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Quantifying work load in neck, shoulders and wrists in female dentists

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Abstract *Objective*: To assess the work load in neck and upper limbs of dentists. *Methods*: Twelve right-handed female dentists (six with and six without a history of definite neck/shoulder disorders, pair-wise matched for age) were studied when performing authentic dental work. Electromyography (EMG) was used to quantify the muscular load of the shoulders bilaterally and of the right forearm. Positions and movements of the head and wrists were measured, using inclinometers and electrogoniometers. *Results*: During work, the median load for the right upper trapezius muscle was 8.4% of the maximal voluntary EMG activity (MVE); during 90% of the time the load was ⩾3.3% MVE ("static" load). The figures were somewhat lower on the left side (7.0% and 2.5% MVE, respectively). Subjects with disorders had over all lower load levels for the trapezius muscles, although not statistically significant at <0.05, than those without disorders. During a standardized reference contraction for the trapezius, the load was 17% MVE, and the quotient between MVE and torque [normalized to maximal voluntary torque (MVC)] was 0.5. These figures may be used for transformations. The muscular load on the right forearm was similar to the loads on the trapezius. The head was, on average, forward tilted ⩾39°, and during 10% of the time ⩾49°. The left hand was held in more static positions, with palmar flexion and ulnar deviation, also reflected by lower angular velocities and repetitiveness, as compared with the right one, which was dorsiflexed. *Conclusions*: Dentists are exposed to high load on the trapezius muscles bilaterally, and steep, prolonged forward bending of the head. Further, for the wrists the postures were constrained, but the dynamic demands were low.

Key words Electromyography · Muscles of the forearm · Musculoskeletal disorders · Upper extremity · Work posture

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Introduction

Musculoskeletal disorders in the neck and upper limbs are common. In some occupations high prevalences have been demonstrated (Hagberg and Wegman 1987). It has been suggested that work-related musculoskeletal disorders are associated with a number of potential risk factors, e.g. joint positions, such as constrained postures, positions close to extremes, steep forward bending of the head, high angular velocities, repetitive movements, high static muscle and joint load, and lack of pauses (Stock 1991; Winkel and Westgaard 1992).

Dentists have a high frequency of symptoms and disorders from the neck and upper limbs. Thus high prevalences of symptoms have been reported for the neck and shoulder (Murtomaa 1982; Milerad and Ekenvall 1990; Rundcrantz et al. 1990; Åkesson et al. 1995; Finsen et al. 1995) and, to some extent, elbows and hands (Rundcrantz et al. 1990; Åkesson et al. 1995; Finsen 1995). Furthermore, a high prevalence of cervical spondylosis as compared with farmers has been shown (Katevuo et al. 1985). Symptoms of the hands and wrists are more common among female dentists than among male ones (Finsen et al. 1995; unpublished data). These high prevalences have been ascribed to the nature of the dental work (Hagberg and Hagberg

1989). The work consists of precision tasks, involving a high degree of visual and manipulative elements, sometimes in combination with exertion of force. Also, there is a clear difference between the demands for the dominant and non-dominant hands. The nature of dentistry requires extremely fine motor co-ordination of the dominant hand, and sometimes forceful grips. The other hand is mostly used as a support and for assistance to get a good view of the operating field, e.g. by using the dental mirror, which demands a static and often forceful grip. Moreover, it is well known that tasks which have a high level of visual, manipulative and reach demands highly influence work postures, especially for the head, neck, arms and hands (Haslegrave 1994).

In epidemiological studies of occupational musculoskeletal disorders, there is a great need for objective and quantitative measures of physical exposure, in order to describe exposure/response relationships (Hagberg 1992; Winkel and Westgaard 1992). However, in dentistry work, muscular load of shoulders and arms and postures of the cervical spine have been investigated in only a few studies (Green and Brown, 1963; Milerad et al. 1991; Finsen 1995). Moreover, no one has yet studied (and characterized) the dynamic components of work, such as angular velocities of the head and the cervical spine. Neither have the wrist positions and movements been studied.

In this study, such simultaneously performed functions, in terms of muscular activity, postures and movements, of the neck, shoulder and wrist regions, were used to describe potential risk factors in female dentists at the most frequent work tasks during authentic general practice dental work.

Materials and methods

Subjects and work task

Subjects

Twelve right-handed female dentists, working in general practice dentistry, gave their informed consent to participate in the study. Their mean age was 45.7 (range 37–60) years and mean duration of employment 20 (range 11–36) years (Table 1).

The participants were selected from a group of 25 dentists included in previous studies (Åkesson et al. 1995). Because of the possibility that musculoskeletal disorders might affect the outcome and to increase the efficiency of the study, a stratification on disorders/non-disorders was made, based on a clinical examination performed 1 year before this study by an experienced physical therapist. Standardized criteria for classification of clinical diagnoses and symptoms were used, according to a method described by Ohlsson et al. (1994a). Subjects with any diseases of the central nervous system or inflammatory rheumatic diseases were excluded ($n = 2$). The remaining 23 subjects met the following criteria:

Group disorders: dentists with a history of definite musculoskeletal disorders. They had at least either one diagnosis, or several findings, from the regions of neck and shoulder, and either arm or hand. Twelve of the 23 dentists were defined as "disorders", according to the definition criteria and of these six were selected. Their problems were mainly localized to the neck and shoulder regions.

Group non-disorders: dentists without definite musculoskeletal disorders. They had no diagnoses, and no, or at most a few findings, from two of the body regions mentioned above. Eleven of the 23 dentists were defined as "non-disorders" according to the definition criteria, six out of these were chosen for the study, pair-wise matched for age to the "disorders" dentists.

Thus, the proportion of disorders among the selected dentists were representative for the study base. There were no marked differences between the groups with regard to years of employment, working hours a day or anthropometric measures (Table 1).

Table 1 Age, employment data and anthropometric data for the studied dentists ($n = 12$)

	Mean (SD)	Range
Age (years)	45.7 (8.7)	37–60
Employment time (years)	20.0 (8.9)	11–36
Weekly working hours (h)	33.2 (7.1)	20–40
Anthropometric data		
Height (cm)	166.8 (5.7)	157–178
Weight (kg)	63.4 (10.4)	45–79
Body mass index (kg/m^2)	22.7 (2.7)	18–27
Hand length		
Right (cm)	18.1 (0.8)	17–19
Left (cm)	18.2 (0.7)	17–19
Right forearm length (cm)	25.1 (1.4)	23–27
Right upper arm length (cm)	34.0 (2.4)	30–38
Eye height above seat (cm)	71.3 (3.0)	67–76
Elbow height above seat (cm)	21.8 (2.6)	18–26

Subjective ratings of symptoms

A 100-mm visual analogue scale (VAS) (Scott and Huskisson 1976) was used to assess the current level of symptoms (pain and discomfort) from the neck and upper limbs on the day of the data collection. The disorders group rated higher than the non-disorders for the neck (35 vs 18) and shoulder regions (right 27 vs 20, left 27 vs 10), regions which had been taken into account at the selection of the subjects. The ratings were, on average, not high for the disorder group. There were no differences in the average ratings for the elbows and hands, which were low for both groups.

Muscular strength and mobility

There were no statistically significant differences between the groups regarding muscular strength (Table 2). However, wrist mobility was somewhat lower and there was a weak tendency to a lower head mobility, for the disorders group, as compared with non-disorders (Table 3).

Work tasks and procedure

All the dentists worked in a chairside sitting position, while operating from the right side of a reclining patient. All had assistance during the treatment from a dental assistant, who was also seated. The dental units, including equipment and instruments, were similar. The recordings were carried out during authentic dental work at the dentist's regular workplace with operations in the upper or lower jaw. The recorded work tasks were representative of general practice

Table 2 Muscular strength for all ($n = 11^a$) dentists, and those without (non-disorders, $n = 6$), and with ($n = 5^a$) disorders

	Side	Group of dentists	Muscular strength (N)	
			Mean (SD)	Range
Hand-grip	Right	All	291 (50)	225–388
		Non-disorders	288 (59)	225–388
		Disorders	295 (43)	248–347
	Left	All	300 (58)	228–428
		Non-disorders	298 (68)	228–428
		Disorders	304 (50)	257–375
Wrist dorsiflexion	Right	All	77 (13)	56–101
		Non-disorders	77 (17)	56–101
		Disorders	77 (8)	69– 88
Shoulder abduction	Right	All	165 (26)	110–221
		Non-disorders	168 (35)	110–221
		Disorders	161 (12)	146–176
	Left	All	154 (22)	109–184
		Non-disorders	153 (27)	109–182
		Disorders	156 (18)	136–184

[a] Of the original 12 dentists, one in the group "disorders" was excluded; she had, due to pain, very low values (136, 99, 44, 50 and 40 N, for right and left hand-grip, right wrist dorsiflexion, and right and left shoulder abduction, respectively)

dentistry, and consisted of preparation and filling of one or more tooth cavities for each patient. All recordings were started simultaneously at the beginning of the treatment, and ended either when the treatment was finished or when the maximal acquisition time for the different recording equipments was reached. Direct observations, performed simultaneously with the recordings, showed that the drilling part constituted, on average, 9.3% of the studied work time, with a range of 4%–16%. Video recordings were made during the whole work session to obtain an overview of the work situation.

Muscular strength

For the shoulder muscles, isometric strength at arm abduction in the scapular plane at 90°, in standing position, was measured by means of a strain gauge force transducer, connected with an adjustable strap around the upper arm, proximal to the elblow joint. Both sides were measured, one at a time. The subject was encouraged to exert three maximal voluntary contractions (MVCs), as attempted vertical pulls, each lasting 3–5 s. MVC also denotes the maximal force, or torque, whichever is applicable, during the MVCs.

For the flexor muscles of the forearm, the isometric muscle force was measured bilaterally as the hand-grip force, by means of a strain gauge force transducer. The subject was seated, with a flexed elbow and the forearm in a semipronated position, resting on a table. The hand was slightly dorsiflexed and the grip distance was 40 mm.

For the extensor muscles of the right forearm, isometric muscle force was measured as the exerted force during attempted dorsiflexion of the wrist. The subject was seated, with a flexed elbow and the forearm in a pronated position, resting on a table, with the hand unsupported, and with a neutral position of the wrist. A glove, with a plywood support on the dorsal side was used, extending from the wrist to the finger tips. A strap was fixed to the plywood support between 10 and 20 mm distal to the metacarpophalangeal joint of the third finger. The strap was connected to a strain gauge force transducer.

For all the force measurements, visual feedback of exerted force, shown on a digital display, was used to further motivate the subject, and the maximum value of three attempts was used.

Measurements during work

Muscular load

Electromyography (EMG) was used for recording the descending part of the upper trapezius muscle bilaterally, as well as for flexor and extensor muscles of the right forearm. The mean recording and analysis duration was 22 (range 14–34) min for dental work (including drilling), of which 1 min 45 s (range 55 s–3 min 29 s) were selected for the analysis of drilling. On average, 5 (range 0–41) s of each recordings of dental work were rejected due to artefacts.

The muscular load was normalized to the maximal voluntary EMG activity (MVE) (Mathiassen et al. 1995). The 1st, 10th ("static" load), 50th (median load) and 90th percentiles (peak load) of the amplitude distribution (= amplitude probability distribution function, APDF) were used to describe the load (Jonsson 1982). In addition to the MVCs, submaximal reference voluntary contractions (RVCs) were performed for some of the muscles (see below). During these, a reference voluntary EMG activity (RVE), and, for the trapezius, a reference voluntary force (also denoted RVC), were recorded. These data were used for relating normalized loads of MVC and MVE to each other, and for evaluation of alternative test contractions. "Muscular rest" was defined as EMG activity below 1.0% MVE.

Surface EMG was recorded with disposable Ag/AgCl electrodes with an active area diameter of 6 mm (D-05-VS, Medicotest, Ølstykke, Denmark). The skin was cleaned with acetone and gently rubbed with fine emery cloth. The electrodes were placed along the direction of the muscle, with a rim-to-rim distance of 2 mm. This arrangement gave a bipolar detection configuration with a centre-to-centre distance of 20 mm between the electrodes. The electrode impedance was measured at 25 Hz, and if it exceeded 10 kΩ, the electrodes were replaced after a renewed skin preparation.

The EMG was amplified, filtered (pass band 10 Hz–2 kHz) and transmitted, using telemetric radio transmitters (IC-600, Medinik, Örbyhus, Sweden). The signals were monitored on an oscilloscope and recorded on an FM tape recorder, bandwidth 0–1.25 kHz (MR-30, Teac, Tokyo, Japan). Off line, the signals were filtered, using a sixth-order Butterworth anti-aliasing filter, with a 3 dB point

Table 3 Joint mobility for all ($n = 12$) dentists, and those without (non-disorders, $n = 6$), and with ($n = 6$) disorders

	Group of dentists	Joint mobility (°)	
		Mean (SD)	Range
Head[a]			
Forward	All	62 (8)	48–73
	Non-disorders	65 (7)	55–73
	Disorders	58 (8)	48–69
Backward	All	62 (9)	46–77
	Non-disorders	62 (11)	46–77
	Disorders	63 (9)	55–74
Right	All	39 (7)	29–50
	Non-disorders	42 (7)	34–50
	Disorders	35 (5)	29–42
Left	All	35 (6)	26–41
	Non-disorders	36 (4)	31–41
	Disorders	33 (7)	26–41
Wrist			
Flexion			
Right[b]	All	132 (11)	108–153
	Non-disorders	137 (10)	126–153
	Disorders	128 (11)	108–138
Left[c]	All	144 (12)	121–158
	Non-disorders	150 (7)	140–158
	Disorders	135 (13)	121–151
Deviation			
Right[b]	All	54 (9)	39–66
	Non-disorders	57 (7)	48–66
	Disorders	51 (10)	39–62
Left	All	56 (7)	43–64
	Non-disorders	60 (3)*	55–64
	Disorders	51 (3)*	43–60

* Statistically significant difference between "non-disorders" and "disorders" ($P < 0.05$, Wilcoxon matched-pairs signed-ranks test)
[a] $n = 11$ for "all" $n = 6$ for "non-disorders", and $n = 5$ for "disorders", due to technical problems
[b] $n = 11$ for "all" $n = 5$ for "non-disorders", and $n = 6$ for "disorders", due to technical problems
[c] $n = 10$ for "all" $n = 6$ for "non-disorders", and $n = 4$ for "disorders", due to technical problems

at 400 Hz and a slope of 36 dB/octave, and continuously digitized and stored on hard disk with a sampling frequency of 1024 Hz per channel, using an IBM-compatible PC with a 12-bit A/D expansion board. The EMG signal was digitally bandpass (30–400 Hz) and notch (50 Hz and all harmonics) filtered. Root mean square (RMS), mean power frequency (MPF) and an artefact index (ART) were calculated for epochs of 1/8 s.

The simultaneous display of RMS, MPF and ART, as well as raw EMG, was used for manual artefact rejection; the parts to be excluded from analysis were marked, using a graphic scroll function. This was also used for marking the beginning and end of the recordings of rest, RVC, MVC, work and drilling parts during work. The noise level was determined as the minimum RMS value obtained, when applying a 19-point (2.375 s) moving window, which calculated the median value to the rest recording. This noise level was subtracted, in a power sense, from all RMS values, before further calculations. RVE was calculated as the median RMS value during RVC. MVE was defined as the maximum RMS value during the three (for the extensor muscles six, see below) MVCs; the maximum value was assessed using a 4-point (0.5 s) moving window, which calculated the average value.

For the trapezius muscles, the muscle belly pars descendens was localized by palpation, and the electrode pair was placed with the centre 2 cm laterally to the midpoint. Rest was recorded in a seated, as well as a standing position, for approximately 30 s each. In order to achieve complete relaxation of the trapezius muscles, an oscilloscope was used for visual biofeedback. MVE was recorded during the above force measurement of the trapezius. During RVC, the subject was standing, with one arm at a time abducted in the scapula plane to 90° during 10 s, with a 1 kg dumbbell held in the hand, and with the back of the hand facing upwards. The glenohumeral torque was calculated for both MVC and RVC, using individual anthropometric properties, calculated from height and weight.

For the flexor and extensor muscles of the right forearm, the electrode pairs were placed over the muscle bellies, localized by palpation during voluntary contractions, with supinated arm over the flexor muscles, at a distance of one-third the forearm length from the elbow, and with pronated arm over m. extensor carpi radialis longus and brevis. Rest was recorded during complete relaxation, which was verified by using the oscilloscope for visual biofeedback. MVE for the flexor muscles was recorded during the measurement of maximal hand-grip force (see above). MVE for the extensor muscles was recorded during measurement of both the maximal extensor force during dorsal wrist flexion, and maximal hand-grip force (see above), whichever gave the highest EMG activity. During RVC for the extensor muscles, the subject was seated, with a flexed elbow and the forearm resting on a table in a pronated position; a 2-kg dumbbell was held for 15 s at about 5–10 mm distance from the surface of the table, which gave a slight dorsal flexion of the wrist.

Inclinations and movements of the head

Triaxial accelerometers were used as inclinometers for recording of the forward and sideways bending, in relation to the line of gravity (Hansson et al. 1992). The inclinometers were fixed, using double-sided adhesive tape, one to the forehead, and the other one to the left of the cervico-thoracic spine at the level of C7-T1. The reference position (0° of forward and sideways bending) was defined as the position obtained with the subject standing in an upright position, looking straight ahead. Maximal mobility during forward, backward, right and left bending were recorded with the subject seated in a straight upright position, with supported lumbar spine. The shoulders were fixed by the examiner, who also checked that the positions were held in a straight direction without any rotation. The mean recording duration during work was 16 (range 13–17) min.

Wrist positions and movements

Biaxial electrogoniometers (M110) and data loggers (DL1001 Penny and Giles Biometrics, Blackwood, Gwent, UK) were used for recording of the flexion and deviation angles of both the right and left wrists (Hansson et al. 1996). The reference position was defined as the wrist angles obtained when the subject was standing and the arms and hands were hanging relaxed alongside the body. A wrists mobility test was also performed (Hansson et al. 1996). The mean recording duration during work was 20 (range 13–25) min.

Results

Muscular load

During dental work there was higher load for the right trapezius, as compared with the left (Table 4). On the

Table 4 Muscular load of the trapezii and the flexor and extensor muscles of the right forearm during dental work including drilling, and drilling only. Mean and (SD), as percentages of the maximal voluntary electromyographic (*EMG*) activity (% *MVE*), are shown for all ($n = 11^a$) dentists, and those without (non-disorders, $n = 6$), and with ($n = 5^a$) disorders, at different percentiles of the EMG amplitude distributions

EMG amplitude distribution (percentile)	Group of dentists	Muscular load (% MVE)							
		Dental work including drilling				Drilling only			
		M. trapezius		Right forearm muscles		M. trapezius		Right forearm muscles	
		Right	Left	Flexor	Extensor	Right	Left	Flexor	Extensor
10th	All	3.3 (1.7)$^{\#}$	2.5 (2.0)$^{\#}$	2.5 (1.5)$^{\#}$	2.6 (1.0)$^{\#}$	5.6 (2.5)$^{\#}$	5.0 (2.8)$^{\#}$	7.7 (4.4)$^{\#}$	5.2 (2.0)$^{\#}$
	Non-disorders	4.1 (2.0)	3.5 (2.2)	2.5 (2.1)	2.8 (1.4)	7.1 (2.2)	6.8 (2.4)	7.5 (4.1)	5.8 (2.2)
	Disorders	2.4 (0.8)	1.3 (0.7)	2.6 (0.7)	2.4 (0.4)	3.8 (1.3)	3.0 (1.4)	7.9 (5.2)	4.4 (1.5)
50th	All	8.4 (2.8)	7.0 (2.6)	9.2 (4.7)$^{\#}$	6.2 (2.0)$^{\#}$	7.7 (3.4)	6.9 (3.4)	13.5 (9.5)†	7.1 (2.4)†
	Non-disorders	9.8 (3.2)	8.6 (2.5)	8.5 (4.0)	6.9 (2.4)	9.8 (3.2)	8.9 (3.1)	12.0 (6.7)	7.8 (2.8)
	Disorders	6.6 (0.8)	5.1 (0.9)	10.1 (5.7)	5.4 (1.0)	5.2 (1.5)	4.4 (1.7)	15.4 (12.8)	6.3 (1.6)
90th	All	15.1 (4.6)$^{\dagger\#}$	11.9 (3.0)$^{\dagger\#}$	24.5 (13.6)$^{\dagger\#}$	11.8 (3.8)$^{\dagger\#}$	10.5 (4.6)$^{\#}$	9.3 (4.0)$^{\#}$	20.7 (14.8)$^{\dagger\#}$	9.8 (3.0)$^{\dagger\#}$
	Non-disorders	17.3 (5.2)	13.6 (2.9)	22.5 (10.9)	12.9 (4.5)	13.3 (4.3)	11.5 (4.0)	18.6 (9.9)	10.7 (3.4)
	Disorders	12.4 (1.3)	9.7 (1.0)	26.9 (17.4)	10.4 (2.7)	7.2 (2.0)	6.6 (2.1)	23.2 (20.2)	8.7 (2.3)

† Statistically significant difference between right and left m. trapezius, or between the flexor and extensor muscles ($P < 0.05$, Wilcoxon matched-pairs signed-ranks test). This test was performed only for group "all", but the differences were consistent for both group "non-disorders" and "disorders"

\# Statistically significant difference between dental work including drilling and drilling only ($P < 0.05$). This test was performed only for group "all", but the differences were consistent for both group "non-disorders" and "disorders"

[a] Of the original 12 dentists, one in the group "disorders" was excluded; she was, due to pain, not able to perform muscular strength tests, acceptable for determining MVE

Table 5 Relations between muscular activity (*RVE* and *MVE*) and exerted glenohumeral torque during reference voluntary contractions (RVC) and maximal voluntary contraction (MVC) respectively, for the trapezius muscles. For the extensor muscles of the right forearm, the muscle activity relation is given. Mean and (SD) are shown for all ($n = 11$[a]) dentists, and those without (non-disorders, $n = 6$), and with ($n = 5$[a]) disorders

Quotient	Group of dentists	Quotient (%)		
		M. trapezius		Forearm muscles
		Right	Left	Extensor
RVE/MVE	All	16.0 (3.1)	17.3 (3.8)	22.4 (10.8)
	Non-disorders	15.7 (3.5)	17.0 (4.1)	22.8 (12.3)
	Disorders	16.5 (3.0)	17.7 (3.8)	22.0 (10.3)
RVC/MVC	All	33.8 (5.2)	35.4 (4.8)	–[b]
	Non-disorders	33.8 (6.4)	36.2 (5.9)	
	Disorders	33.7 (3.8)	34.5 (3.4)	
(RVE/MVE)/(RVC/MVC)	All	47.9 (8.5)	49.1 (10.0)	–[b]
	Non-disorders	46.6 (6.8)	47.0 (8.6)	
	Disorders	49.4 (10.8)	51.7 (11.9)	

[a] Of the original 12 dentists, one in the group "disorders" was excluded; she was, due to pain, not able to perform muscular strength tests required for determining MVE
[b] Not applicable

contrary, for the drilling part of the work, the differences between the right and left trapezius were small.

For the trapezius "muscular rest" (<1.0% MVE) was found, during dental work, for more than 1% of the time in almost all dentists (right side 8/11, left 10/11). Few "rested" more than 10% of the time (right 0/11, left 2/11) and nobody more than 50% (not in table). During drilling, only one dentist "rested" for more than 1% of the time (on the left side), and nobody more than 10%.

The load levels for the right forearm muscles were similar to the trapezii, except that the peak load (24.5% MVE) for the flexor muscles was higher. This implies that the forearm muscles also are highly active during a considerable time fraction of work. For the forearm load, a difference in activation pattern between flexors and extensors was found. The flexors had higher peak and median loads than the extensors during drilling (Table 4). The same tendency was seen during dental work.

For the forearm muscles "muscular rest" was found, during dental work, for more than 1% of the time in many dentists (flexors 8/11, extensors 7/11); few "rested" more than 10% of the time (flexors 2/11, extensors 1/11) and nobody more than 50%. During drilling, nobody "rested" for more than 1% of the time.

During drilling, the load for all the muscles was much less varied; the "static" loads were higher than during dental work, and the peak loads were lower than for dental work. Further, for the 1st percentile, the mean loads were 3.9%–4.7% MVE for all the muscles (not in table).

Subjects with disorders had lower loads for both the right and left trapezius muscles (up to 50%, and almost statistically significant ($P < 0.1$), for median and peak loads on the left side) during dental work, as well as drilling (Table 4). For the forearm, there were no corresponding differences between these groups.

At the performance of the RVC test, the average EMG activity for the trapezius muscles was 17% MVE and the corresponding torque was 35% MVC (Table 5), which gave an EMG/torque relation of 0.5. The average coefficient of variation (CV = SD/mean) for the RVE/MVE relation for m. trapezius was 21%, while, for the extensor muscles, there was a larger variation (CV = 48%). For the extensor muscles, the highest activity was obtained during the specific dorsiflexion test of the wrist for 6 of the 11 subjects, who were able to perform acceptable tests, versus 5 during the hand-grip test. The correlation coefficient between MVE and RVE normated loads was 0.95, based on the 66 individual values for 10th, 50th, and 90th percentiles for the right and left trapezius muscles.

Thus, when we used RVE (as an alternative to MVE) for normalization of the EMG for the trapezius, the same patterns were found for differences between the groups, between right and left side and between drilling and dental work.

Inclinations and movements of the head

Dental work implied steep forward bending of the head (Table 6, Fig. 1). For example, during 90% of the time (10th percentile), the head was forward tilted $\geqslant 17^\circ$, half the time $\geqslant 39^\circ$, and 10% $\geqslant 49^\circ$. The sideways bending was symmetrical, and centred around an almost neutral position (5° to the left). From the difference between head and C7-T1 measurements, it is obvious, that a major part of the head inclination is performed in the cervical spine (forward, 50th percentile: head 39°, C7-T1 15°, i.e. roughly about 24° above the level of C7-T1). The range of motion (95th–5th percentile) for sideways bending was somewhat lower than for forward/backward bending.

Table 6 Positions and movements of head and C7-T1 during dental work. Mean and (SD) are shown for all ($n = 11^a$) dentists, and those without (non-disorders, $n = 6$), and with ($n = 5^a$) disorders, at different percentiles of the angular and velocity amplitude distributions. For sideways angles, positive values denote bending to the right

Distribution (percentile)	Group of dentists	Head		C7-T1	
		Forward	Sideways	Forward	Sideways
Positions (°)					
10th	All	17 (9)	−17 (11)	4 (7)	−8 (6)
	Non-disorders	19 (10)	−23 (11)	4 (9)	−11 (7)
	Disorders	14 (9)	−9 (7)	5 (5)	−5 (2)
50th	All	39 (7)	−5 (9)	15 (7)	−2 (5)
	Non-disorders	41 (8)	−7 (10)	15 (7)	−3 (7)
	Disorders	37 (6)	−3 (7)	14 (8)	0 (2)
90th	All	49 (7)	14 (11)	22 (9)	7 (8)
	Non-disorders	50 (9)	19 (12)	25 (8)	9 (11)
	Disorders	48 (4)	9 (8)	20 (10)	5 (2)
95th–5th	All	42 (9)	39 (15)	23 (7)	20 (8)
	Non-disorders	41 (7)	50 (6)	26 (4)	25 (7)
	Disorders	42 (11)	24 (7)	19 (8)	13 (3)
Velocities (°/s)					
10th	All	0.0 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
	Non-disorders	0.0 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
	Disorders	0.0 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
50th	All	4.2 (0.8)	6.0 (1.0)	2.6 (0.8)	2.6 (0.7)
	Non-disorders	4.4 (1.0)	6.2 (1.1)	3.0 (0.9)	2.9 (0.7)
	Disorders	3.9 (0.3)	5.7 (0.8)	2.1 (0.3)	2.1 (0.2)
90th	All	26 (7)	32 (8)	18 (5)	16 (5)
	Non-disorders	29 (8)	36 (9)	21 (6)	19 (5)
	Disorders	22 (3)	28 (4)	14 (2)	13 (2)

[a] Of the original 12 dentists, one in the group "disorders" was excluded, due to technical problems

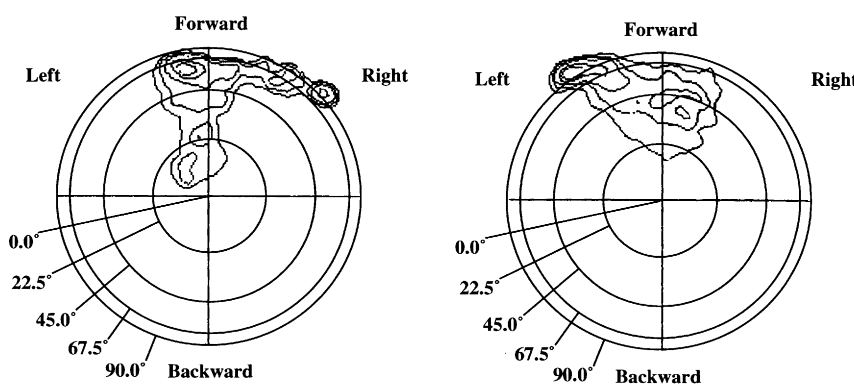

Fig. 1 Contour plots of the two-dimensional distributions of head positions, during 17 min of dental work in the upper jaw for one dentists (left), and in the lower jaw for another dentist (right), both without disorders. The origin represents an upright position, and the concentric circles inclinations of 22.5°, 45°, 67.5° and 90°. Both dentists worked bent forward (median position left 47° and right 48°). Work in the upper jaw implies a sidebending to the right >33° for 10% of the time, while work in lower jaw >34° to the left

In addition, the angular velocities for the head were low; for at least 10% of the time, the head was held in an almost fixed position (velocity ⩽0.1°/s) and the median forward/backward velocity was 4.2°/s (Table 6). The velocities of C7-T1 were lower than those of the head, both in sideways and forward/backward directions. The sideways velocities were higher than the forward/backward ones for the head, while for C7-T1 they were in the same range. The forward/backward peak velocity (90th percentile) of the head was 26°/s and the sideways one was 32°/s. Subjects with disorders showed a lower (almost statistically significant, $P < 0.1$) range of motion in sideways bending of both the head, and C7-T1, than subjects without (Table 6). Similarly, subjects with disorders showed, for C7-T1, a tendency to lower velocities than subjects without. However, the most impressive trait was the greater variation of C7-T1 velocities in the non-disorders group. As to positions, the influence of whether work was in the upper or lower jaw was so great, that a comparison between the groups was not relevant.

Work in the upper or lower jaw influenced the direction of side bending of the head, and to some extent C7-T1 (Table 7). The other variables did not reflect any

Table 7 Head and C7-T1 sideward inclination in 11[a] dentists during work in upper ($n = 5$), or lower jaw ($n = 6$). Mean values and (SD) are shown at different percentiles of the angular amplitude distributions. Positive angles denote bending to the right

Distribution (percentile)	Positions (°)			
	Head		C7-T1	
	Upper jaw	Lower jaw	Upper jaw	Lower jaw
10th	− 7 (3)[x]	−25 (9)[x]	−5 (2)	−11 (7)
50th	2 (5)[x]	−11 (5)[x]	1 (3)	− 4 (6)
90th	21 (12)	9 (8)	10 (9)	4 (7)
95th–5th	37 (18)	40 (14)	20 (10)	19 (7)

[a] One of the original 12 dentists was excluded, due to technical problems during recording

[x] Statistically significant difference between work in upper and lower jaw ($P < 0.05$, Mann–Whitney test)

obvious differences. Thus, during work in the lower jaw, the head was bent >25° to the left during 10% of the time, as compared with only >7° during work in the upper jaw. The range of motion was not clearly influenced.

Wrist positions and movements

There were large differences between the right and left hands, regarding both wrist angles and dynamic parameters (Table 8). The two-dimensional displays of wrist angle distributions revealed the occurrence of combinations of flexion and deviation angles, close to the extreme, e.g., the combination of high palmar flexion and ulnar deviation for the left hand (Fig. 2).

The right hand was held in a more dorsiflexed position throughout the work (10th, 50th and 90th percentiles), as compared with the left one (Table 8). For example, on average (central position), the right hand was 21° dorsiflexed, while the left one was 3° palmar flexed. For deviation angles, the right hand was in a more radially deviated position throughout the work. In addition, the deviation range of motion was 11° wider for the left hand. The left hand showed lower velocities, more pauses and lower repetitiveness (MPF) than the right one, for both flexion and deviation. This implies a more static type of work for the left hand. When comparing subjects with and without disorders, there was a tendency to lower velocities in the former group (Table 8).

Discussion

Muscular load

We used MVE for normalization of the EMG activity. Provided that the MVE is correctly assessed, the muscular load during work is related to the maximal capacity of the subject. However, due to pain inhibition, subjects with pain might not be able to fully activate their muscles. Thus, there is a risk of underestimation of MVE (and hence an overestimation of the load), especially among subjects with disorders. Indeed, one subject was excluded because of this problem. It is also an ethical question as to whether the subjects with pain should really be forced to perform MVCs because of the risk of causing further injury. Conversely, RVE can be obtained in most subjects, except those who cannot abduct their arms to the test position. Also, it is easier to instruct the subject. Hence, there are advantages of using RVE instead of MVE, especially since measurement of RVE is less time consuming and requires less equipment. One disadvantage of RVE is that the relation to the maximal capacity of the subject is lost. Palmerud et al. (1995) have shown that the activity of the trapezius muscles in comparable positions, without external load, can be voluntarily decreased to as little as 56% of the initial activity by means of instructions and visual biofeedback. This implies, that overstabilization of the shoulder muscles occurs, and might vary between individuals, and hence makes the RVE value sensitive to, for example, personal traits and disorders. However, we performed the RVC test with a simple instruction to raise the arm, and without any biofeedback, and we used an external load, which should have made it more difficult to voluntarily reduce the muscular activity. Moreover, the CV for the trapezius RVE was reasonable, and there were only small differences between the groups without and with disorders. Also, when we used RVE instead of MVE to normalize the EMG, the same patterns were found for differences between the groups, between right and left side and between drilling and dental work. Thus, for the trapezius muscle, RVE might be an alternative to MVE in field studies, and the average RVE of 17% MVE can be used for transformation of load levels between RVE and MVE. Moreover, the quotient between RVE and RVC (0.5) can be used for transformation of load levels between MVE and MVC for trapezius load levels below 17% MVE. However, if men or women in occupations with higher force demands are studied, parallel use of RVE and MVE is still recommended, in order to determine the RVE/MVE relation in such groups.

For the extensor muscles, however, RVE does not seem to be suitable as an alternative to MVE, due to the high CV. Conceptually, MVE should be determined as the maximum EMG activity obtained from the muscles in any combination of posture and attempted movements (Schüldt and Harms-Ringdahl 1988). However, in field studies there is a need to minimize the time and equipment used for the calibration procedures. For the extensor muscles, the hand-grip test was as good as the specific dorsiflexion test for recording of MVE. Hence, the two tests are both suitable. If the hand-grip test is used as the only MVE test for the extensor

Table 8 Wrist positions and movements for left and right hands during dental work. Mean values and (SD) are shown for all dentists ($n = 12$), and those without (non-disorders, $n = 6$), and with ($n = 6$) disorders. Positive values denote flexion in palmar direction and deviation in ulnar direction, *MPF* mean power frequency

	Group of dentists	Flexion				Deviation			
		Right		Left[a]		Right		Left	
Positions (°)									
Distribution (percentile)									
10th	All	− 42	(7)[b†]	− 27	(7)[†]	− 14	(6)[b†]	− 6	(7)[†]
	Non-disorders	− 38	(8)[b]	− 24	(5)	− 12	(5)[b]	− 8	(6)
	Disorders	− 45	(4)	− 30	(10)	− 16	(6)	− 4	(8)
50th	All	− 21	(6)[b†]	3	(11)[†]	− 2	(7)[b†]	12	(15)[†]
	Non-disorders	− 18	(6)[b]	3	(7)	0	(5)[b]	11	(13)
	Disorders	− 24	(5)	2	(18)	− 4	(8)	13	(18)
90th	All	7	(9)[b†]	22	(13)[†]	12	(7)[b†]	31	(11)[†]
	Non-disorders	9	(7)[b]	23	(13)	15	(5)[b]	30	(10)
	Disorders	5	(11)	21	(15)	10	(8)	31	(13)
95th–5th	All	62	(10)	61	(15)	35	(5)[†]	46	(9)[†]
	Non-disorders	61	(7)	60	(18)	37	(5)	48	(7)
	Disorders	63	(12)	63	(12)	33	(4)	44	(11)
Movements									
Velocities									
Below 1°/s (% of time)									
	All	18	(6)[†]	36	(6)[†]	27	(6)[†]	41	(6)[†]
	Non-disorders	17	(5)	36	(6)	26	(6)	40	(7)
	Disorders	19	(8)	35	(6)	28	(6)	41	(6)
Distribution (percentile; °/s)									
50th	All	6.2	(2.3)[†]	1.5	(1.1)[†]	2.7	(1.2)[†]	0.7	(0.6)[†]
	Non-disorders	6.8	(1.5)	1.6	(1.3)	3.1	(1.3)	0.8	(0.8)
	Disorders	5.7	(2.9)	1.3	(0.8)	2.3	(1.2)	0.6	(0.4)
90th	All	45	(8)[†]	31	(12)[†]	26	(4)[†]	19	(6)[†]
	Non-disorders	48	(6)	32	(14)	29	(4)*	21	(7)
	Disorders	41	(8)	28	(7)	24	(3)[≠]	17	(2)
Amplitude (RMS; °)	All	13.9	(2.2)[†]	11.7	(2.9)[†]	8.2	(1.1)	8.0	(1.7)
	Non-disorders	14.2	(1.5)	12.2	(3.4)	8.8	(0.9)	8.6	(2.2)
	Disorders	13.7	(2.9)	11.1	(2.3)	7.6	(1.0)	7.4	(0.9)
Repetitiveness (MPF; Hz)	All	0.18	(0.04)[†]	0.15	(0.03)[†]	0.20	(0.04)[†]	0.14	(0.02)[†]
	Non-disorders	0.20	(0.03)	0.15	(0.03)	0.21	(0.04)	0.15	(0.02)
	Disorders	0.17	(0.04)	0.15	(0.03)	0.18	(0.02)	0.13	(0.02)

[†] Statistically significant difference between right and left hand ($P < 0.05$, Wilcoxon matched-pairs signed-ranks test). This test was performed only for group "all", but the differences were consistent for both group "non-disorders" and "disorders"
* Statistically significant difference between "non-disorders" and "disorders" ($P < 0.05$)
[a] $n = 10$ for "all", $n = 6$ for "non-disorders", and $n = 4$ for "disorders", due to technical problems
[b] $n = 11$ for "all", $n = 5$ for "non-disorders", and $n = 6$ for "disorders", due to technical problems

muscles, this means that only one test is needed, to obtain MVE for both flexors and extensors of the forearm. Of course, if only the hand-grip test is used, the maximal recorded MVE on group level will decrease (in our material to 90%), and the assessed load levels during work will increase accordingly (to 111%).

Jonsson (1982) suggested a maximum acceptable "static" load of 5% MVC (related to the maximum force/torque), a median load of 14% and a peak load of 70%. The relation between EMG activity and exerted force or torque cannot be assumed to be linear from 0 to 100% MVC. However, for the trapezius muscles, a linear relation up to 30% of maximum torque can be assumed (Jonsson 1982). In our material, the normalized RVE/RVC relation for the trapezius muscles was 0.5 at the lower load levels. Thus, the recommendations for unacceptable load levels (Jonsson 1982) have to be multiplied by this factor to be applicable to our figures. Hence, both the "static" and median loads, for both right and left m. trapezius, exceeded the recommendations by Jonsson, while the peak load did not. However, other recommendations for acceptable "static" load have been suggested, e.g., 1% MVC (Aarås 1987). Further, according to Westgaard (1988),

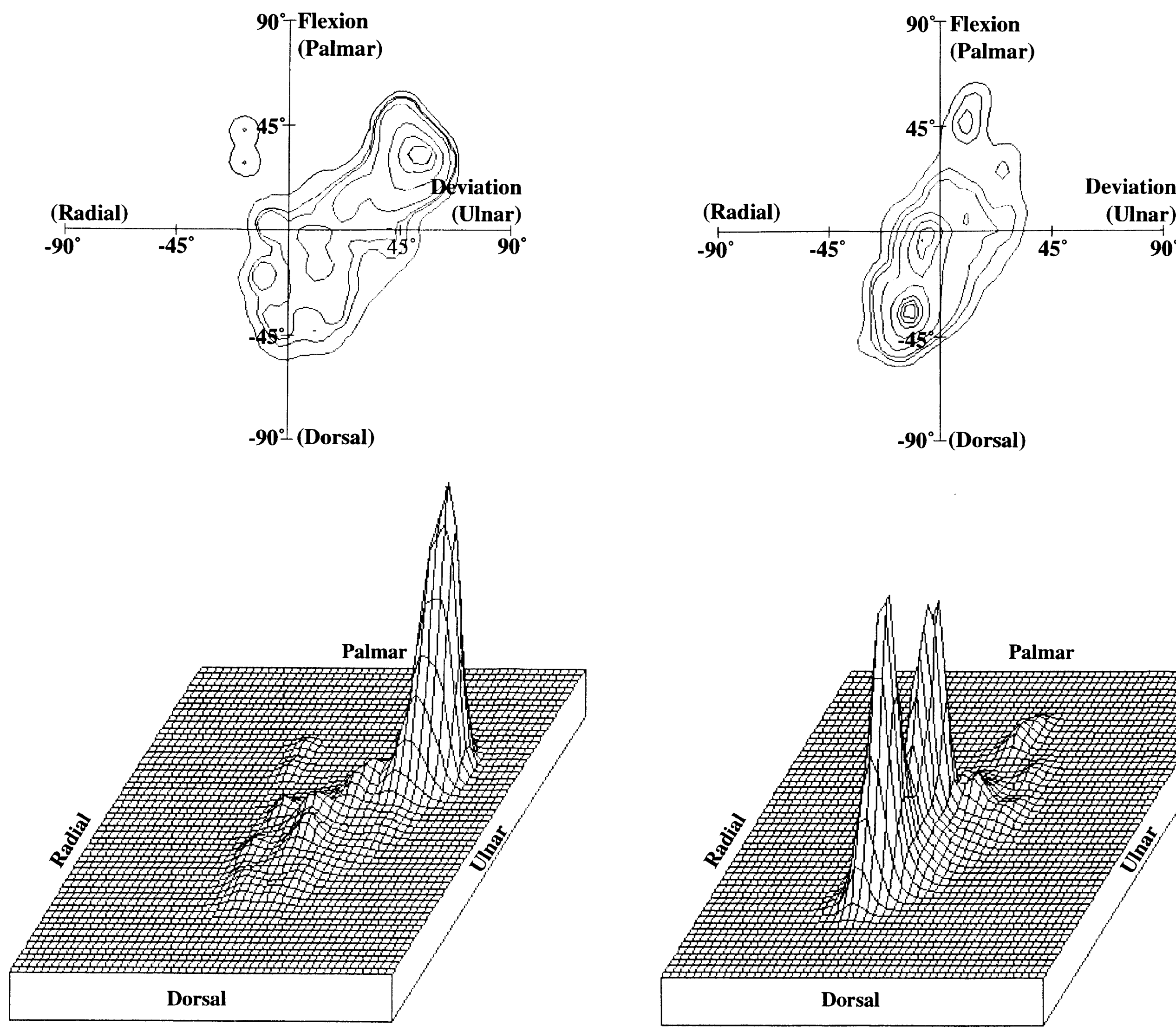

Fig. 2 Contour (upper) and axonometric (lower) plots of the two-dimensional wrist angle distributions for the left hand (left) and right hand (right), simultaneously recorded during 18 min of dental work, performed by one dentist. The dorsiflexed position, without much deviation, of the right hand is obvious. In contrast, the left hand is held in a combination of palmar flexion and ulnar deviation. The "island to the northwest", in the contour plot for the left hand, reflects a static position in combined palmar flexion and radial deviation, maintained for a short time

the combination of load and pattern of pauses is more relevant than the "static" load for determining acceptable strain. On the basis of the properties of our equipment and data analysis algorithms, we define "muscular rest" as a load below 1.0% MVE. This corresponds, considering the methodological differences, to the limit proposed by other authors (Veiersted et al. 1990; Veiersted et al. 1993). In the present dental work, "muscular rest" was recorded during only a very low fraction of the time, which may constitute a health risk for the dentists.

The load on the right trapezius was, regarding "static", median and peak levels, higher than on the left one. This may depend on the different work tasks of the two hands and the fact that the possibility of giving good support to the forearm and hand is better on the left side. The right (dominant) hand is performing more manipulative operations throughout the treatment, while the left one, often holding the mirror, is acting mostly as a support. The left hand and forearm can therefore be supported against the patient's head or the backrest of the dental chair, which gives a good opportunity to lower the left arm to a position closer to the body, and it is thus possible to decrease the muscle activity in the shoulder region. This may be the explanation why there was a tendency for subjects with disorders to show a lower EMG activity in the left trapezius during work than those without disorders, which cannot be explained by a reduced maximum capacity due to pain inhibition.

The differences between the groups in muscular activity during the standardized tests (RVE) were very small. This indicates, that there were no general variations in the use of their muscles. However, during work, the disorders group was able to decrease remarkably the use of their muscles, by up to one-third of the load. This indicates that no less than one-third of the muscular load on the trapezius muscles for the non-disorders subjects might be unnecessary. The lack of a corresponding reduction of load for the forearm muscles, can be ascribed to either the actual work demands, or to different characteristics of the forearm muscles, as compared with the trapezius.

Milerad et al. (1991) found "static", median and peak loads of trapezius (averaged for left and right side) at about 2, 6, and 15% MVE, and Finsen (1995) 9, 13, and 18% MVE during comparable work tasks of dental work. The peak loads are in agreement with our average value of 14% MVE. However, our findings show somewhat higher "static" (2.9%) and median (7.7%) loads than Milerad et al (1991), but lower than Finsen (1995). Furthermore, our findings show equal "static" load, but a somewhat higher median one than Christensen (1986) found in female assembly plant employees.

The CV in our data was about half of that presented by Milerad et al. (1991) and Finsen (1995). At the lower load levels, especially as regards the "static" load, the noise compensation method is crucial. On the one hand, if no noise compensation is performed, erroneously high "static" load levels will be obtained. On the other hand, if a linear subtraction of the noise amplitude is made, instead of the correct power sense subtraction, an overcompensation will occur, which will be obvious only at low levels. This probably accounts for the variation between our data and that of the other authors.

The median level of 3.9% MVE for the extensor muscles of the forearm found by Milerad et al. (1991) is lower than our findings (6.2% MVE). Also, the "static" load (derived from their figure) of approximately 1% MVE, is lower than our corresponding value of 2.6% MVE, while the peak load of about 13% MVE is in accordance with our value of 11.8% MVE. Also, for all these figures, the noise reduction method used may be of importance.

Moore et al. (1991) simulated combinations of high and low force, with high and low repetitiveness, according to Silverstein et al. (1986). Among other exposure variables, the activity of the flexor muscles of the forearm was measured. Assuming an RVE/RVC relation of 0.5, the "static" load of the forearm flexors in our dentists clearly exceed all combinations of repetitiveness and force. Indeed, our median load matches the highest of those combinations. Thus, although dental work can neither be considered to be demanding of extremely high force, nor highly repetitive, the "static" and median muscle activities are rather high and might be a risk factor for developing disorders.

We found differences in the forearm load between the activity in flexors and extensors. This is in accordance with differences in the activation pattern between the extensor and flexor muscles of the forearm (Hägg et al. 1994). It has been concluded that the role of the extensors, with their more "static" activation, is as a wrist stabilizer during gripping work, which contributes to the forearm strain in manual work.

The somewhat higher EMG activity level found in the forearm muscles during drilling may be explained either by the work performance itself, or by a vibration provoked tonic reflex contraction (Radwin et al. 1987), or by a combination of both. Drilling is one of the most critical and precision-demanding work tasks, in that it can cause severe damage to vulnerable tissues outside the teeth, if the drill slips. This can explain why a very firm grip is mostly applied during this operation. Although, it cannot be excluded that vibration exposure might provoke a tonic vibration reflex, it is more likely that the gripforce is affected at vibration exposure at lower frequencies (20–160 Hz) (Radwin et al. 1987; Park et al. 1993) than found in dentistry. However, if such an effect exists, it cannot be quantified in a study such as the present one. Still, it is the total muscle load during work that is of the most interest from a health point of view.

The relatively high load on the forearm muscles, during drilling, without pauses, is not considered to be a risk factor for development of disorders, as the exposure time for this operation is very limited, lasting on average only 9.3% of the total treatment time.

Inclinations and movements of the head

Among the dentists, the steep forward bending of the head was combined with a considerable sideward one. This combination is more strained than a pure forward flexion, and implies a higher load on the cervical spine, which is a probable risk factor for development of symptoms in the neck region. Moreover, the head position was locked, shown by the low velocities. This might explain why subjects with disorders seem to avoid the extreme side-bent positions. Our measurement showed a forward-bent head-position $\geqslant 17°$ during 90% of the work time, and $\geqslant 39°$ for 50%. This is in accordance with findings by Finsen (1995). Furthermore, Green and Brown (1963) found that dentists, during an average of 69% of the time, worked in a "head-down" position, according to their vague definition.

From earlier studies, it is well known that neck/shoulder disorders, and combinations of both, are common among dentists (Rundcrantz et al. 1990; Åkesson et al. 1995; Finsen 1995). We therefore assume, that the work posture for dentists plays an important role as a risk factor for the development of work-related disorders. This is in accordance with other studies (Hagberg and Hagberg 1989; Haslegrave 1994).

In the present study, video recordings revealed that the lumbar spine was supported by the backrest throughout the treatment. The degree of inclination of C7-T1 makes no distinction between flexion of the thoracic or the lumbar spine or the hips. For more detailed analysis of the thoracic and lumbar spine movements, an additional inclinometer has to be used. However, the difference between the inclination of the head in relation to that of C7-T1 indicates, that the position of the head is mainly due to flexion above the C7-T1 level.

Wrist positions and movements

We found extremely dorsiflexed positions of the wrist of the dominant hand, as well as a combination of extreme palmar flexion and ulnar deviation in the non-dominant one. This may be of pathogenetic importance. Thus, although the pathogenesis of work-related wrist disorders is still not fully understood, special attention has been paid to both positions and movements of the wrists. Hence, it has been suggested, due to the location of the disorders in the soft tissue around the joints, that mechanical stress factors play an important role (Armstrong et al. 1994)

As to positions, the tendons in and around the carpal tunnel are of special interest, because of their possible contribution to the carpal tunnel syndrome (CTS). It has been shown that the pressure on the median nerve increases at dorsiflexion of the wrist (Lundborg 1988), which, in turn, reduces the space inside the carpal tunnel. Palmar flexion, on the other hand, may squeeze the nerve between the flexor tendons and flexor retinaculum. Palmar flexion appeared to be a greater risk for CTS than dorsiflexion (Loslever and Ranaivosoa 1993). Further, wrist positions affect the work performance. Thus, an extreme degree of palmar flexion reduces the gripping power. Also, extreme dorsiflexion (hyperextension) does not permit effective use of the distal phalanges for fine manipulative movements (due to the tension of the flexor muscles of the fingers; Tichauer 1975), factors which disturb highly precision-demanding work with handtools with thin grips, as in dentistry. A position of 30° dorsiflexion and 10° ulnar deviation is recommended as an optimal functional position at work with handtools, while wrist postures beyond dorsiflexion 10–50° and ulnar deviation 0–20° are not acceptable (Kilbom et al. 1993). The wrist position of our dentists exceeded those limits during a considerable fraction of the work time (flexion: right $\geqslant$10%, left $\geqslant$50%; deviation: right $\geqslant$50%, left $\geqslant$20%). Moreover, this pattern was combined with high grip force, as is indicated by the EMG activity in the muscles of the forearm. This combined exposure may, according to suggested injury-provoking mechanisms (especially in women exerting high force; Silverstein et al. 1986), explain frequent wrist/hand disorders among dentists (Rundcrantz et al. 1990; unpublished data).

As to movements, repetitive exertions may lead to hypertrophy of the flexor tendons and increase of the synovia, as well as oedema of tissues inside the carpal tunnel (Armstrong et al. 1984). Indeed, repetitive wrist movement is a risk factor for CTS (Silverstein et al. 1986, 1987). Moreover, Marras and Schoenmarklin (1993) found that velocity and acceleration parameters displayed significant relationships with "cumulative trauma disorders (CTD)" in hand or wrist. However, in the dentists in this study, the dynamic components – velocity and repetitiveness (MPF) – were low, as compared with, for example, workers in the fish-processing industry (Ohlsson et al. 1994b) and other industrial workers (Marras and Schoenmarklin 1993). Indeed, dentists are more likely to develop other wrist disorders than CTS, e.g. tendon-related symptoms and non-specific pain of the hand itself (unpublished data).

The supination and pronation of the forearm might also be of interest to quantify. Such measurements would make it possible to compensate for the main measurement error, which is caused by the inherent cross-talk of the goniometer in combination with pronation or supination (Hansson et al. 1996).

Disorder/non-disorder

The subjects with disorders had a clear history of long-lasting, intense complaints, as well as clinical findings. Although the clinical examination was not performed in connection with the measurements, the presently observed lower mobility in the disorders group, as compared with the others, indicates persistent disorders. Moreover, the subjective pain assessment (VAS) in those with disorders was higher.

Although the present subjects were few, the dentists with disorders had muscular loads up to one-third lower than those without. A recent study (Carlson et al. 1996), which reports that patients with muscle pain had lower trapezius EMG activity than those without, is compatible with our findings. There is no reason to believe that this lower load had caused the disorders; rather, this would be an adaptation caused by the disorders. Indeed, dentists with musculoskeletal disorders seem to work in a more optimal and "load"-saving manner. They are probably continuously reminded of the need to practise good ergonomic principles to avoid fatigue and overload of the most affected structures. This makes it possible for them to continue their occupation. However, in spite of low load, they still suffered from their disorders. Further, their low load indicates, that the high strain in dentists without disorder is unnecessary, which means a potential for prevention (see below).

Almost all the pair-wise matched dentists were also, in fact, performing work as a pair in the same jaws. We therefore assume that the differences between subjects with and without disorders, do not depend on work in different jaws.

Future perspective of quantitative measurements of physical work load

Concepts, such as constrained postures, positions close to extremes, steep forward bending, lack of pauses, repetitiveness, dynamic motion, etc., have been analysed with the objective and quantitative methods used in this study. Methods with this capacity are needed in order to collect relevant and standardized data in epidemiological studies, and will also be generally applicable for comparing work load in different studies.

In order to determine, in epidemiological studies, any causal influence of exposure to disorders, the exposure measurements should, ideally, be performed before the occurrence of the disorders. However, such prospective studies are cumbersome. Thus, most studies are cross-sectional. At that time, many individuals have disorders, and may not be representative as to the exposure that preceded it. Moreover, the healthy subjects may be survivors, who, due to an optimal mode of performing the work task and/or low susceptibility, may not be representative.

More epedimiological studies, combining both direct exposure measurements, as used in this study, and detailed clinical investigations of the disorders, are needed to assess exposure/response relationships. This should, eventually, enable establishment of guidelines for physical work load, and measurement strategies to control the adherence to these.

Prevention

The dentists need, not only functionally designed dental equipment, but also instruction and training in ergonomic principles as applied to dentistry. As a preventive step, students should, from the beginning of their undergraduate studies, be trained to perform work within optimal postures and good habits. Special attention must be paid to work postures and movement patterns that influence head and wrist positions and, furthermore, to measures that lower the static load on the shoulder muscles; factors which, due to the localization of disorders found in dentists, might play the most important role for prevention of future disorders.

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References

Aarås A (1987) Postural load and the development of musculoskeletal illness. Scand J Rehab Med Suppl 18

Åkesson I, Lundborg G, Horstmann V, Skerfving S (1995) Neuropathy in female dental personnel exposed to high-frequency vibrations. Occup Environ Med 52:116–123

Armstrong TJ, Castelli WA, Evans G, Diaz-Perez R (1984) Some histological changes in carpal tunnel contents and their biomechanical implications. J Occup Med 26:197–201

Armstrong TJ, Werner RA, Rempel DM (1994) Biomechanical aspects of work-related wrist disorders. Proceedings of the IEA'94. Toronto, vol 2. Occupational health and safety, pp 225–227

Carlson C, Wynn KT, Edwards J, Okeson JP, Nitz AJ, Workman DE, Cassisi J (1996) Ambulatory electromyogram activity in the upper trapezius region. Patients with muscle pain vs. pain-free control subjects. Spine 5:595–599

Christensen H (1986) Muscle activity and fatigue in the shoulder muscles of assembly-plant employees. Scand J Work Environ Health 12:582–587

Finsen L (1995) Biomechanical analyses of occupational work loads in the neck and shoulder. A study in dentistry. PhD thesis, National Institute of Occupational Health, Copenhagen

Green EJ, Brown ME (1963) Body mechanics applied to the practice of dentistry. J Am Dent Assoc 67:679–697

Hagberg M (1992) Exposure variables in ergonomic epidemiology. Am J Ind Med 21:91–100

Hagberg M, Wegman DH (1987) Prevalence rates and odds ratios of shoulder-neck diseases in different occupational groups. Br J Ind Med 44:602–610

Hagberg M, Hagberg C (1989) Risks and prevention of musculoskeletal disorders among dentists. In: Brane D, Edling C (eds) Occupational hazards in the health professions. CRC Press Boca Raton, pp 323–332

Hägg GM, Öster J, Byström S (1994) Forearm/hand load exposure in automobile assembly line workers measured as electromyographic activity in flexors and extensors and wrist angle motion. Proceedings of the IEA '94. Toronto, vol. 2. Occupational health and safety pp 129–131

Hansson G-Å, Björn F, Carlsson P (1992) A new triaxial accelerometer and its application as an advanced inclinometer. Proceedings of the 9th International Congress of ISEK, Florence, Italy, 28 June–2 July 1992 (Abstract, pp 207)

Hansson G-Å, Balogh I, Ohlsson K, Rylander L, Skerfving S (1996) Goniometer measurement and computer analysis of wrist angles and movements applied to occupational repetitive work. J Electromyogr Kinesiol 6:23–35

Haslegrave CM (1994) What do we mean by a "working posture?" Ergonomics 37:781–799

Jonsson B (1982) Measurement and evaluation of local muscular strain in the shoulder during constrained work. J Hum Ergol 11:73–88

Katevuo K, Aitasalo K, Lehtinen R, Pietilä J (1985) Skeletal changes in dentists and farmers in Finland. Commun Dent Oral Epidemiol 13:23–25

Kilbom Å, Sperling L, Wikström L, Kadefors R, Dahlman S (1993) A model for ergonomic evaluation of work with hand tools. In: Nielsen R, Jørgensen K (eds) Advances in industrial ergonomics and safety V. Taylor and Francis, London, pp 629–636

Loslever P, Ranaivosoa A (1993) Biomechanical and epidemiological investigation of carpal tunnel syndrome at workplaces with high risk factors. Ergonomics 36:537–554

Lundborg G (1988) Nerve injury and repair. Churchill Livingstone, Edinburgh, pp 102–124

Marras WS, Schoenmarklin RW (1993) Wrist motions in industry. Ergonomics 36:341–351

Mathiassen SE, Winkel J, Hägg GM (1995) Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies: a review. J Electromyogr Kinesiol 5:197–226

Milerad E, Ekenvall L (1990) Symptoms of the neck and upper extremities in dentists. Scand J Work Environ Health 16:129–134

Milerad E, Ericson MO, Nisell R, Kilbom Å (1991) An electromyographic study of dental work. Ergonomics 7:953–962

Moore A, Wells R, Ranney D (1991) Quantifying exposure in occupational manual tasks with cumulative trauma disorders potential. Ergonomics 34:1433–1453

Murtomaa H (1982) Work-related complaints of dentists and dental assistants. Int Arch Occup Environ Health 50:231–236

Ohlsson K, Attewell R, Johnsson B, Ahlm A, Skerfving S (1994a) An assessment of neck and upper extremity disorders by questionnaire and clinical examination. Ergonomics 37:891–897

Ohlsson K, Hansson G-Å, Balogh I, Strömberg U, Pålsson B, Nordander C, Rylander L, Skerfving S (1994b) Disorders of the neck and upper limbs in women in the fish processing industry. Occup Environ Med 51:826–832

Palmerud G, Kadefors R, Sporrong H, Järvholm U, Herberts P (1995) Voluntary redistribution of muscle activity in human shoulder muscles. Ergonomics 38:806–815

Park HS, Bernard MS, Martin J (1993) Contribution of the tonic vibration reflex to muscle stress and muscle fatigue. Scand J Work Environ Health 19:35–42

Radwin RG, Armstrong TJ, Chaffin DB (1987) Power hand tool vibration on grip exertions. Ergonomics 30:833–855

Rundcrantz BL, Johnsson B, Moritz U (1990) Cervical pain and discomfort among dentists. Epidemiological, clinical and therapeutic aspects. Part 1. A survey of pain and discomfort. Swed Dent J 14:71–80

Schüldt K, Harms-Ringdahl K (1988) Activity levels during isometric test contractions of neck and shoulder muscles. Scand J Rehab Med 20:117–127

Scott J, Huskisson EC (1976) Graphic representation of pain. Pain 2:175–184

Silverstein BA, Fine LJ, Armstrong TJ (1986) Hand wrist cumulative trauma disorders in industry. Br J Indust Med 43:779–784

Silverstein BA, Fine LJ, Armstrong TJ (1987) Occupational factors and carpal tunnel syndrome. Am J Ind Med 11:343–358

Stock SR (1991) Workplace ergonomic factors and the development of musculoskeletal disorders of the neck and upper limbs: a meta-analysis. Am J Ind Med 19:87–107

Tichauer ER (1975) Occupational biomechanics. The anatomical basis of work-place design. (Rehabilitation monograph no 51). The Centre for Safety, School of Continuing Education and Extension Services, New York University, New York, pp 22–31

Veiersted KB, Westgaard RH, Andersen P (1990) Pattern of muscle activity during stereotyped work and its relation to muscle pain. Int Arch Occup Environ Health 62:31–41

Veiersted KB, Westgaard RH, Andersen P (1993) Electromyographic evaluation of muscular work pattern as a predictor of trapezius myalgia. Scand J Work Environ Health 19:284–290

Westgaard RH (1988) Measurements and evaluation of postural load in occupational work situations. Eur J Appl Physiol 57:291–304

Winkel J, Westgaard R (1992) Occupational and individual risk factors for shoulder-neck complaints. Part II. The scientific basis (literature review) for the guide. Int J Ind Ergon 10:85–104