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ORIGINAL ARTICLE

Evaluation of muscular activity, local muscular fatigue, and muscular rest patterns among dentists

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Abstract
In a previous study, dentists reported very high scores for perceived physical workload, but only low to moderate scores for the musculoskeletal system. This is difficult to explain when other occupational groups in the dental services are compared, and is the main reason why the present study was performed. To measure muscular activity, a surface electromyography (sEMG) study was done, and included the subjects who reported neck and shoulder complaints in the previous study. A portable sEMG system (MyoGuard) was used to collect a myoelectric signal on-line and analysis of the myoelectric signal in a computer. sEMG was recorded from both trapezius muscles for approximately 4 h during an ordinary working day. Twenty-seven dentists participated in the study. The results show accumulated rest% fairly close to that of female cashiers and supermarket employees and increased average rectified value percent (ARV%) during work that could contribute to the very high workload perceived by dentists.

Key Words: *Dentistry, ergonomics, surface electromyography*

Introduction

The prevalence of complaints stemming from the musculoskeletal system is high among employees in dental practice [1–4]. In recent years, public dental practice in Sweden has seen major changes, including change of organization, the introduction of computerized routines, and changed professional roles. Increased psychosocial demands and reduced influence in one's work may explain the feeling of stress and distress among the staff [5]. In a previous questionnaire study on dentists, Rolander & Bellner reported high perceived physical work demands on several work variables. The prevalence of musculoskeletal complaints was high in this study too, particularly for neck and shoulders, while the perceived pain intensity for these locations was low. Furthermore, there was only weak correlation between perceived physical work demands and perceived pain intensity in neck and shoulders, which could not be satisfactorily explained [6]. However, many authors have reported that self-reported questionnaire-based workload is associated with serious problems of validity [7–9]. Questions concerning working postures involving parts of the body offer too poor reproducibility and should be evaluated with more accurate methods [9,10]. A new study using the surface electromyography (sEMG) technique has therefore been performed on dentists with high-perceived physical workload; muscular activity, local muscular fatigue, and accumulated muscular rest patterns are evaluated. In biomechanics and ergonomics, sEMG can be used to evaluate muscular activity level (amplitude sEMG), localized muscular fatigue (frequency sEMG), the timing of muscular contraction, and muscular rest. There is a positive quantitative relationship between sEMG amplitude and muscular contraction level. There is also a relation between the frequency spectrum of the sEMG and muscular fatigue, with a drift of the mean frequency towards the lower end of the spectrum as a sign of fatigue [11].

Our hypothesis is that measured physical load during work is lower than the perceived physical load. We expect confounders in the psychosocial environment to influence perceived workload results. Therefore our intention in this study was to evaluate whether the

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dentist's work is as heavy as the perceived physical demands and workload results shown by Rolander & Bellner [6].

The aim of this study was to examine whether the dentists who reported high physical load during dental work in the Rolander & Bellner study [6] also show sEMG signs of high muscular activity or muscular fatigue.

Material and methods

Subjects

sEMG studies are expensive and time-consuming [12], and therefore a strategic selection was carried out among the dentists. It was assumed that it would be easier to find out if there were any signs from sEMG of high physical load in this group. The 27 dentists included in the study (10 M and 17 F) were selected from the 73 dentists reported in the Rolander & Bellner study [6]. Inclusion criteria were a score higher than 5 (hard conditions) on physical demands (factor 1) and physical load (factor 2) on 10-point VAS scales. Mean age was 48 years (SD 7.1, range 31–60). All were employed in dental clinics in Jönköping county, Sweden, and had worked as dentists for an average of 19 years (SD 8.5, range 2–35). Fourteen dentists worked full-time and 13 part-time 30–39 hours a week. Nine dentists regularly worked overtime. All but one were right-handed.

Recording of myoelectric signals

Muscle load exposure was registered with an EMG recorder, the MyoGuard system (Biolin Medical, Göteborg, Sweden). This system is a portable unit for on-line collection and analysis of myoelectric signals (Figure 1). It consists of a central processing unit with a microcomputer calculating signal parameters in both time and frequency domains, a memory card for continuous recording of signal parameters, a battery pack, a preamplifier with a connecting wire, and disposable electrodes. A detailed description of the system has been presented by Sandsjö [13].

A pair of disposable pre-gelled EMG electrodes (Blue Sensor N-00-S; Medicotest A/S, Ølstykke, Denmark) was attached bilaterally on the skin over the upper trapezius muscles. The centers of the electrodes were 2 cm apart and 2 cm lateral to a point midway between the spinous process of the vertebra C7 and the acromion (Figure 1) [14,15] to avoid the innervation zone [16]. The indifferent electrode was placed over the spinous process of C7. Prior to application of the electrodes, the skin was cleaned with an antiseptic alcohol solution and gently abraded with sandpaper. All cables were carefully secured with elastic tape to minimize motion disturbance but allow maximum freedom of movement. The electrodes were attached 10 min before the EMG recorder was switched on.

Figure 1. The MyoGuard system. A portable EMG equipment for collection and on-line processing of myoelectric signals. The figure shows electrode placement over the left and right trapezius muscles and the datalogger unit on the right side of the hip.

Signal processing

The signal was preamplified (×10) in a unit placed close to the electrodes. The signal was filtered and analog-to-digital converted. The amplification level was set manually during a reference contraction with both arms elevated simultaneously without any weight in the hands. The level obtained during a contraction was set to 2/16 of the input range of the MyoGuard unit [13]. Sampling frequency was 1024 Hz. The method involves taking the 10 to 400 Hz bandpassed myoelectric signal and reducing it to estimates of normalized average rectified value (ARV) and mean power frequency (MPF) each second.

The ARV and MPF obtained from the sEMG signal were downloaded to a computer. The MyoSoft program was used to calculate the average of the ARV and MPF estimates on a 60-s basis during the whole period of measurement. sEMG amplitude, measured as ARV, was used as a measure of muscular activity during the whole measure period. Normalization was performed by dividing all ARV values by the value obtained from the reference contraction and expressed as a percentage of this value. The frequency content of the signal was studied by calculating the frequency spectrum, with the MPF as an indicator of muscle

fatigue. The MPF value was normalized in the same way as ARV, with all values expressed as percentages of the value obtained from the reference contraction.

Registration of reference and resting values

Before starting the measurement during work, each subject was seated on an ordinary working chair with the lumbar spine resting against the back support. The subject performed three reference contractions, each lasting for 20 s. The reference contraction was performed with both arms held horizontally and in 10° forward flexion from the frontal plane simultaneously without any weight in the hands. The reference contraction with the smallest dispersion was chosen for normalization. The amplitude obtained was set to 100% ARV, corresponding to a maximum voluntary contraction (MVC) level in the upper trapezius of about 15% [17]. Each reference contraction was followed by a registration with the muscle at rest. Three 20-s resting recordings were performed when each subject was sitting with the arms loosely placed on the lap and the shoulder muscles relaxed. The lowest recorded value plus 10% of the reference ARV value was used as rest threshold value, which is the borderline between background or noise activity and muscle activity [13].

All ARV values below the rest threshold value are assumed as muscular rest. Furthermore, accumulated muscular rest was calculated as a percentage of the measure time.

The sEMG recordings were performed during an ordinary working day at the dentist's normal workplace. Measurements started with the first patient in the morning, and went on for between 3 h and 45 min and 4 h and 30 min of the day. During these hours, the dentists wrote an activity report. The measure time was divided into work (3 h and 30 min) and coffee break (mean 23 min, range 15–60 min). Work includes all the tasks performed by the dentist without a coffee break.

Statistics

Data obtained from the MyoGuard system were processed in computer programs which have been developed in our research group. ARV and MPF were calculated on a 60-s basis. All statistical analyses are performed in SPSS, version 12.02 (SPSS Inc., Chicago, Ill., USA) and were significant on $\alpha = 0.05$. Descriptive statistics are presented in mean, percent, range and 95% confidence interval (CI 95%). Differences between gender and between dentists in special dental service and district dental service on ARV%, accumulated rest%, and MPF% were performed with covariance analysis with age and period of employment as covariates. ARV%, accumulated muscular rest%, and MPF% during work and coffee break were calculated with repeated measure ANOVA with age and period of employment as covariates. Test of normality was performed using Kolmogorov-Smirnov. Of all variables, only accumulated muscular rest% during work and MPF% during coffee break were significantly separate from normality ($p < 0.05$). Those variables were also tested with the Mann-Whitney U-test for independent samples and the Wilcoxon signed-ranked test for related samples. No differences between parametric and non-parametric tests were found, so only results from the parametric test are shown. Linear regression analysis was performed with time as an independent variable and ARV%, accumulated muscular rest%, and MPF% as dependent variables. Results are presented in correlation coefficients (r) for the entire group and in slope coefficients (B) on an individual level.

Results

Accumulated muscular rest during work

Mean muscular rest percent was 33.8 on the right side (CI 95% = 26.5–41.1, range 14.3–73.0%) and 31.0% (CI 95% = 24.0–38.0, range 0.1–65.8%) on the left side.

EMG amplitude levels during work

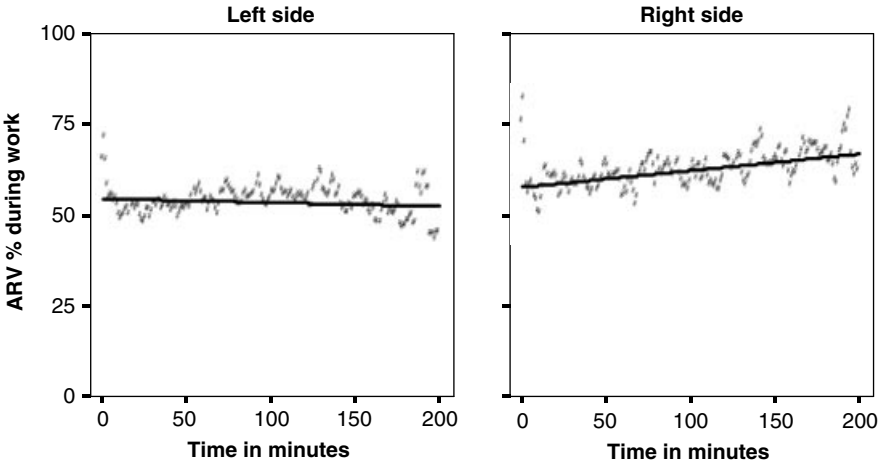
Mean normalized ARV values from the trapezius muscle, representing muscular activity, are presented in Figures 2 and 3. Right and left sides are presented separately. Mean ARV for the right side ($n = 27$) was 62.3% (CI 95% = 55.8–68.8, range 35–116%) of the calibration value, and for the left side ($n = 25$) 54.0% (CI 95% = 45.1–58.8, range 24.5–79.4%). The correlations coefficients (r) were 0.53 ($p < 0.001$) and -0.15 ($p < 0.05$) for right and left sides, respectively.

When regression analysis was performed for each individual separately, there was a fairly large variation, with slope coefficients (B) from -0.2 to $+0.9$ on the right side and from -0.1 to $+0.4$ on the left. Eighteen of the dentists (67%) had negative slopes coefficients (B) on the right side and 12 (48%) on the left.

EMG power frequency during work

Mean normalized MPF values from the trapezius muscle, representing occurrence of local muscular fatigue, are presented in Figures 4 and 5. Left and right sides are presented separately. Mean MPF was 93.7% (CI 95% = 91.1–96.3, range 76.0–108.5%) on the right side and 95.3% (CI 95% = 93.3–97.2, range 86.5–105.3%) on the left. The correlation coefficients (r) were 0.05 ($p > 0.05$) and -0.26 ($p < 0.001$) for right and left sides, respectively.

When regression analysis was performed for each individual separately, there was some variation, with slope coefficients (B) from -0.05 to $+0.2$ on the right side and -0.12 to $+0.12$ on the left. Eight of the dentists (27%) had negative slope coefficients (B) on the right side and 16 (64%) on the left.



Figures 2 and 3. Regression plot of ARV% during work on time (min). Upper left trapezius muscle correlation coefficient (r) = −0.15 (p < 0.05) and upper right trapezius muscle correlation coefficient (r) = 0.53 (p < 0.001).

A visual comparison was obtained for all dentists with a positive slope on ARV% during work. This was compared with MPF% during work and none had a negative slope, which shows no typical sign of muscle fatigue.

Mean ARV%, mean MPF%, and mean accumulated muscular rest% during work were also tested with univariate ANOVA for gender differences and for differences between dentists in special dental service and district dental service. No significant differences were found, nor were covariates age and periods of employment significant (p > 0.05).

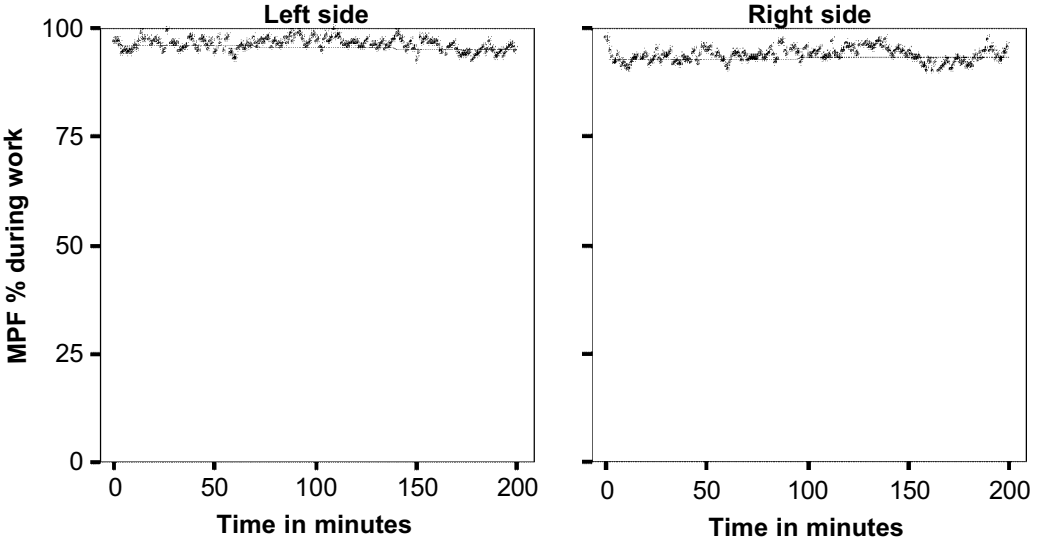
Differences between work and coffee break

Table I gives the data for differences between ARV%, accumulated muscular rest%, and MPF% during work and during coffee break for both right and left sides. ARV% decreases significantly (right side p < 0.01, left side p < 0.001) and accumulated muscular rest% increases significantly during coffee break for the right side (p < 0.001), but not for the left side (p > 0.05). MPF% did not change significantly for either side (p > 0.05).

There were no significant differences with repetitive ANOVA (p > 0.05) between gender or dentists in special dental services and district dental services. The covariates age and period of employment were not significant (p > 0.05).

Discussion

In the present study, sEMG recordings showed 31–34% accumulated muscular rest, muscular activity levels were 50–65% of the calibration value, and the



Figures 4 and 5. Regression plot of MPF% during work on time (min). Upper left trapezius muscle correlation coefficient (r) = −0.26 (p < 0.001) and upper right trapezius muscle correlation coefficient (r) = 0.05 (p > 0.5).

Table I. Differences in EMG pattern between work and coffee break for left and right sides. ARV%, accumulated muscular rest%, and MPF% as mean differences (m diff), 95% confidence intervals (CI 95% diff), and 95% probability (p)

	Left $n=23$				Right $n=26$			
Total	m diff	CI 95% diff		p	m diff	CI 95% diff		p
ARV% work − ARV% coffee break	22	35	10	<0.001	10	4	16	<0.01
Accumulated muscular rest% work − Accumulated muscular rest % coffee break	−5	10	−19	>0.05	−19	−12	−26	<0.001
MPF % work − MPF% coffee break	1	2	−1	>0.05	−0.6	1	−2	>0.05

Covariates appearing in the model are evaluated at age and period of employment. The covariates were not significant ($p>0.05$).

normalized MPF values were centered on an initial value of 93–95% during the recorded working time.

Muscle activity

The amplitude of the sEMG signal has been used extensively for evaluating muscular activity [18]. The calibration value was obtained by simultaneously holding both arms horizontally and in 10° forward flexion from the frontal plane without any weight in the hands [17]. Palmerud et al. [19] found that the activity of the trapezius muscles in a comparable position could be voluntarily reduced by 56% by means of instruction and visual biofeedback. This implies that over-stabilization of the shoulder muscles occurs and might vary between individuals and result in an over-estimation of the ARV during the measurements. However, we performed the reference contraction with a simple instruction to raise both arms simultaneously without any biofeedback. In spite of this, the mean ARV levels in the present study for both upper trapezius muscles were only 50–65% of the calibration level. This load level value is comparable with load levels shown in female cashiers, white-collar workers, and female supermarket employees (see Table II). The muscular activity obtained by holding the arm in 90° elevation corresponds to about 10–15% of MVC [17]. An approximately linear relation can be assumed at these low activity levels. Consequently, the recorded sEMG levels in the present study correspond to 5–9% of MVC. Åkesson [20] reported a median load of 8.4% of MVC in the upper trapezius muscles when performing dental work, showing almost the same values as found in the present study. The muscle activity values in the present study seem to be typical for this kind of work. Muscle activity levels below 10% of MVC are considered to be very low [21].

It has been hypothesized that, due to an orderly recruitment of motor units [22], low threshold (type 1) fibers are vulnerable to muscle contractions of long duration, even at very low amplitudes, this is known as the "Cinderella hypothesis" [23]. The findings of an excess of so-called "ragged red" muscle fibers in myalgic muscles support this theory [24]. A consequence is that periods of total muscle relaxation are important for the prevention of myalgic disorders in the trapezius muscle. In this study, we used time proportion of total muscle relaxation (accumulated muscle rest%) as an indicator of recovery time for the low-threshold motor units [15]. The accumulated muscle resting time was 31–34% of the recorded working time. Hägg & Åström [25] examined 23 medical secretaries during typewriting. They found 14.4% accumulated muscular rest on the right side of the upper trapezius muscle and 17.3% on the left side among those who had no symptoms from the upper trapezius muscle. In a study of cleaners, a group known to have a high frequency of complaints from the musculoskeletal system, Nordander et al. [26] compared them with office workers. They found a median accumulated resting time of 1.5% for cleaners and 12% for office workers. Compared with the results in these studies, the dentists in our study had a fairly high amount of accumulated muscular rest. However, the work/rest threshold in the present study is defined as the mean ARV value of the best, i.e. the lowest, of the attempted rest, to which 10% of the reference voluntary electrical activation (RVE) of reference contraction was added.

Table II. Comparisons between different professions with the same EMG equipment

	Sandsjö [33]		Sandsjö [19]		Rissén et al. [32]		Present study	
	Female supermarket employees with pain		White-collar workers		Female cashiers		Dentists	
	m (left side) $n=18$	m (right side) $n=18$	m (left side) $n=57$	m (right side) $n=57$	m (left side) $n=31$	m (right side) $n=31$	m (left side) $n=25$	m (right side) $n=27$
ARV%	50%	52%	39%	47%	53%	59%	54%	62%
Accumulated muscular rest%	23%	24%	51%	32%	26%	24%	31%	34%

In the present study, the RVE used corresponds to 10–15% MVC [17]. Consequently the work/rest threshold is about 1.5–2% MVC. This is higher than in the studies by Hägg [23] (0.3–0.5% MVC) and Nordander et al. 1% MVC [26] and might explain the higher amount of accumulated muscular rest in the present study compared with their results.

The results of four studies (including the present study), performed with the MyoGuard system on four different professions are compared in Table II using the same unloaded reference contraction as in the present study.

Table II indicates that accumulated muscle resting time for dentists in our study is 20% lower compared with male white-collar workers on the left side [18], but approximately 10% higher than that of female cashiers [27] and female supermarket employees [28] on both sides.

Neck/shoulder complaints and EMG values

The dentists in the present study perceived low to moderate complaints from the neck/shoulder region. Åkesson [20] reported that dentists with muscle pain had lower muscle activity in the trapezius muscle than those without. However, the difference was not significant. Suggesting that dentists with pain reduce their workload to avoid more pain, Nordander et al. [26] compared cleaners and office workers both with and without neck/shoulder disorders and found no differences in accumulated muscular rest between subjects with and without disorders. Other studies have shown that a low amount of accumulated muscular rest is associated with a higher risk of musculoskeletal symptoms in the neck/shoulder region [25,29,30]. However, the literature is not consistent on this point, and it is unclear what impact pain has on the EMG amplitude. Prolonged static contractions, with low accumulated muscular rest, can result in an overload of type 1 muscle fibers and may still be a primary risk factor for musculoskeletal disorders [23]. The dentists in the present study had an amount of accumulated muscular rest% comparable with white-collar workers on the right side. It is well documented that office work is associated with a high prevalence of myalgia [25]. In addition, accumulated muscular rest% is fairly close to that of female cashiers and supermarket employees and an increased ARV% during work that can contribute to a very high perceived workload during the dentist's work. It is possible that the amplitude analyses can explain the findings in the Rolander & Bellner [6] study.

Muscle fatigue

It is well documented that the myoelectric frequency spectrum is displaced towards lower frequencies during a sustained static muscular contraction. This has been interpreted as a sign of muscular fatigue [11]. For quantification of localized muscular fatigue, the lowering of the spectral mean (MPF) or median frequency (MDF) has been used as an estimator. It has been shown that a reduction of MPF of more than 8% can be indicative of muscular fatigue [31]. In the present study, we saw no such change of MPF (apart from an initial reduction of the EMG frequency, often seen), indicating absence of localized muscular fatigue. On the right side, there was an increase of ARV during work, possibly caused by increased muscle fatigue [32]. This, however, is contradicted by the absence of MPF changes in the present study. Even the individual slope among those dentists who had an increase of ARV did not show any decrease of MPF. However, the normalized MPF in the present study is evaluated of the dentists during their work. Luttmann et al. [33] proposed repeated reference contractions or reference activities during the EMG measurements, since the ARV values depend on both muscle activity and muscle fatigue. This method could have shown temporal changes in the MPF and ARV indicating for muscle fatigue. On the other side, it appears that the dentist's work is not so varied that any significant change of muscle activity will occur during work [34]. During coffee break, there was a significant decrease of ARV values on both sides and an increase of accumulated rest on the right side, showing that the subjects could relax their trapezius muscles.

In conclusion, the present study shows an accumulated rest% fairly close to that of female cashiers and supermarket employees and an increased ARV% during work that could possibly contribute to a very high perceived workload during the dentist's work. However, there are some limitations in the sEMG method used. The muscular rest threshold is relatively high, which could imply that low physical load during dental work is considered as muscular rest instead of as a low static load. Another limitation is the method used to evaluate the MPF values, which could imply that the increase of ARV% is not connected with muscular fatigue. Our hypothesis that physical load during work for dentists is lower than perceived physical load is therefore not satisfactorily answered and cannot be rejected. Consequently, it is still necessary to explore the high perceived physical workload found by Rolander & Bellner [6].

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