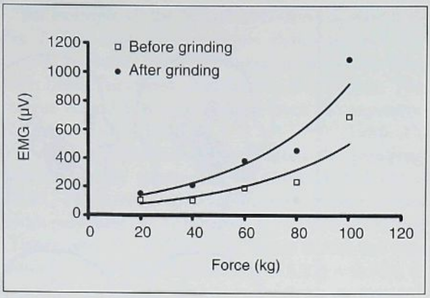

Fig 2 Typical example of a force/EMG curve determined before and after the grinding exercise in a single subject. An exponential relationship fit the force/EMG curve best. The grinding exercise shifted the curve upward.

could for 3 to 4 seconds. Verbal encouragement was given to obtain the maximal effort. The peak value was stored on a display. This was repeated up to 3 times at intervals of 30 to 45 seconds, as previously described.[10] After they recorded MVOF, the subjects were instructed to perform 4 submaximal contractions corresponding to 20, 40, 60, and 80% of MVOF, in random order (target levels). The subjects increased the force up to the specified target level and held the contraction for about 2 to 3 seconds with the use of visual feedback. A computer program automatically determined peak MVOF during the maximal and submaximal contractions and the corresponding root-mean-square (RMS) value of the EMG signals in a 50-millisecond window. The difference between the target levels and the contraction levels actually performed was on average 4.8 ± 2.9%, indicating that the forces produced by the subjects were consistent. The application of a 50-millisecond RMS window served as a type of high-pass filter of the EMG signal and was chosen to limit the impact of the low-frequency content (< 10 Hz) of the EMG signal. The levels of the actual force (kg) and the corresponding EMG amplitude (μV) were then plotted in a force/EMG curve. For each subject, the coefficient of determination (r^2) for a linear, exponential, and power fit was calculated to determine the best description of the force/EMG curve (Fig 2).

Experimental Grinding. The subjects were instructed to move their mandible from the intercuspal position to the right side canine-canine

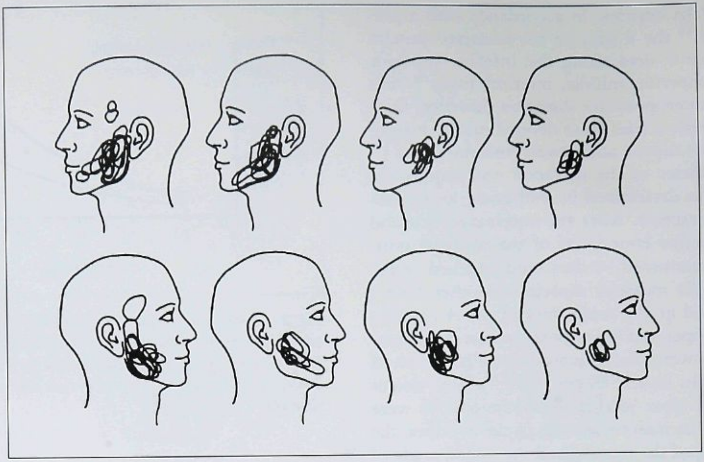

Fig 3 Pain distribution following the grinding exercise (*left to right:* after exercise, day 2, day 3, day 4). Note that 7 of 12 subjects still reported pain localized to the left TMJ on day 2. On day 4, 7 of 12 subjects still had very low levels of pain around the masseter muscles.

position and back to the intercuspal position again, keeping the EMG activity level above 50% of MVOF. To standardize movements, right-side grinding only was performed in this study. The movement was repeated every 2 seconds (0.5 Hz) for 5 minutes (equaling 1 trial). An electronic metronome and visual feedback of the filtered and corrected EMG activity from the right masseter muscle helped the subjects maintain the rhythm and force of grinding.

Statistical Analysis

Parametric statistics (mean ± SEM) and 1- and 2-way analyses of variance (1-ANOVA and 2-ANOVA) with repeated measures were used to describe the data. The factors for the repeated VAS and MPQ measures were either trials (9 levels) or time (days 1 to 4) and chewing task (before-after). The 2 factors for the repeated PDT measures were time (days 1 to 4) and sites (9 sites in the masseter and 2 sites in the temporalis). The factors for the fit of the force/EMG curves were grinding task (before-after) and muscle (4 levels). The levels of significance were adjusted for multiple pairwise comparisons with the Tukey test (SigmaStat, SPSS). Significance was accepted at $P < 0.05$.

Results

Pain Drawings and McGill Pain Questionnaire

Immediately after the 9 trials of grinding activity, 7 of 12 subjects experienced bilateral pain in the masseter muscles, temporomandibular joint (TMJ) regions, and the temporal area; 2 subjects reported unilateral pain in the right masseter muscle only; and 3 subjects had unilateral pain only in the left masseter and temporalis muscles (Fig 3). The day after the grinding exercise (day 2), 7 subjects still reported pain localized around the left TMJ (Fig 3). The following days after the exercise, the number of subjects reporting pain decreased, as did the areas of pain (Fig 3).

The MPQ data were obtained from 11 of the 12 subjects. Analysis of the pain rating index from the MPQ demonstrated that the grinding exercise had a significant effect on the sensory and affective dimensions of pain (1-ANOVA, $F(4,40) = 12.3$, $P < 0.001$; $F(4,40) = 12.9$, $P < 0.001$), with significantly higher ranks immediately after the 9 trials, as compared to baseline and postexercise days (Tukey test, $P < 0.001$). The most frequently chosen words (more than 30%) from the MPQ were "tender," "tense," and "tiring."

Visual Analogue Scale

A progressive increase took place in the VAS scores of pain intensity, unpleasantness, and soreness during the course of the 9 repeated trials of exercise (1-ANOVA, $F(9,99) > 11.4$, $P < 0.001$) (Figs 4a, 4c, and 4e). The VAS scores of pain intensity, unpleasantness, and soreness measured before and after the 1-minute chewing task indicated significant effects from the grinding exercise (2-ANOVA, $F(4,44) > 6.309$, $P < 0.001$) but no significant differences between before and after chewing (2-ANOVA, $F(1,11) < 1.992$, $P > 0.186$) (Figs 4b, 4d, and 4f). All VAS scores were significantly higher immediately after the grinding exercise, as compared to the baseline and postexercise days (Tukey test, $P < 0.014$). Only the VAS scores of soreness were significantly higher on the first postexercise day (day 2) as compared to the baseline values (Tukey test, $P < 0.023$) (Fig 4f).

Pressure Algometry

The PDT on the right and left masseter muscles were significantly influenced by the grinding exercise (2-ANOVA, $F(4,44) > 2.73$, $P < 0.043$) and by recording sites (2-ANOVA, $F(8,88) > 5.12$, $P < 0.001$). The PDT on the right masseter muscle (mean: 188 ± 19 kPa) decreased significantly on the first postexercise day (day 2) as compared to baseline and the third postexercise day (day 4) (Tukey test, $P < 0.046$) (Fig 1). The PDT were generally lower at site d. The PDT on the left masseter muscle (mean: 185 ± 18 kPa) showed a similar pattern with the lowest values on the first postexercise day (Tukey test, $P < 0.012$), particularly at site d. Pain detection thresholds on the right and left temporalis muscles (209 ± 30 and 224 ± 27 kPa, respectively) were not significantly influenced by the grinding exercise (2-ANOVA, $F(4,44) < 2.4$, $P > 0.066$) but the values at site j were significantly lower than the values at site k (2-ANOVA, $F(1,11) > 10.38$, $P < 0.009$; Tukey test, $P < 0.009$).

The PDT measured on the finger (control site) did not change significantly during the course of the study (1-ANOVA, $F(4,44) = 0.646$, $P = 0.633$) (Fig 5).

Maximal Voluntary Occlusal Force and Force/EMG Curves

The measurements of MVOF obtained before the grinding exercise, after the exercise, and in the following 3 days were not significantly different (1-ANOVA, $F(4,44) = 6.56$, $P > 0.626$) (Fig 6).

An example of the force/EMG curve is shown in Fig 2. The statistical analysis indicated that the curves fit better with exponential functions than with linear functions (Tukey test, $P < 0.003$). The factors A and B were extracted from the exponential relationship $EMG = A \times e^{B \times force}$ (Table 1). There were significant effects from the grinding exercise on the constant A (2-ANOVA, $F(1,11) = 10.81$, $P < 0.007$), with significantly higher values after grinding as compared to before grinding (Tukey test, $P < 0.028$). The factor B was not significantly changed (2-ANOVA, $F(1,11) = 0.356$, $P = 0.563$). In effect, this corresponds to an upward shift of the force/EMG curve, ie, more EMG activity at the same force level.

Discussion

The main finding in this experimental grinding study in healthy subjects was low levels of pain, unpleasantness, and soreness, without significant changes in maximal voluntary occlusal force in the postexercise period.

Experimental Grinding

The advantage of human experimental grinding studies is the potential to control a number of variables, such as duration and level of muscle activity, in addition to the specific type of movement. However, this advantage may also represent an inherent weakness, since the variables may not exactly match clinical conditions. The grinding effort in the present study represented a total duration of 2,700 seconds at about 50% of MVOF. Kydd and Daly[21] found that the total duration of masseter muscle activity in bruxers was around 660 seconds. Ikeda et al[22] reported that the mean peak EMG activity level in bruxers, expressed as a percentage of MVOF, was 56.5 ± 9.7% and that the grinding duration per night was much shorter (about 128 seconds: 8 hours sleep × 2 bruxism events per hour × 8-second duration per event) than the duration in the present study. The total duration of grinding of EMG activity above 20% of the maximal voluntary contraction in bruxers can be estimated to be no less than 500 to 600 seconds, according to Lavigne et al.[23] Therefore, it seems unlikely that bruxers will exert more and longer grinding activity than that used in the present study. Obviously, an important difference is that bruxism can occur every night for many nights, months, or years, whereas the present experimental grinding was performed on a single

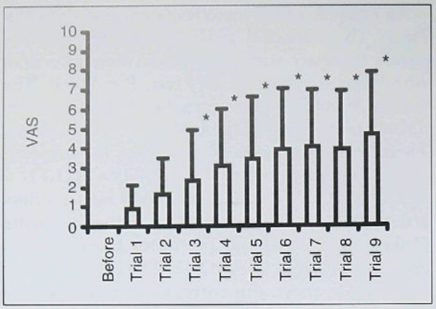

Fig 4a Pain intensity during grinding exercise.

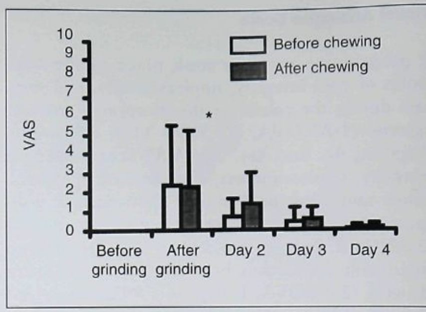

Fig 4b Pain intensity before and after chewing exercise.

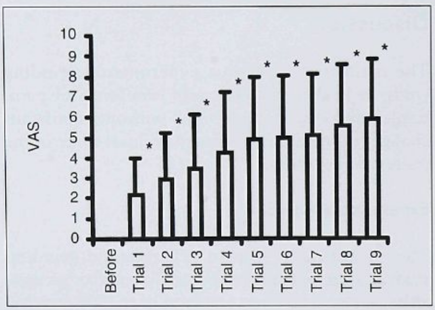

Fig 4c Unpleasantness during grinding exercise.

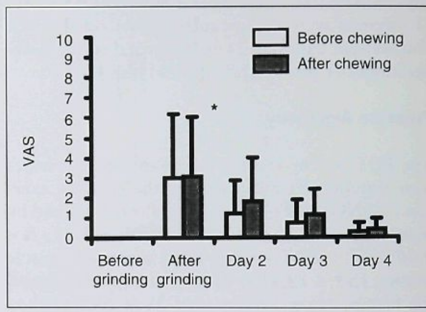

Fig 4d Unpleasantness before and after chewing exercise.

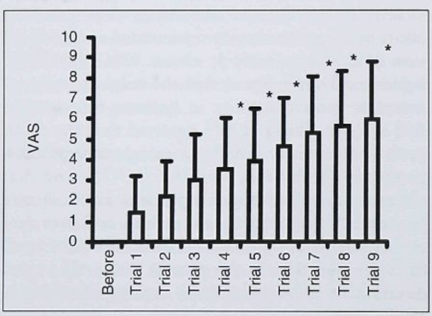

Fig 4e Soreness during grinding exercise.

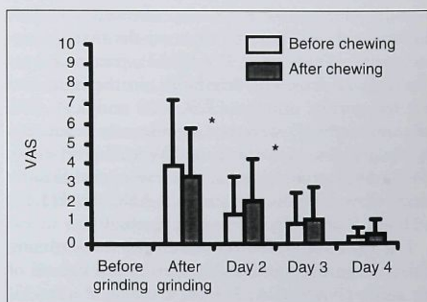

Fig 4f Soreness before and after chewing exercise.

Figs 4a to 4f All VAS scores (mean ± SEM; n = 12) increased progressively during the grinding exercise (a, c, and e). Immediately after grinding, the VAS scores were significantly increased (b, d, and f). On day 2, only soreness was increased significantly. The 1-minute chewing task did not influence VAS scores. * = significantly different from values obtained before exercise (Tukey test, $P < 0.05$).

Table 1 Analysis of Force/EMG Curves*

Muscle	Factor A		Factor B	
	Before	After	Before	After
Left masseter	49.3 ± 6.7	72.7 ± 8.3†	0.0253 ± 0.0019	0.0214 ± 0.0029
Right masseter	49.1 ± 14.2	67.5 ± 10.4†	0.0546 ± 0.0242	0.0266 ± 0.0031
Left temporalis	35.8 ± 7.5	38.5 ± 8.1	0.0325 ± 0.0050	0.0309 ± 0.0054
Right temporalis	72.2 ± 8.2	88.7 ± 13.2†	0.0228 ± 0.0020	0.0357 ± 0.0153

*Mean ± SEM, described by exponential function ($EMG = A \times e^{B \times force}$).
† = significant differences between before and after values (Tukey test, $P < 0.05$).

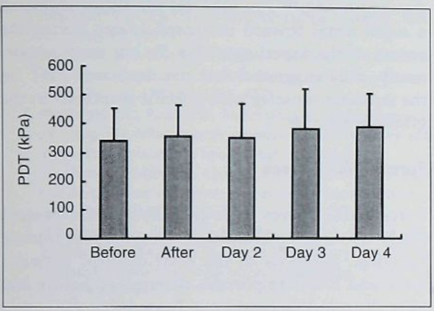

Fig 5 Mean values (n = 12) and SEM of pain detection thresholds (PDT) on the right middle finger. There were no statistically significant differences (1-ANOVA, $P > 0.05$).

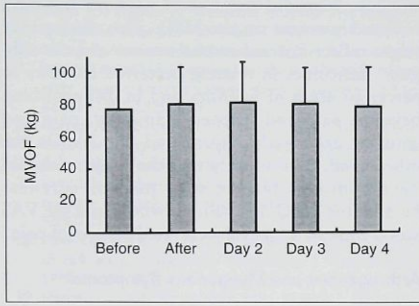

Fig 6 Mean values (n = 12) and SEM of maximal voluntary occlusal force (MVOF) before grinding exercise, after exercise, and on the following days. There were no statistically significant differences (1-ANOVA, $P > 0.05$).

day. However, Rugh and Harlan[24] demonstrated that periods with muscle pain often were preceded by only 1 or 2 nights with increased EMG activity. It remains to be determined whether repeated bouts of strong grinding activity would lead to more significant levels of muscle pain, although it has been shown that repeated bouts of clenching activity at 25% MVOF do not cause a progressive increase in pain or soreness.[10] Furthermore, it should be emphasized that nocturnal orofacial motor activities appear to be very distinct from voluntary movements, such as daytime clenching.[25] Thus, future experimental grinding studies in awake subjects should try to simulate the nocturnal jaw movement patterns and duration of EMG activity as closely as possible.

Many studies have examined the effects of various grinding and clenching tasks on healthy subjects.[9–13,26–28] At least 2 important points can be inferred from these studies. First, all types of sustained EMG activity cause pain immediately after the exercise; this is probably related to ischemic reactions in the muscle tissue.[29] Second, only some of the studies have examined the subjects the following days after the exercise, eg, Clark et al,[9] Svensson and Arendt-Nielsen,[10] and Glaros et al.[11] The latter studies generally report very low levels of pain and soreness. This was also found in the present study. The mechanisms of the delayed type of pain are thought to involve microinjuries to muscle tissue and inflammatory responses.[30–32] In this aspect PEMS in masticatory muscles seems to be different from that in limb muscles, where pain and soreness peak after 2 days.[33] Furthermore, it is characteristic for PEMS in limb muscles that the maximal voluntary contraction is greatly reduced (by 40%), while this was not the case in the present experiment. In addition, the 1-minute chewing task did not reveal any significant effect of dynamic movements on the perceived pain intensity. The question posed in the title of this paper should nevertheless be answered by a "yes, experimental grinding models can be used to induce PEMS, but only low levels of PEMS." It should be noted that the PDT and VAS measurements indicated only a weak effect the first day after the grinding exercise, whereas the pain drawings suggested pain in 7 of 12 subjects for up to 3 days after the exercise. In fact, 5 of 7 subjects who drew an area of pain on the drawings also reported pain on the VAS, but at a very low level. The 2 other subjects who did not report pain on the VAS reported soreness on the MPQ. This discrepancy might reflect internal inconsistencies and the subjects' difficulties in relating perceived intensity to perceived areas of intensity and in distinguishing between pain and soreness. However, pain and soreness are clearly interrelated (Fig 4). On the other hand, it is unlikely that the subjects should have confused fatigue with pain or soreness because the MPQ, the pain drawings, and the VAS scores indicated that subjects rated aspects of pain.

Arthrogenous and Myogenous Symptoms

An interesting finding in the present study was that 7 of 12 subjects reported pain localized around the left TMJ region on day 2. Manual palpation of the joints supported the subjective pain reports. One possibility is that the symptoms originated in the lateral pterygoid muscle, which had performed eccentric contractions during the grinding exercise. Another possibility for the contralateral TMJ pain could be that the joint was overloaded by the grinding exercise. Recent biomechanical studies of the TMJ during loading in lateral positions support the notion that the contralateral joint is more compressed than the ipsilateral joint, provided that the tooth contact is predominantly on the working side.[34,35]

Pressure algometry was used as a quantitative tool for assessment of jaw muscle pain and soreness.[36,37] The observed differences between the sites agree with the findings of previous studies.[18,19,38] In this study, PDT on the temporalis muscle were higher than on the masseter muscle, but the PDT on the temporalis muscle were not influenced by the grinding exercise. In contrast, the results indicated that the anterior part of the masseter muscles was more sensitive to the grinding exercise than the other sites on the muscle (Fig 1). Furthermore, there were no differences between PDT on the left and right side after the unilateral grinding exercise, and the pain was often unilateral. This finding agrees with the study by Reid et al,[38] in which PDT did not differ between the more painful and the less painful sides. Thus, unilateral grinding may only cause PEMS-like symptoms in relatively specific regions of the masticatory muscles. In accordance with this suggestion, Baker et al[39] demonstrated site-dependent changes in PDT on the quadriceps femoris muscle following strong eccentric work. Furthermore, it is likely that myogenous symptoms will occur mainly on the working side as a result of higher EMG activity compared to the balancing side during laterally directed biting.[40] The PDT on the finger indicated a slight trend toward increased values during the course of the experiment (Fig 5), but more importantly, they suggested that the decreased PDT on the masseter muscles were specific responses to the grinding exercise.

Force/EMG Curves

Force/EMG curves were included in the present study as electrophysiologic measures of muscle function. Analysis of the relationships between force and EMG amplitudes determined before and after the grinding exercise indicated that the curves shifted upward. Muscle fatigue has previously been reported to cause increased steepness in the force/EMG curve.[41] Many studies used only EMG to measure masticatory muscle fatigue and showed a shift of the mean-power frequency to lower frequency levels.[42–44] In contrast, the studies that used both EMG and measures of force indicated a resistance of the masticatory muscles to fatiguing exercises.[45–48] It was suggested that the striking fatigue resistance might be due to a high oxygenation of the masticatory muscles or a greater proportion of slow-twitch fibers, as compared to limb muscles.[45] Hagberg[49] reported that the slope of the force/EMG curve at low-force levels decreased when lidocaine was injected into painful and tender masseter muscles. From the present study we cannot determine whether the observed force/EMG changes reflected muscle fatigue or were a result of immediate pain symptoms. Further studies on the modulation of force/EMG curves are warranted.

This study in healthy subjects has demonstrated that 45 minutes of strong experimental grinding activity can cause marginal and self-limiting symptoms in the TMJ and masticatory muscles in the days following the exercise. Further research is needed to identify other risk factors in clinical TMD patients.

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