Nerve Conduction and Sensorineural Function in Dental Hygienists Using High Frequency Ultrasound Handpieces

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Background *Oscillatory vibration from industrial power tools poses a well-recognized risk of peripheral nerve injury. There have been reports of elevated vibrotactile perception thresholds (VPT) among dentists, dental technicians, and dental hygienists, using rotary devices and ultrasonics. Elevated VPTs are an indicator of small fiber nerve or mechanoreceptor injury, but the high frequencies associated with dental instruments are presumed by the ISO to exceed physiological response upper thresholds. This study examines nerve conduction and sensorineural deficits in dental hygienists.*

Methods *A cross-sectional study of 94 experienced dental hygienists was conducted to assess peripheral nerve function and clinical signs and symptoms. Specialized testing included measurement of VPTs for three different categories of mechanoreceptors, sensory nerve conduction tests with fractionated digit and palmar segments, and measurement of calibrated pinch force with force sensitive resistors (FSRs) during a simulated procedure.*

Results *Chronic hand paresthesias were described by 44.7% of experienced dental hygienists. Sensory nerve conduction velocity (SNCV) across the wrist-palm segment of the median nerve. VPTs were particularly elevated at the FAII mechanoreceptor among experienced dental hygienists. Compared to participants without carpal tunnel syndrome (CTS), as defined by study criteria, 14 experienced hygienists with diagnosed CTS had almost twice the average weekly use of vibratory instruments −8.3 hr versus 4.5 hr, and had SNCV deficits along the digit −47.11 m/sec (+8.70) versus 42.57 m/sec (+8.25), and across the wrist −44.04 m/sec (+7.15) versus 41.36 m/sec (+9.27). There was a distinct subset of dental hygienists (27%) with a combination of low calibrated pinch force in simulations, subjective loss of strength and elevated VPTs, especially in the FAII mechanoreceptor population −110.82 db (+8.57) versus 104.84 db (+6.80) in the rest of the cohort. This subset also had a higher prevalence of paresthesias (67% vs. 39%) and greater cumulative vibration exposure (OR = 1.206 [CI 1.005–1.448]), than other hygienists.*

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Conclusions *The high levels of paresthesias observed among dental hygienists appear to be attributable to several pathophysiological mechanisms, including, sensory nerve demyelination at the carpal tunnel and intrinsic to the digits, and dysfunction of fingertip mechanoreceptors. A distinct sub-population appears to exhibit a high level of accumulated abnormality.* Am. J. Ind. Med. 49:313–326, 2006. © 2006 Wiley-Liss, Inc.

KEY WORDS: vibrotactile threshold; sensory nerve conduction velocity; ultrasonics; dental hygienists

INTRODUCTION

Work with vibratory tools is associated with sensorineural dysfunction in the fingertips [Griffin and Bovenzi, 2002]. These deficits are distinct from nerve compression disorders, such as carpal tunnel syndrome (CTS) that affect larger myelinated nerve fibers [Brammer and Pyykko, 1987; Gemne, 1994]. Changes in tactile function associated with occupational use of vibratory tools have been measured as raised vibrotactile perception thresholds (VPTs) in mechanoreceptor populations at a fingertip [Brammer et al., 1990; Lundborg et al., 1997]. Dentists, dental technicians, and dental hygienists are exposed to high frequency oscillatory vibration from rotary handpieces or ultrasonic scalers; the use of these devices is associated with dental hygiene tasks. In a 1994 survey of 135 dental hygienists, performed by the American Dental Association (ADA), two of three of the most representative tasks for dental hygienists involved the use of ultrasonic instruments: hand scaling or root planing (31.3%), ultrasonic scaling (18.5%), and polishing (10.5%) [Horstman et al., 1997]. Ultrasonic scalers and rotary devices operate with high frequencies −6,000 to 40,000 Hz [Akesson et al., 2001], producing exposure to the hands that is presumed to exceed the upper-frequency physiological limit of potential tissue damage, thus obviating the need for control [International Organization for Standardization, 2001]. Therefore, it is surprising that several studies have shown raised VPTs in dentists [Lundstrom and Lindmark, 1982; Ekenvall et al., 1990; Akesson et al., 1995], in dental hygienists [Ekenvall et al., 1990; Conrad et al., 1993], and in dental technicians [Hjortsberg et al., 1989]. Raised VPTs in industrial workers exposed to pneumatic tools appear to occur at much lower vibration frequencies [Brammer and Pyykko, 1987; Virokannas, 1992].

The upper extremity problems of dental hygienists are not limited to sensorineural abnormalities. CTS appear to be frequently diagnosed among dental hygienists [Gerwatowski et al., 1992]. Dental hygiene personnel commonly report more diffuse neuromuscular problems involving the neck, shoulders and upper limb [Liss et al., 1995; Horstman et al., 1997]. Akesson et al. [1999] reported on the natural history of neuromuscular and musculoskeletal symptoms in a cohort of dental hygienists and found high rates of symptoms in the hands, wrists, and hips. The symptoms were severe enough to be associated with premature abandonment of the profession. Since nerve transmission and mechanoreceptor deficits may contribute to various patterns of hand dysfunction and paresthesias [Johannson and Westling, 1984; Johnson, 2001], the reported high prevalence of neuromuscular symptoms and diagnoses among dental hygienists underlines the relevance of quantitative sensory assessments in this professional population. Accordingly, we have attempted to resolve unanswered questions on the association between high frequency vibration and sensorineural dysfunction by performing a more extended survey with enlarged study size compared to previous studies, and with receptor-specific vibrotactile measurements and segmental nerve conduction measurements.

Two cohorts, one consisting of experienced dental hygienists and another of dental hygiene students, were available for these analyses as part of another study. In this study, we report on the observed sensory deficits and motor function among the experienced dental hygienists. Some basic data are reported from the dental hygiene student group for comparison; however, the dental hygiene students are an inception cohort and are not treated as a referent group for the experienced dental hygienists. Among the experienced dental hygienists, the results from quantitative tests have been compared between sub-groups.

SUBJECTS AND METHODS

Experienced Dental Hygienists

Ninety-four (94) dental hygienists from Connecticut consented to participate in a longitudinal study of health effects associated with vibration from ultrasonic instruments. This study includes their baseline or prevalence findings, only. Selection criteria included: at least 5 years of experience as a licensed dental hygienist; current employment, and exposure to high frequency instruments, including ultrasonic magnetostrictive and piezoelectric scalers, sonic scalers, and air and rubber cap polishers. In addition, there could be no history of job reassignment due to an acquired musculoskeletal or neuromuscular condition affecting the upper extremity. Recruitment followed announcements distributed

through the State's Dental Hygiene Professional Organization, and included presentations at their statewide meetings. It was presented as a study of musculoskeletal and sensory problems in dental hygienists with a focus on dental instruments. Based on preliminary prediction of a 20% response rate and a target of 80 subjects, 400 individuals were randomly selected from professional lists and contacted by mail and phone. The recruitment goal was exceeded, thus the excess of participants. In all, 92 women and 2 men consented to participate (24% response rate). Participants had an average age of 45.5 years and an average employment of 21.8 years. The Human Subjects Committee of the University of Connecticut Health Center approved all phases of the study including the mechanisms for contact and solicitation.

Student Dental Hygienists

Sixty-six (66) first year dental hygiene students were recruited into the study in their second semester. They comprised two-thirds of eligible class members from Connecticut's three dental hygiene training programs. Students were assembled as an inception cohort, their initial evaluation being the first phase of a longitudinal study with criteria for eligibility including willingness to participate in future years. Because of the small dental hygiene class size, and the decision to limit recruitment to in-state students, likely to be in local practice after graduation, recruitment was active, relying on faculty endorsement. The average age of the students was 26.1 years and all but two students were female. The student group was not asymptomatic, already having some acquired symptoms in their first year [Morse et al., 2003].

Questionnaire

Participants completed a self-administered questionnaire, with student and practicing hygienist versions. Generic groups of questions were directed to vibration-specific and more general musculoskeletal disorders. Exposure-specific questions were developed to profile each work environment. These were originally profiled by two members of the study team experienced in dental hygiene (C M-T, M A-S), then revised in numerous focus groups, distributed in an exploratory questionnaire [Morse et al., 2003], and refined for the final version. Particular attention was paid to historical variability in work schedules, equipment and procedural changes, and multi-site employment. There was particular attention to patient type (and calculus density), patient and work volume, use of instruments, and changes in work practice. Manikin type drawings for purposes of symptom localization were used, with emphasis on each upper extremity region with symptom specific dermatomes [Viikari-Juntura et al., 1996], in order to better define self-reported CTS related symptoms [Katz and Stirrat, 1990]. The musculoskeletal symptom questionnaire was formulated from multiple sources, in particular from the Connecticut Upper Extremity Surveillance Project (CUSP) [Warren et al., 2000], which in turn was taken largely from previously validated instruments: the US Department of Health National Health Interview Survey (NHIS) 1988, the Occupational Safety and Health Administration (OSHA) Draft Checklist [OSHA, 1995], the Dutch Monitor Survey, the Job Content Questionnaire [Karasek and Theorell, 1990], and the Standardized Nordic Questionnaire [Oberg and Oberg, 1993]. We included sections of the validated Levine Functional Status and Symptom Severity Scales [Levine et al., 1993]. Symptom questions also included staging with the Stockholm Workshop Scale, a consensus instrument used for classifying sensorineural and vascular symptoms of the hand-arm vibration syndrome [Brammer et al., 1987; Gemne et al., 1987].

Physical Examination

A detailed neuromuscular examination of the upper extremity and neck-shoulder regions was designed with the following goals:

● elicitation of clinical signs
● semi-quantitative assessment of neuromuscular, vascular, and musculoskeletal function
● development of clinical diagnoses

The exam included more than 20 recognized clinical provocation tests, including the Adson's test, Roos test, Allen's test, Wright's test, Tinel's signs, Phalen's test, and Finkelstein's test. Each clinical test and detailed procedure was reviewed for consistency with other standardized examinations [Sluiter et al., 2001; Nilsson, 2002]. The examining physician was also required to render clinical diagnoses that were circumscribed by inclusion rules. Diagnoses included in the analysis are presented in Table I. Accordingly, conditions such as CTS involved multiple criteria including the presence of physical signs. The term "study defined CTS" is used to distinguish this examiner determined algorithmic diagnosis. Provocative maneuvers, such as Adson's test, required qualification of intensity, distribution, associated posture, and nature of symptoms, consistent with consensus approaches used in other studies.

Vibrotactile Perception Threshold

Vibrotactile perception thresholds were determined at the fingertips of the 3rd and 5th digits of both upper extremities using a laboratory tactometer meeting the requirements of ISO 13091-1 [International Organization for Standardization, 2001]. The apparatus consists of a vibration stimulator mounted on a vertically adjustable track; an arm support on which the hand and forearm rest with the palm facing up; a vibration sensor and accompanying

TABLE I. Common Diagnoses and Diagnostic Criteria; Dental Hygienists

Diagnosis	Criterion
Hand and wrist	
Carpal Tunnel syndrome	Paresthesias in a median nerve distribution, and positive Tinel's, or positive Phalen's, or positive compression test
Canal of Guyon syndrome	Paresthesias in an ulnar nerve distribution, and positive Tinel's over the canal of Guyon
Shoulder	
Rotator cuff tendonitis	Deltoid pain with overhead work and weakness with elevation
	Pain on resisted abduction, external rotation, or internal rotation of shoulder or, resisted elbow flexion, or painful arc on active upper arm elevation
Impingement syndrome	Exclude rotator cuff tendonitis
	Painful arc and flexion or abduction $<150°$
Scapular Instability	Reliance on strap muscles for abduction and flexion $>90°$, and winging on abduction/endorotation or, locked shoulder forward posture with inability to internally rotate
Neck and chest wall	
Brachial plexus compression/medial	Radiating pain and paresthesias from pectorales with deep supra-scapular palpation
Brachial plexus compression /lateral	Radiating pain and paresthesias from pectorales with deep sub-scapular palpation
Head forward posture	Record if neck flexed $>10°$ and AC joint rounded beyond mid-clavicular line

electronics to record the stimulus at the skin surface; and a computer to administer the psychophysical algorithm, calculate VPTs and identify inconsistencies in performance. A 3 mm diameter cylindrical flat-ended probe was lowered onto the fingertip and maintained in contact with a static compressive force of 0.05 N. Sinusoidal bursts of vibration, each of different intensity (accelerations), were applied to the skin at a selected frequency close to the physiologic threshold of perception. Subjects signalled when the stimulus was detected by pressing a switch, then releasing the switch when the stimulus was no longer perceived. Inconsistencies and errors in subject performance were detected by a patented procedure and displayed to the operator during measurement [Brammer and Piercy, 1995]. The vibratory stimulus was presented at three distinct frequency ranges designed to elicit thresholds from the SAI, FAI, and FAII slow and fast-acting mechanoreceptors. Thresholds were determined at the fingertips of digit III and V in order to distinguish median from ulnar nerve innervations and to ensure correspondence with recording electrode sites that were used in the sensory nerve conduction studies. Measurements of VPT were conducted at frequencies of 4 Hz (mediated by SAI receptors); 32 Hz (mediated by FAI receptors), and; 125 Hz (mediated by FAII receptors). All results are reported in accelerations in units of decibels (dB) re 10^{-6} m/sec^2.

A calibration procedure was performed on each test day using a built-in reference signal of known acceleration. Daily variability was always less than 1 dB at all measured frequencies and usually less than 0.5 dB.

Nerve Conduction Studies

Sensory nerve conduction velocities (SNCV) were measured distally for the median and ulnar nerves in both upper extremities. All studies were performed on a Nicolet Viking Quest® device. The approach to SNCV was adapted from that developed by Sakakibara et al. [1994, 1998]. There was a common site of stimulation for all distal measurement of the median and ulnar nerves with recording electrodes placed at the mid-palm, base and distal digit, in order to separate a proximal digit to distal digit measurement (PDDD) from a more conventional wrist to proximal digit (WPD) and wrist to palm (WP) measurement. Because of our interest in assessing CTS, a transpalmar SNCV (from wrist to mid-palm) was also measured for both median and ulnar nerves. All nerve conduction tests were preceded by at least 30 min of hand warming and studies did not proceed until the temperature at the base of the 2nd digit was $>31°C$. This was an accommodation to the Sakakibara et al. [1994] observation that digital SNCV is reduced in vibration-exposed individuals and that cold provoked hands in subjects with vascular dysfunction might alter nerve conduction measurements. All results are reported as velocities (in m/sec), determined from time of stimulation to onset of action potential. This reflects an emphasis on fastest conducting sensory fibers and provides an easily interpretable value (velocity) for a measurement that lack customary corresponding normal values for latency. A more detailed description of this technique can be found in Cherniack et al. [2004a].

Maximum Voluntary Grip Force, Pinch Force, and Calibrated Pinch Force

Maximum voluntary three-finger pinch (three-jaw chuck) was measured on a standard 30 lb pinch gauge dynamometer. In order to assess the relationship between the maximum voluntary pinch force and the typical force expended during dental work, a force measurement was

performed during work simulation. This was termed the "calibrated pinch force." The calibration procedure was individualized to each participant. First, the participant was asked to grip a manual scaler with their firmest pinch. A force sensitive resister (FSR) was placed on the glabrous pad of the second digit along the crease of maximum skin indentation. Next, the participant performed a series of pinches on an instrumented pinch dynamometer. Fifteen randomly selected measurements were made at increments of 2.5 lbs at a range from 0 to 15 pounds. Voltages were recorded and an individual correlation was later calculated between voltages and lbs. Each participant performed a series of typical scrapes on a dental manikin using a manual scaler. An average of three to five typical strokes was made, and continuous measurements were recorded for later conversion into mean and peak values. The association between voltages and force was non-linear at higher forces, presumably due to hysteresis and compliance of the FSR. Therefore, a transformation was used to mathematically manage the force–voltage relationship at higher forces. We elected to use a single power fit model to transform the voltage data. In most cases, fit could be improved by selecting an individualized model. However, we elected to default to a single best model rather than "purifying" the associations, although this lead to some anomalous results. Calibrated pinch force is the outcome of this process of transforming voltage to force. Because the methodology was not sufficiently developed for use with the first subjects, there are calibrated pinch force measurements on only a subset of the entire cohort. They were performed on 77 of the experienced hygienists (80%). Seven dental hygienists had a calibrated pinch force that exceeded 30 lbs, and was greater than the corresponding dynamometer determined maximum voluntary pinch force, which was less than 30 lbs in all cases. The incompatibility at higher forces was attributed to mechanical limitations of the FSR and corresponding power fit model. We elected to exclude these cases, rather than to apply a more complex model. Experienced hygienists, who were not tested, because they were evaluated prior to refinement of the simulation, were compared with tested subjects for differences in age, work tenure, manual instrument use, and vibratory instrument use. The two populations appeared to be identical.

Data Analysis and Statistics

Analyses were performed using SPSS and SAS statistical packages. Continuous data were summarized as means and standard deviations. Differences between group means were tested using one or two-way analyses of variance and multiple comparison tests. Linear regression (with and without adjustment for symptom level) was used with VPTs regressed on common covariates. Variables were included in the model when the P-value of the F-statistic for regression coefficients was <0.05. For comparisons of groups of unequal size, Satterwaithe tests for unequal populations were used. The term significant refers to the 95% confidence internal (CI), not including 1.00, or to $P < 0.05$ for the F-statistic. All tests were two-tailed.

Stepwise logistic regression was used to evaluate the relationship between explanatory variables and dichotomous outcomes. Entry and staying significance were set at $P < 0.2$.

RESULTS

Comparison of Dental Hygienists and Students

As expected, the dental hygienists and dental hygiene students differed significantly in their ages and self-reported exposures (see Table II). The average extent of accumulated practice among students (3.0 years [SD 4.3]) for the most part reflects experience as dental technicians. The estimated current weekly vibratory and ultrasonic instrument use by practicing hygienists (5.1 hr) suggests that there has been a more recent decrease in overall vibratory and ultrasonic instrument use, given an estimated lifetime average weekly exposure of 10.8 hr, over a professional career that was on average slightly longer than 20 years. However, in prevalence studies, self-reported estimates of cumulative hours of work exposure, such as those used in this study, may exceed observer-reported current effort by a substantial margin [Akesson et al., 2001]. Recollections of differences between past and present exposure cannot be presumed to be valid. Practicing hygienists were four times more likely than students to have a pre-existing diagnosis of CTS. Survey-reported sensorineural symptoms reached a clinical threshold on the Stockholm Workshop Scale in 45% of hygienists and 9% of students. However, vascular symptoms had an almost identical prevalence in both groups, affecting 12% of both students and hygienists.

Despite the two-decade difference in age between dental hygienists and students, there were no meaningful differences in finger specific SNCV (proximal digit–distal digit) between the student and practicing hygienist groups (Table III). On average, the median nerve SNCV across the dominant wrists of dental hygienists (wrist-palm) was 6.6 m/sec slower than for students. The difference was 4.4 m/sec for the contralateral non-dominant median nerve segment. Differences, while present, were smaller for the ulnar SNCVs. In fact, slowing across the transcarpal segment of dominant and non-dominant median nerves (wrist-palm) accounted for the entire difference between the wrist-proximal digit segments that differentiated students from experienced hygienists.

Compared to students, VPTs mediated by the FAII mechanoreceptor populations at 125 Hz appear to be elevated at the 3rd and 5th digit in both upper extremities of the experienced dental hygienists. In general, variability in the VPTs tended to be greater in the experienced hygienists than

TABLE II. Experienced Dental Hygienist and Student Demographics

	Dental hygiene students	Experienced dental hygenists
Number of subjects	66	94
Age (SD)	26.1 (6.4)	45.5 (8.8)
Gender (number (% women))	65 (98.5)	92 (97.9)
Ethnic origin (number (%))		
White	60 (95.2)	91 (96.8)
Black	2 (3.2)	1 (1.1)
Other	1 (1.6)	2 (2.1)
Current smokers (%)	6.4	4.4
Years in practice (SD)	3.0 (4.3)	21.8 (8.3)
Duration of exposure to vibration and ultrasonic tools (years (SD))	1.0 (1.9)	17.1 (8.7)
Current manual tool use (hours/week (SD))	5.2 (5.5)	12.0 (7.3)
Current vibratory and ultrasonic tool use (hours/week (SD))	3.0 (3.9)	5.1 (5.4)
Historical cumulative exposure to vibration and ultrasonic tools (hours $\times$ 1,000 (SD))	0.3 (0.6)	10.8 (11.5)
Any MSP[a] in the past year (number(%))	27 (561)	81 (86.7)
Study defined CTS[b,c] (number (%))	3 (4.6)	17 (18.1)
Sensorineural stage (%)		
Stage 0	90.9	55.9
Stage 1	4.6	29.0
Stage 2	1.5	5.4
Stage 3	3.0	9.7
Vascular stage (%)		
Stage 0	87.9	88.3
Stage 1	3.0	6.4
Stage 2	6.1	4.3
Stage 3	3.0	1.1

[a]Musculoskeletal Pain: upper extremity pain, aching, stiffness, burning, numbness, or tingling occurring more than three times and lasting >1 week.
[b]Carpal Tunnel syndrome.
[c]Dominant hand and non-dominant hand combined.

in the students, despite their being a greater number of experienced hygienists. Because age is a potential confounder of mechanoreceptor function, VPTs were regressed on age for the experienced dental hygienists. There were no detectable associations between age and any of the VPT measurements. This was so, even though the hygienists represented a normally distributed population with considerable age range (26–70 years).

Correlation Between Sensory Nerve Conduction Velocity and Vibrotactile Perception Threshold

SNCV and VPT are in principle dependent in part on the integrity of Aβ myelinated nerve fibres. There is, therefore, the possibility that elevated (i.e., less sensitive) VPTs among

dental hygienists reflect more proximal dysfunction in nerve trunks. In Table IV, SNCVs and VPTs are examined among experienced dental hygienists for each of the three mechanoreceptor populations for co-relatedness of individual SNCV segments. In no case was there a significant correlation between SNCVs in either short or long sensory nerve segments and the corresponding VPTs. While faster SNCV might seem to be the logical correlate of a lower VPT, there was no consistent pattern in the direction (sign) of the correlation coefficient, except at 125 Hz.

Symptoms Associated With Quantitative Sensory Tests

In Table V, the experienced dental hygienists are separated into a subgroup with numbness and tingling

TABLE III. Nerve Conduction (m/sec) and Vibrotactile Perception Threshold (dB re 10^{-6} m/sec^2 —(Mean(SD)) in Dental Hygienists

	Students	Hygienists
Dominant hand, Median Nerve		
Nerve conduction velocity		
Proximal digit—distal digit	46.9 (7.6)	46.4 (8.7)
Wrist—proximal digit	52.6 (4.8)	46.7 (7.2)
Wrist—palm	50.3 (4.7)	43.6 (7.5)
Vibrotactile perception threshold		
Frequency: 125 Hz	103.0 (7.5)	107.0 (8.8)
Frequency: 32 Hz	102.7 (6.8)	104.4 (6.3)
Frequency: 4 Hz	83.4 (4.5)	83.6 (5.1)
Dominant hand, ulnar nerve		
Nerve conduction velocity		
Proximal digit—distal digit	46.0 (10.2)	46.1 (9.6)
Wrist—proximal digit	52.3 (5.8)	50.7 (5.5)
Wrist—palm	51.4 (6.1)	49.3 (6.9)
Vibrotactile percdeption threshold		
Frequency: 125 Hz	100.6 (6.2)	104.3 (8.8)
Frequency: 32 Hz	104.0 (5.7)	104.5 (11.8)
Frequency: 4 Hz	83.8 (3.6)	84.2 (4.5)
Non-dominant hand, median nerve		
Nerve conduction velocity		
Proximal digit—distal digit	47.5 (9.3)	45.0 (8.3)
Wrist—proximal digit	51.9 (4.2)	48.8 (7.3)
Wrist—palm	50.8 (5.0)	46.4 (7.8)
Vibrotactile perception threshold		
Frequency: 125 Hz	101.3 (7.8)	105.2 (9.0)
Frequency: 32 Hz	102.5 (6.0)	103.8 (6.5)
Frequency: 4 Hz	83.3 (4.3)	83.2 (4.8)
Non-dominant hand, ulnar nerve		
Nerve conduction velocity		
Proximal digit—distal digit	43.9 (9.9)	45.8 (10.7)
Wrist—proximal digit	52.7 (8.1)	51.5 (5.0)
Wrist—palm	50.8 (4.9)	49.2 (4.1)
Vibrotactile perception threshold		
Frequency: 125 Hz	98.9 (5.5)	103.2 (9.3)
Frequency: 32 Hz	102.9 (7.2)	104.2 (7.2)
Frequency: 4 Hz	83.4 (4.0)	84.6 (5.1)

TABLE IV. Correlations Between Vibrotactile Perception Threshold and Sensory Nerve Conduction Velocity in Experienced Dental Hygienists

	(N > 150)		
	Digit–mechanoreceptor		
Sensory nerve segment	**FAII**	**FAI**	**SAI**
	Digit 3 – 125 Hz	Digit 3 – 32 Hz	Digit 3 – 4 Hz
DMPDDDV			
PCC	−0.14	−0.03	−0.07
Prob	0.08	0.72	0.42
DMWPV			
PCC	−0.10	−0.05	−0.01
Prob	0.26	0.52	0.92
NDMPDDDV			
PCC	−0.02	−0.024	0.016
Prob	0.78	0.766	0.840
NDMWPV			
PCC	−0.05	−0.16	−0.07
Prob	0.57	0.05	0.38
	Digit 5 – 125 Hz	Digit 5 – 32 Hz	Digit 5 – 4 Hz
DUPDDDV			
PCC	−0.05	0.04	−0.04
Prob	0.47	0.67	0.67
DUWPV			
PCC	−0.12	0.02	0.11
Prob	0.15	0.78	0.17
NDUPDDDV			
PCC	−0.02	0.01	0.02
Prob	0.84	0.88	0.84
NDUWPV			
PCC	−0.06	−0.03	−0.07
Prob	0.48	0.71	0.36

PCC, Pearson correlation coefficient; Prob, probability > |r| under H0: Rho = 0; D, dominant; ND, non-dominant; M, median nerve; U, ulnar nerve; PDDDV, proximal-distal digit (finger) velocity; WPV, wrist-palm (transpalmar) velocity.

(paresthesias) and a subgroup without significant paresthesias. Fully 44.7% of the experienced dental hygienists (n = 42) reported frequent numbness and tingling. Neither proximal symptoms (neck pain or shoulder pain) nor proximal signs (positive Adson's test or brachial compression test) occurred differentially among subjects reporting hand paresthesias. However, CTS in the dominant hand, determined by physical examination and structured diagnosis (study defined CTS as described in Table I), was significantly more common in subjects with self-report of paresthesias compared to subjects without paresthesias (23.8% vs. 7.7%). Quantitative tests produced an even more emphatic delineation. There was a significant difference in SNCV across the wrist to proximal digit segment between those with and without paresthesias. This difference was not detectable in the ulnar innervated 5th finger and in digital segments (proximal digit-distal digit), whether innervated by median or ulnar nerves. Symptomatic subjects had elevated VPTs at 125 Hz for every tested digit; due to the variance, this was statistically positive for only one comparison (125 Hz in the non-dominant 5th digit). As will be described below, a distinct sub-group probably accounts for this trend in VPT.

In summary, proximal signs and symptoms compatible with nerve compression did not differentiate subjects with paresthesias. However, a diagnosis of study defined CTS and focal SNCV slowing from the wrist to the proximal digit did predict these symptoms.

TABLE V. Symptoms, Nerve Conduction (m/sec) and Vibrotactile Perception Threshold (dB re 10^{-6} m/sec^2—(Mean (SD)) for Dominant and Non-Dominant Hand in Dental Hygienists

	Experienced dental hygienists	
Numbing and tingling	Absent	Present
Numbing and tingling (number (%))	52 (55.3)	42 (44.7)
Neck symptom (number (% of each group))	36 (69.2)	32 (76.2)
Shoulder symptom (number (% of each group))	17 (32.7)	16 (38.1)
Adson's 135 or mechanical allodynia*		
Dominant hand side	18 (35.3)	16 (38.1)
Non-dominant hand side	17 (32.7)	15 (35.7)
Study defined CTS (number (%))		
Dominant hand	4 (7.7)*	10 (23.8)
Non-dominant hand	4 (7.7)	6 (14.3)
Dominant hand, median nerve		
Nerve conduction velocity		
Proximal digit—distal digit	46.9 (8.3)	46.0 (9.3)
Wrist—proximal digit	48.0 (7.0)*	45.0 (7.2)
Wrist—palm	44.8 (7.3)	42.1 (7.6)
Vibrotactile perception threshold		
Frequency: 125 Hz	106.0 (7.8)	108.2 (9.8)
Frequency: 32 Hz	104.6 (5.9)	104.1 (6.9)
Frequency: 4 Hz	84.2 (5.0)	82.9 (5.1)
Dominant hand, ulnar nerve		
Nerve conduction velocity		
Proximal digit—distal digit	47.8 (9.3)	44.1 (9.7)
Wrist—proximal digit	50.8 (5.8)	50.6 (5.3)
Wrist—palm	49.6 (8.1)	48.9 (4.9)
Vibrotactile perception threshold		
Frequency: 125 Hz	103.0 (7.0)	106.1 (10.6)
Frequency: 32 Hz	103.4 (14.6)	105.8 (6.8)
Frequency: 4 Hz	84.3 (4.8)	84.1 (4.2)
Non-dominant hand, median nerve		
Nerve conduction velocity		
Proximal digit—distal digit	46.1 (9.1)	43.8 (7.1)
Wrist—proximal digit	50.2 (7.4)*	47.1 (6.9)
Wrist—palm	47.5 (7.4)	45.1 (8.0)
Vibrotactile perception threshold		
Frequency: 125 Hz	103.9 (7.1)	106.8 (10.9)
Frequency: 32 Hz	103.3 (6.2)	104.5 (6.8)
Frequency: 4 Hz	83.2 (4.7)	83.2 (5.0)
Non-dominant hand, ulnar nerve		
Nerve conduction velocity		
Proximal digit—distal digit	44.0 (8.7)	47.1 (12.9)
Wrist—proximal digit	51.8 (5.7)	51.2 (4.0)
Wrist—palm	49.4 (4.2)	49.0 (4.1)
Vibrotactile perception threshold		
Frequency: 125 Hz	101.7 (7.0)	105.2 (4.0)
Frequency: 32 Hz	104.8 (6.5)	103.4 (8.1)
Frequency: 4 Hz	85.3 (5.2)	83.6 (5.0)

Adson's test or the Abduction external rotation test involves abducting the shoulder to 135° and palpating a pulse, and eliciting symptoms of paresthesia.
Mechanical allodynia refers to excessive pain from mild palpation over the brachial plexus.
*$P < 0.05$.

Risk Factors and Quantitative Sensory Tests

Since exposure or presumed intrinsic risks, such as age and body habitus might predispose a subject to an elevated VPT, a series of risk factors were tested for their association with VPT. These included age, test finger circumference, height, body-mass index (BMI), and current weekly use of manual and vibratory and ultrasonic tools. In Table VI, VPTs at 125 Hz for the experienced dental hygienists are regressed on these common risk factors in both dominant and non-dominant hands on the 3rd and 5th fingers. Associations with both the 32 and 4 Hz VPTs were also examined, but they were uniformly much weaker and are not reported. Regression coefficients are recorded only when the *P*-value of the F-statistic was $<0.05\%$. Age did not predict elevated VPT in this group of experienced dental hygienists. In addition, neither manual tool use nor vibratory and ultrasonic tool use consistently accounted for the variations in the VPTs. While all of the models were significant, analyzed risk factors accounted for more than 12% of the variance in only one location (non-dominant 3rd digit).

Experienced dental hygienists with and without a study defined diagnosis of CTS in the dominant hand are compared in Table VII. Age, years of employment, and estimated time spent on manual procedures were similar between the two groups. Although statistical significance was lost with conservative adjustment for unequal sample size, subjects with current diagnosed CTS had nearly twice the self-reported weekly average and cumulative hourly use of vibratory and ultrasonic instruments. In addition, SNCVs along the median nerve of the affected hand differed as much in the proximal digit to distal digit segment (4.6 m/sec slower) as in the wrist-proximal digit segment (5.4 m/sec slower). Only the latter was statistically significant. In contrast, ulnar nerve VPTs and SNCVs were nearly identical in the CTS and non-CTS groups.

Pinch Force and Vibrotactile Perception Threshold

The analysis of hand function among the practicing dental hygienists produced results that at first seemed anomalous. Cumulative work experience was associated with a higher calibrated pinch force in the work simulations. Among experienced dental hygienists with calibrated pinch force in the work simulations measurements ($n = 67$), 40 (59%) reported a weakened pinch in the course of professional employment. This group reported either weaker or much weaker strength also had a raised calibrated pinch force in the simulated task compared to participants without subjective strength deficits (12.9 lb vs. 9.7 lb) and a raised VPT at the 125 Hz receptor (106.9 dB vs.104.9 dB). To avoid ambiguity, we use the terms strength and weakness for

TABLE VI. Regression of Vibrotactile Perception Thresholds on Common Covariates in Experienced Dental Hygienists

Dependent variable	Age	Finger circumference	Height	BMI	Vibration exposure h	Manual exposure h	Adjusted R-square	Probility > |F|
125 Hz receptor								
3rd digit—dominant		−0.32					0.04	0.03
5th digit—dominant					0.34		0.04	0.04
3rd digit—non-dominant	0.67		−0.35	−0.46			0.12	0.01
5th digit—non-dominant					0.41		0.04	0.03

Regression coefficients are listed when *P*-value for F-statistic <0.05.
R-square is for full model.
F-statistic is calculated for full model.

subjective responses and calibrated pinch force to indicate instrumented measures. However, correlation coefficients between calibrated pinch force and VPT were negative in all cases. Since weakness was associated with an increased

TABLE VII. Demographics, Nerve Conduction (m/sec) and Vibrotactile Perception Threshold (dB re 10^{-6} m/sec^2—(Mean(SD)), of Experienced Dental Hygienists With or Without Study Defined Carpal Tunnel Syndrome (CTS)

	No CTS	CTS
Number of subjects	80	14
Age (SD)	45.8 (8.7)	44.1 (9.2)
Years in practice (SD)	21.7 (8.3)	22.6 (8.8)
Duration of exposure to vibration and ultrasonic tools (years (SD))	16.9 (8.6)	18.0 (9.8)
Current manual tool use (hours/week (SD))	12.0 (7.3)	11.9 (7.6)
Current vibration and ultrasonic tool use (hours/week (SD))	4.5 (4.6)	8.3 (8.1)
Historical cumulative exposure to vibration and ultrasonic tools (hours × 1,000 (SD))	9.7 (9.4)	17.1 (18.7)
Median nerve		
Nerve conduction velocity		
Proximal digit—distal digit	47.1 (8.7)	42.6 (8.3)
Wrist—proximal digit	47.5 (6.5)	42.1 (9.3)*
Wrist—palm	44.0 (7.2)	41.4 (9.3)
Vibrotactile perception threshold		
Frequency: 125 Hz	106.9 (9.2)	107.1 (6.5)
Frequency: 32 Hz	104.2 (6.1)	105.5 (7.7)
Frequency: 4 Hz	83.6 (5.0)	83.3 (5.4)
Ulnar nerve		
Nerve conduction velocity		
Proximal digit—distal digit	46.4 (9.3)	44.4 (11.2)
Wrist—proximal digit	50.9 (5.7)	49.4 (4.2)
Wrist—palm	49.0 (5.5)	51.0 (12.2)
Vibrotactile perception threshold		
Frequency: 125 Hz	104.2 (8.7)	105.1 (9.8)
Frequency: 32 Hz	104.4 (12.5)	105.1 (7.5)
Frequency: 4 Hz	84.3 (4.6)	83.7 (4.2)

*$P < 0.01$.

calibrated pinch and with a raised VPT, we had expected calibrated pinch force and VPT to be positively correlated.

An explanation for this apparent anomaly can be understood by reviewing Table VIII. The experienced dental hygienist population was dichotomized at the mean measured calibrated pinch force, as pinch ≥10.9 lb or <10.9 lb. The 32 subjects with pinch >10.9 lbs in the simulation had similar VPTs regardless of their perception of weakness. Their maximum voluntary pinch force, measured by dynamometry, was high. However, the 40 subjects subjectively reporting loss of strength (listed in Table VIII as ''mildly weaker'' and ''much weaker'') had a tendency towards a lower maximum voluntary pinch, while those with a pinch ≥10.9 lb had a higher calibrated pinch force in the simulation. It should be noted that the calibrated pinch force/maximum voluntary pinch force ratio was >1.0 for the group reporting weakness with a calibrated pinch force of ≥10.9 lb. This is an artefact introduced by the power fit model at higher calibrated pinch forces. The 17 subjects reporting no loss of strength but exhibiting a pinch <10.9 lbs in simulation also tended to have a higher maximum voluntary pinch than the 40 subjects reporting weaker hand strength. The VPTs were essentially identical for the two groups with a calibrated pinch of ≥10.9 lb. On the other hand, the 18 subjects with self-described weakness and pinch <10.9 lbs were distinctly different from the three other sub-groups. While their maximum voluntary pinch force was almost identical to that of the sub-group with subjective weakness but a pinch ≥10.9 in the simulation, their VPTs were markedly different from the other three groups, being significantly higher at 125 Hz and having a nearly significant elevation at 32 Hz. Thus, the 26.9% of all subjects with a combination of symptoms of subjective weakness, a pinch <10.9 lbs, and elevated VPTs appear to comprise a distinct sub-population, distinguished from other dental hygienists. When compared to the other subjectively weak group that actually had unremarkable VPTs and a pinch >10.9 lbs, their distinctiveness is emphasized.

In order to determine if the sub-group pinch <10.9 lbs, raised VPT, and subjective acquired weakness differed in

TABLE VIII. Calibrated Pinch Force and VPT in Experienced Dental Hygienists—Dominant Hand

| Perceived hand strength | Variable name | Pinch force group | | | |
| | | Pinch ≥10.9 | | Pinch <10.9 | |
		N	Mean (SD)	N	Mean (SD)
Stronger and no change (N = 27)	Calibrated pinch (lbs)	10	15.7 (4.1)	17	6.4 (3.0)
	Three jaw chuck pinch (max voluntary pinch)		17.4 (2.6)		16.4 (2.0)
	Cal pinch/max pinch		0.9 (0.3)		0.4 (0.2)
	FAII TTS—125 Hz (db)		103.2 (5.3)		105.8 (7.1)
	FAI TTS—32 Hz (db)		102.8 (5.0)		101.4 (6.5)
	SAI TTS—4 Hz (db)		80.7 (2.9)		82.2 (4.5)
Mildly weaker and much weaker (N = 40)	Calibrated pinch (lbs)	22	19.1 (6.7)	18	5.4 (3.2)
	Three jaw chuck pinch (max voluntary pinch)		14.8 (2.7)		14.3 (2.8)
	Cal pinch/max pinch		1.3 (0.5)		0.4 (0.2)
	FAII TTS—125 Hz (db)		103.7 (5.5)		110.9 (8.6)*
	FAI TTS—32 Hz (db)		104.0 (7.3)		105.2 (5.0)
	SAI TTS—4 Hz (db)		82.4 (5.5)		84.0 (5.1)**

*$P < 0.05$.
**$P < 0.01$.

terms of possible disease risk or symptoms, these subjects were compared to the rest of the cohort (Table IX). While inferences need to be conditioned by the small group size (n = 18), the results were striking. Age, length of employment, and current use of manual and vibratory and ultrasonic instruments were similar. Various proximal signs and symptoms and the diagnosis of study defined CTS were similar for the two groups, although there were few study defined CTS cases (n = 12). Subjects with subjective weakness did have a comparatively reduced maximum voluntary pinch force, and a much lower ratio of calibrated pinch/maximum voluntary pinch. Frequent paresthesias were almost twice as prevalent in subjects exhibiting raised VPTs, a pinch <10.9 lbs, and reporting weakness. VPT's were elevated at all frequencies for the ulnar nerve and were elevated at 125 Hz for the median nerve, the latter showing the most significant difference. For all but one segment (ulnar nerve wrist-proximal digit), SNCV results did not differentiate the two sub-groups. There was a tendency for the SNCVs to be higher in the weak sub-group.

In Table X, odds ratios are presented following stepwise logistic regression with the regressor variable being "weak" and "non-weak" sub-groups and the independent variables being identifiable risk factors that maintained significance in the model at the level of $P < 0.2$. Vibration exposure in years did appear to be preferentially associated with the weak sub-group with an OR of 1.77 (CI 1.12–2.80). VPT threshold elevation at 125 Hz was also associated with this sub-group. Vibration exposure and raised VPT were associated with subjective weakness and low calibrated pinch force in the work simulation (OR 1.55, CI 1.14–2.12). Age and maximum voluntary pinch force were not associated with status in the weak sub-group and the most generic measure of exposure, years in the field (profession), lacked association with weakness.

DISCUSSION

There are distinct limitations, as well as the absence of a recognizable physiologic mechanism, hindering the interpretation of published studies on raised VPTs among practicing dental hygienists. They involve limitations of measurement devices and of study design: study groups were small (<30 subjects); there were limited estimates of oscillatory exposure to the hands; no study employed a mechanoreceptor-specific measurement technique for determining VPTs; and only one study [Hjortsberg et al., 1989] included a parallel test of sensory nerve conduction velocity (SNCV). However, that study did not isolate the digital segment where specific vibratory injury seems to occur among industrial workers [Sakakibara et al., 1994, 1998]. Thus, a more proximal nerve trunk injury, such as CTS, cannot be differentiated from distal injury.

This cross-sectional study has avoided many, but not all, limitations of its predecessors. The results suggest a complex phenomenon that cannot be reduced to a simple exposure-response relationship. The pertinent observations are as follows.

● Experienced dental hygienists with paresthesias were more likely to be diagnosed with clinical CTS, as defined in the study, on blinded physician's evaluation than non-symptomatic hygienists, and were more likely to have slower SNCVs along the median, but not the ulnar, nerve.

TABLE IX. Characteristics of Experienced Dental Hygienists Classified as "weak"* and "not weak"**

	Weak	Not weak
Number of subjects	18	49
Age (SD)	44.7 (9.4)	45.6 (8.3)
Years in practice (SD)	21.9 (7.5)	21.6 (8.8)
Duration of exposure to vibration tools (years (SD))	18.6 (7.9)	15.4 (9.1)
Current manual tool use (hours/week (SD))	12.4 (5.0)	11.2 (7.2)
Current vibratory tool use (hours/week (SD))	4.8 (4.4)	4.4 (4.6)
Historical cumulative exposure to vibration and ultrasonic tools (hours × 1,000 (SD))	11.3 (10.8)	9.8 (11.2)
Calibrated pinch force (lbs)[a]	5.4 (3.2)	14.0 (7.7)
Three jaw chuck pinch (maximum voluntary pinch force)[a]	14.3 (2.8)	15.9 (2.7)[b]
Cal pinch/max pinch[a]	0.4 (0.2)	0.9 (0.6)[c]
Symptoms[a]		
Numbing and tingling (N (%))	12 (66.7)	19 (38.8)[b]
Neck symptom (N (%))	14 (77.8)	33 (67.4)
Shoulder symptom (N (%))	6 (33.3)	16 (32.7)
Adson's 135 or mechanical allodynia (N (%))	8 (47.1)	16 (32.7)
Study defined CTS (N (%))	3 (16.7)	9 (18.4)
Nerve conduction[a] (m/sec) and VPT (dB re 10^{-6} m/sec^2—mean (SD))		
Median nerve		
Nerve conduction velocity		
Proximal digit—distal digit	48.0 (8.0)	46.8 (9.1)
Wrist—proximal digit	48.0 (7.5)	46.6 (7.2)
Wrist—palm	44.1 (8.3)	44.0 (7.2)
Vibrotactile perception threshold		
Frequency: 125 Hz	110.8 (8.6)	104.8 (6.8)[c]
Frequency: 32 Hz	105.2 (5.0)	102.9 (5.7)
Frequency: 4 Hz	84.3 (5.4)	82.1 (4.7)
Ulnar nerve		
Nerve conduction velocity		
Proximal digit—distal digit	47.8 (7.7)	45.9 (9.8)
Wrist—proximal digit	53.5 (5.1)	50.4 (5.2)[b]
Wrist—palm	50.6 (5.7)	49.5 (8.0)
Vibrotactile perception threshold		
Frequency: 125 Hz	106.0 (8.5)	102.3 (7.4)[b]
Frequency: 32 Hz	108.6 (6.5)	102.3 (14.8)[b]
Frequency: 4 Hz	85.7 (4.7)	83.2 (4.0)[b]

*Weak, hand strength is mildly weaker or much weaker; calibrated pinch force is <10.9 lbs.
**Not weak, all other cases.
[a]Based on dominant hand.
[b]$P < 0.05$.
[c]$P < 0.01$.

- Experienced dental hygienists with clinical CTS, as defined in the study, have reduced SNCV along the median nerve compared to their colleagues that was at least as extensive along the digit as along the wrist-palm segment. A diagnosis of study defined CTS is not

TABLE X. Estimated Odds Ratios for Key Variables Differentiating the "weak" and "non-weak" Subgroups

Variable	Point estimate	95% CI	
Age	0.71	0.54	0.94
Years in field	0.76	0.55	1.07
Vibration years	1.77	1.12	2.80
Cumulative vibration hours	1.21	1.01	1.45
Maximum voluntary pinch	0.28	0.11	0.71
VPT 125 Hz digit 3	1.55	1.14	2.12
SNCV wrist-proximal digit 3	0.56	0.36	0.87

associated with increased VPTs. There is, however, a trend towards greater vibratory tool use accompanying the diagnosis of study defined CTS.

- There is a distinct and substantial sub-group of experienced dental hygienists who have a combination of subjective hand weakness, low calibrated pinch force in task simulations, paresthesias, and raised VPTs in a pattern that appears to involve primarily, but not exclusively, large deficits at 125 Hz.

- Age differences, descriptive exposure variables, and the presence of Raynaud's phenomenon do not appear to account for much difference in VPTs among the experienced dental hygienists.

Conrad et al. [1993] reported raised VPTs in 16 subjects 3 years after their completion of dental hygiene training, using a simple vibrotactile device that summed responses at 125, 250, and 500 Hz. Using a similar method, Akesson et al. [1995] compared VPTs between 30 experienced dental hygienists and the same number of non-vibration exposed medical personnel. VPTs were higher in the dental hygienists at every frequency, and significantly so in the non-dominant hand when the test frequency was >125 Hz. In a study of 10 dental technicians exposed to high frequency vibration and 10 controls, Hjortsberg et al. [1989] performed vibrometry at 100 Hz, and saw significantly higher thresholds in the exposed population. There were, however, no clear-cut associations between simple measures of exposure and raised VPTs. Our results are in agreement with these reports.

There are, however, some important differences. These include observations that some generic explanatory variables for raised VPT, such as age and habitus, previously reported by other investigators [Gerr et al., 1995], did not appear to effect this female cohort; exposures, albeit crudely assessed, were weakly associated with VPT for the aggregated cohort; and age and work related differences between the students and the experienced hygienists were observed in SNCV, but were segment specific (Table III), the digital velocities being identical. While these results may be attributable to the uncertainties of the study, self-selection and strong cohort effects may provide a more etiologic explanation. For

example, the evidence that abnormalities, such as CTS or musculoskeletal pain (MSP) seem to be acquired in the experience dental hygienists may only reflect initial cohort differences or self-selection (see Table II). The extent to which the experienced dental hygienist cohort has been shaped by exclusion due to exposure and symptoms or by inclusion due to pathology provoked motivation cannot be excluded. However, the robust comparisons between sub-groups mitigate against the effects of self-selection. While the calibrated pinch measurement during simulation was rudimentary, it is unlikely such a strong effect will be fundamentally altered by a more precise measurement.

The absence of a correlation between SNCV and VPT reinforces the observation that end organ and/or distal nerve function can be differentiated from measured electrical activity in afferent nerve trunks [Johnson et al., 2000], and that injury to sensory organs and their afferents may be selective. It is notable and consistent with other observations that the diagnosis of CTS, while associated with reduced SNCV, does not appear to be linked to a raised VPT [Cherniack et al., 1996]. The relationship between age and experience and SNCV has several interesting but inconsistent variations.

One of the most interesting observations involved the location of SNCV slowing in subjects with study defined CTS. SNCVs along the digital segments in the experienced dental hygienist cohort as a whole appeared to be indistinguishable from those of the students. However, the sub-group of experienced dental hygienists with study defined CTS had a more generalized pattern of slowing across both the wrist and the fingers. One interpretation is that mononeuropathy at the wrist creates a more distal injury pattern. The slowing in the wrist-proximal digit segment in the median nerve among experienced dental hygienists with study defined CTS lends support to this interpretation. These results mirror our earlier findings that industrial workers with clinical diagnoses of CTS were as likely to have conduction deficits intrinsic to their digits as across the wrists [Cherniack et al., 2004a]. An implication is that age or exposure related SNCV slowing across the wrist is not necessarily an indicator of clinical CTS, and that the mechanisms associated with paresthesias are imperfectly represented by conventional nerve conduction testing. There is, therefore, a potential for spurious attribution of causation.

The suggestion that increased hours of vibratory and ultrasonic tool use, but not manual device use, are more common in experienced dental hygienists diagnosed with CTS, as defined in the study, raises additional considerations. Since SNCV deficits were also identified distally in the digits in this group, it cannot be assumed that pathology arises only across the wrist, or is due to an unrecognized biomechanical exposure factor, causing proximal entrapment, such as a postural thoracic outlet syndrome. Using orthodromic stimulation techniques, Hjortsberg et al. [1989] concluded

that some of the abnormalities they observed in the sensory thresholds of dental hygienists might arise from digital nerves, rather than from mechanoreceptors. It is difficult to hypothesize a physiologic mechanism by which high frequency oscillation would affect peripheral nerves at the wrist. However, there are mechanisms by which stimuli that are chronically irritating to either high or low threshold receptors might alter axonopathic function of either C or $A\beta$ fibers [Mannion et al., 1999] or of end organs. A quite different explanation may be hidden within the uncertainties over cause and effect. Follow-up with participants has suggested a decrease in effort and discomfort when ultrasonic handpieces are substituted for manual instruments. Subtle symptoms or risk perception may sway use towards ultrasonic handpieces. While such a sequence is plausible, it cannot be deduced from a cross-sectional design.

The most intriguing unanswered questions concern the distinct sub-group characterized by increased VPTs, sub-jective weakness, and reduced calibrated pinch forces. Perhaps the most likely explanation of the magnitude of the effect evident in Table X is that the profile of raised VPT and diminished applied force arises naturally in the population, as a distinct sub-type, either presenting as a sensorineural profile at baseline or as an unfavorable phenotype evolving over time. There is clear evidence that a raised VPT is associated with decreased grip force in vibration-exposed industrial workers, but this has usually been interpreted as a function of exposure rather than an expression of suscept-ibility [Farkkila et al., 1980, 1986]. The fact that no sub-group with elevated VPTs was discernible in the students mitigates against a simple population-based explanation of susceptibility. Moreover, the high prevalence of paresthesias in the weak experienced dental hygiene sub-group and evidence for reduced acuity at frequencies identified with several populations of mechanoreceptors in this sub-group (see Table IX) suggests more generalized acquired dysfunc-tion in the $A\beta$ fiber afferent or end organ. The association with cumulative exposure to vibratory and ultrasonic tool use, but not with manual instrument use, provides additional insight into the sub-group with elevated VPTs. This association occurs despite a lack of association between vibratory exposure and elevated VPTs in the cohort as a whole. Vibratory exposure was also associated with clinical study defined CTS, even though the weak subgroup and the CTS population had limited overlap. In short, there were apparent associations between vibratory exposure and two different pathologies associated with paresthesias—study defined CTS and weak pinch accompanied by raised VPTs. The association of vibratory exposure with two clinical syndromes rather than with the continuous quantitative outcomes variables–SNCV and VPT–suggests elicitation of more than one neuropathic mechanism, and a difference between clinical expression and the underlying pathophy-siology.

Recent evidence suggests that each mechanoreceptor population possesses a distinct role in tactile function [Johnson, 2001]. Of particular relevance to the present study is the finding that the perception of features of a surface in contact with the remote end of a device held in the hand is mediated by the FAII receptors, from which is constructed a perceptual image of the work surface [Brisben et al., 1999]. This last observation may have particular pertinence to the weak experienced dental hygienists sub-group, since the two foci of abnormality were raised VPTs in the FAII mechanoreceptor population and a perceived functional deficit in hand strength.

As a concluding caveat, both the observed relationship between hand function and sensory deficits and the seeming confirmation of earlier observations on sensory deficits in dental hygienists should serve as a stimulus for further investigation. However, it would be premature to overstate the case. The identification of a particular pattern of altered performance and physiology does not establish causation, particularly in a prevalence study. In particular, the association of experimentally-defined performance metrics with recalled antecedent exposures probably belongs to the category of significant observation rather than explanation of etiology.

CONCLUSIONS

A cross-sectional study has been conducted of experienced dental hygienists who operate ultrasonic handpieces. To minimize biases introduced by the self-selection of subjects, symptoms and the results of quantitative sensory testing have been compared between sub-groups, formed by: (a) reports of paresthesias; (b) diagnosis of study defined CTS, or, (c) weak hand grip. Subjects reporting paresthesias (55.3%) are more likely to be diagnosed with study defined CTS and possess slower SNCVs along the digit as well as well as the palm-wrist segment of the median, but not the ulnar nerves. A diagnosis of study defined CTS (14.9%) was not associated with increased (i.e., less sensitive) VPTs, but there was a trend towards greater use of ultrasonic handpieces in this sub-group. There is also a distinct sub-group of dental hygienists (26.9%) comprising those with subjective hand weakness, low pinch force in task simulations, paresthesias, and a pattern of elevated (i.e., less sensitive) VPTs that reaches statistical significance for thresholds mediated by the FAII receptors (125 Hz). The pattern of deficiencies may be especially relevant to the dental hygiene profession, as the FAII receptors are known to be responsible for sensing the perception of surface features at the remote end of a hand-held device.

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