KUOPION YLIOPISTON JULKAISUJA C. LUONNONTIETEET JA YMPÄRISTÖTIETEET 180
KUOPIO UNIVERSITY PUBLICATIONS C. NATURAL AND ENVIRONMENTAL SCIENCES 180

ESKO RYTKÖNEN

High-Frequency Vibration and Noise in Dentistry

Doctoral dissertation

To be presented by permission of the Faculty of Natural and Environmental Sciences of the University of Kuopio for public examination in Auditorium L1, Canthia building, University of Kuopio, on Friday 25th February 2005, at 12 noon

Department of Environmental Sciences
University of Kuopio

KUOPION YLIOPISTO
KUOPIO 2005

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ISBN 951-781-318-X
ISBN 951-27-0013-1 (PDF)
ISSN 1235-0486

Kopijyvä
Kuopio 2005
Finland

Rytkönen, Esko. High-frequency vibration and noise in dentistry. Kuopio University Publications C. Natural and Environmental Sciences 180. 2005. 80 p.
ISBN 951-781-318-X
ISBN 951-27-0013-1 (PDF)
ISSN 1235-0486

ABSTRACT

In dentistry, high-speed drills and ultrasonic scalers expose the hands of the users to high-frequency vibration. Finger symptoms have been reported among dental personnel. In this study, weighted vibration according to standard ISO 5349-1 and high-frequency vibration up to 10 kHz (ultravibration) of dental handpieces were measured in the laboratory and during dental treatments. In addition, weighted vibration and ultravibration of dental laboratory hand tools and common electric motor-operated hand tools were measured. The weighted vibration of dental hand tools varied in this study from 0.01 – 3 m/s^2. The highest levels were measured in the dental laboratory. The highest ultravibration acceleration was measured in air-turbine handpieces, in which the weighted vibration values were lowest. The vibration of common hand tools varied widely, and weighted vibration values did not predict the levels of ultravibration.

The new non-contact vibration measurement method was compared with the traditional accelerometer method as follows: the vibration of 12 handpieces was measured during idling with a laser vibrometer, and simultaneously with the accelerometer. Both measurement methods gave nearly the same results. A group of dentists responded to a questionnaire on their working conditions, lifestyle, and health status. The data showed that vibration exposure in dentistry may increase the risk of frequent finger symptoms that are perceived as vibration-related.

Air-turbine and micromotor handpieces, suction tubes and ultrasonic scalers are common noise sources in dental care. In this study, the sound power levels of new and old instruments were tested. During the simulated work, the average A-weighted sound power level of the new and old handpieces was 74-80 dB(A), that of the power suction tube 75 dB(A), the saliva suction tube 73 dB(A) and the ultrasonic scaler 81 dB(A). The average ultrasound level of the ultrasonic scaler was 107 dB at the one-third octave band of 25 kHz. In the in situ measurements, the A-weighted sound exposure level of the dentist was occasionally over 85 dB(A), and the equivalent continuous A-weighted sound pressure level was 76 dB(A). The noise level was most powerful in the one-third octave band of 40 kHz, where it was 74 dB. When disturbances in communication and other non-auditory effects of noise are taken into account, technical noise control measures are recommended. If hearing protectors are used, even the very light protectors are sufficient.

In order to develop standardized vibration and noise measurement methods for dental handpieces, more research and method development are needed.

Universal Decimal Classification: 331.432.4, 331.432.6, 534

National Library of Medicine Classification: WA 470

Medical Subject Headings: vibration; noise; ultrasonics; dentistry; dentists; dental high-speed equipment; occupational exposure; fingers

To Eeva, Mikael and Juhana

ACKNOWLEDGEMENTS

This work was performed at the Kuopio Regional Institute of Occupational Health. I wish to express my sincere thanks to Professor Jorma Rantanen, former Director General, and Professor Harri Vainio, Director General of the Institute of Occupational Health, for creating a positive atmosphere for research work. My warmest thanks and gratitude are due to docent Esko Sorainen, Ph.D., my supervisor for his encouraging and friendly guidance through every phase of the study. My sincere thanks are due to my other supervisors Professor Taisto Raunemaa, Ph.D. and docent Erkki Björk, Ph.D., for their invaluable support and guidance.

I wish to express my special thanks to docent Jussi Pekkarinen, Ph.D., and Seppo Aatola, Ph.D., for their constructive criticism and expert review of the final manuscript. I also wish to thank Terttu Kaustia, M.A. for the revision of the language of this thesis.

I owe my sincere thanks to my co-authors docent Päivi Leino-Arjas, D.Med.Sci., and Svetlana Solovieva, Ph.D. for stimulating collaboration.

I am also thankful to Professor Juhani Kangas, Director, and the staff of the Kuopio Regional Institute of Occupational Health for positive atmosphere during my long career in Kuopio. I am also grateful to Raija-Leena Pajula and Pirkko Kultamaa for their exellent library services.

Financial support was provided by the Finnish Work Environment Fund, for which I am sincerely grateful.

Finally, I thank my dear wife Eeva and our sons Mikael and Juhana for their love and encouragement throughout the preparation of this dissertation.

Kuopio, February 2005

Esko Rytkönen

ABBREVIATIONS AND SYMBOLS

a	acceleration
ACGIH	American Conference of Governmental Industrial Hygienists
a_{hv}	vibration total value
a_{hwx}	frequency-weighted rms acceleration value in the direction x
a_{hwy}	frequency-weighted rms acceleration value in the direction y
a_{hwz}	frequency-weighted rms acceleration value in the direction z
ANOVA	one way analysis of variance
a_w	frequency-weighted rms acceleration value
A(8)	daily vibration exposure value
BMI	body mass index
CI	confidence interval
EC	European Community
EN	European standard
EU	European Union
f	frequency
HAVS	hand-arm vibration syndrome
ILO	International Labour Office
IRPA	International Radiation Protection Association
ISO	International Organization for Standardization
L_A	A-weighted sound pressure level
L_{Aeq}	time weighted average of the A-weighted sound pressure level
$L_{Aeq,T}$	averaged A-weighted sound pressure level over an average working day
LDAc	laser doppler accelerometer
LDV	laser doppler velocimeter
$L_{EX,8h}$	daily noise exposure level
$\overline{L_p}$	average sound pressure level averaged over the measurement surface
L_W	sound power level
L_{WA}	A-weighted sound power level
NIOSH	National Institute for Occupational Safety and Health
OR	odds ratio
rms	root mean square
S	area of the measurement surface
SD	standard deviation
SLV	scanning laser vibrometer
S_0	area of the reference surface
TLV	threshold limit value
v	velocity
VWF	vibration-induced white finger

ORIGINAL PUBLICATIONS

I Rytkönen E, Sorainen E. Vibration of dental handpieces. *AIHA J (Fairfax, Va)* 2001;62:477-481.

II Rytkönen E, Sorainen E, Leino-Arjas P, Solovieva S. Hand-arm vibration exposure of dentist. Submitted.

III Rytkönen, E, Sorainen E. High-frequency vibration of dental laboratory hand tools compared to common hand tools. Submitted.

IV Sorainen, E, Rytkönen E. High-frequency noise in dentistry. *AIHA J (Fairfax, Va)* 2002;63:231-233.

V Sorainen, E, Rytkönen E. Noise level and ultrasound spectra during burring. *Clin Oral Investig* 2002;6:133-136.

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CHAPTER 1
GENERAL INTRODUCTION TO OCCUPATIONAL HIGH-FREQUENCY VIBRATION AND NOISE IN DENTISTRY

1 LITERATURE REVIEW

1.1 Hand-arm vibration

1.1.1 Effects on man

The human body is a complex, active, intelligent and dynamic structure. Its vibration characteristics and responses to vibration are not easily predictable nor well known. Knowledge of the injurious effects of hand-transmitted vibration is incomplete. Some things are known and others are commonly assumed [1].

The term "hand-arm vibration" is frequently used to mean vibration exposure from power tools, but the term "hand-transmitted vibration" is more precise to indicate that vibration enters the body at the hand [1].

The vibrational behaviour and system modelling of the human hand-arm system has been studied since the beginning of the research on hand-arm vibration. The models vary from spring-mass-damper systems with one degree of freedom to non-linear four-mass models which consider also gripping force [1, 2].

The dynamic response of the finger-hand-arm system has usually been studied by measurements of the mechanical impedance of the hand. In most studies, the test subject holds a handle mounted on a laboratory vibrator. In the published studies, different methods and measures have been used, and therefore direct comparison between the results is not easy. The dynamic response of the fingers differs from the dynamic response of the hand, but there are very few relevant studies on the topic [1].

In order to study the time-dependent deformation behaviour of the fingertip, numerical simulations were performed under ramp-like loading with different ramping periods and sinusoidal vibration of the contacting plate at three different frequencies (1, 10, and 31.5 Hz). The simulations suggested that the soft tissue of the fingertip is subjected to high local stress and strain under dynamic loading, and the fingertip may separate from the vibrating contact surface due to the viscous deformation behaviour of the soft tissue. For a given deformation, the high frequency loading produces higher stress in the tissues compared to that obtained at low frequency loading [3].

According to laboratory tests, a great amount of vibration energy is absorbed by the human hand and arm within the frequency range of 20-5000 Hz. The transmission of vibration energy to different parts of the hand and arm decreases with the distance from the source and depends greatly on the vibration frequency. Higher frequencies are more concentrated to the contact surface between the hand and the handle. There are also differences in the energy transmission due to different types of exposure, random or sinusoidal vibration [4].

The transmission of vibration increases exponentially as hand-grip force increases [5]. Gender difference in power absorption has not been found [6].

The exposure of the hand-arm system to vibration is very complex. Among the factors to be considered when reporting occupational hand-transmitted vibration exposure are vibration characteristics, source of the vibration, other environmental conditions, characteristics of the exposed persons, quantification of effects in individuals, and quantification of effects in groups [1]. The first two factors can be seen as most important.

Effects of vibration to the hands were first reported in 1911 in workers using pneumatic tools [7]. Since then, many studies on vibration injuries have been reported, e.g. [8-11].

Exposure to hand-transmitted vibration is associated with an increased occurrence of several symptoms, the most significant being white fingers, neuropathy, and muscle weakness. White-finger disease has been a well known symptom for a long time. The complex of peripheral vascular, neurological and musculoskeletal disorders associated with exposure to hand-transmitted vibration is called the hand-arm vibration syndrome (HAVS). The vascular component of the HAVS is represented by a secondary form of Raynaud´s phenomenon known as vibration-induced white finger (VWF). Tingling and numbness of the fingers are often mentioned as the first symptoms of VWF [1, 12-15]. The relation between white finger and vibration exposure has been extensively investigated. However, the amount of vibration exposure required to cause different disorders is not known precisely. To study blood circulation in the finger, the middle finger of the subject´s right hand was exposed to 125 Hz at 44 m/s^2 for different time periods. For the vibration stimuli investigated, the reduction of finger blood flow during exposure was the same during continuous and intermittent vibration. Although this study showed some evidence that was consistent with the notion that intermittent vibration has a less severe effect than continuous vibration, the evidence is not yet conclusive [16].

The signs and symptoms of VWF might be categorized according to their type (e.g. numbness, tingling, blanching or cyanosis), their extent (e.g. number of digits affected), their severity (e.g. area of digit affected), their frequency of occurrence (e.g. number of attacks per year), the stimulus required to produce an attack (e.g. summer or winter temperatures), the time course of an attack (e.g. recovery time), the effects of an attack (e.g. tactile sensitivity during an attack), the neurological signs at other times (e.g. sensory loss), the self-enforced restrictions on activities (e.g. no swimming or fishing), and so on [1].

The mechanisms of vibration injury are uncertain. Comprehensive explanatory models of vascular disorders produced by hand-transmitted vibration have been created [1].

In the United Kingdom, an extensive assessment process is going to produce the largest worldwide database on vibration-exposed workers. In this process, the medical assessment procedure has been shown to be a practical and time-saving tool for assessing a large number of claimants with suspected hand-arm vibration syndrome [17].

The effects of impulse vibration exposure have been studied more widely in recent years, e.g. [4, 18-20]. The vibration impulses contain high frequency components which have not been considered in the measurements according to ISO (International Organization for Standardization) standard 5349-1 [21]. Vibration which contains impacts has a significant influence on energy absorption compared to vibration without impacts. The risk of noise impulses on hearing damage increases if the impact lasts long and the rise time is short. Vibration impacts should be evaluated in a similar way. It is assumed that vibration impacts

with a short rise time increase the risk of vibration injuries [4]. The hand-arm vibration syndrome was common among Swedish car mechanics in spite of their short daily exposure times, mainly to nut-runners [22]. The transients of vibration cause destruction of the cell membrane of blood cells and other biological tissues in the hand [23]. A higher risk of possible inner ear damage may be expected if there is exposure to shock-type vibration in addition to simultaneous impulse noise [21]. In a questionnaire study of 8139 respondents 185 (2.2 %) reported severe hearing difficulty, and 1151 (14 %) reported finger blanching. Hearing difficulty was about twice as common in men and women who reported finger blanching. The data support an association between finger blanching and hearing loss, which is not explained by confounding occupational exposure to noise [24].

1.1.2 Evaluation

The vibration may enter the body at both the fingers and the palm of the hand, and the exposure is very complex. It is therefore difficult to propose a comprehensive method for the evaluation of vibration exposure [1, 15]

According to the EC (European Community) Vibration Directive [25] the daily exposure limit value standardised to an eight-hour reference period A(8) shall be 5 m/s^2, and the daily exposure action value standardised to an eight-hour reference period shall be 2.5 m/s^2, as defined in ISO standard 5349-1 [15].

International standard ISO 5349-1 describes the evaluation of hand-transmitted daily vibration exposure, A(8), specified in terms of frequency-weighted vibration acceleration and daily exposure time, and is based on the 8-h energy-equivalent acceleration value. The primary quantity of vibration is the rms frequency-weighted acceleration. The frequency-weighting curve is shown in Figure 1.

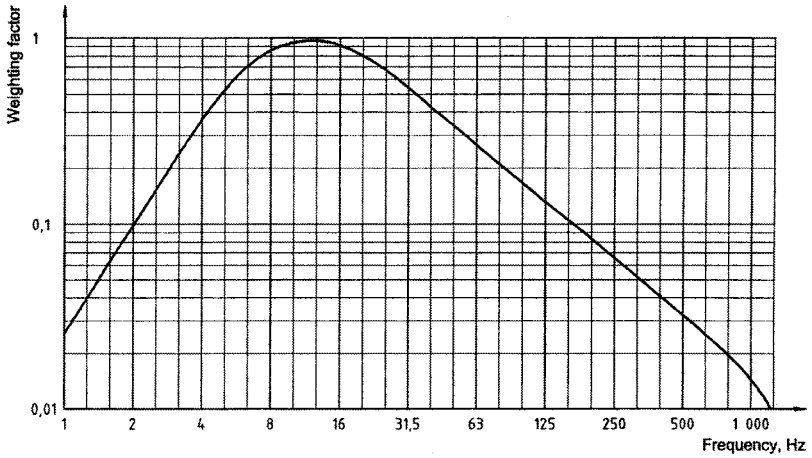

Figure 1. Frequency-weighting curve for hand-transmitted vibration, band-limiting included (schematic) [15].

The frequency range in ISO 5349-1 covers one-third octave bands from 6.3 Hz to 1250 Hz. The frequency weighting reflects the assumed importance of different frequencies in causing injury to the hand, but this is not well supported by epidemiological or experimental studies of

physiological or pathological changes. It is based on subjective sensations at low and medium frequencies, and has been extrapolated to higher frequencies [15, 26]. There is evidence that vascular disorders of the fingers occur most often with tools with dominant frequencies of vibration in the approximate range of 25-250 Hz. This finding may arise either because these are the most common frequencies of vibrating tools, or because they are the most damaging frequencies [1, 27]. The currently used frequency weighting functions should be verified, especially at higher frequencies [4, 21]. In the USA, The National Institute for Occupational Safety and Health (NIOSH) proposes the use of the frequency-unweighted acceleration in the one-third octave bands of 5-5000 Hz [28].

It is assumed that vibration in each of the three directions is equally detrimental. Measurements should therefore be made in all three directions. The frequency-weighted rms acceleration values for the x-, y- and z-axes a_{hwx}, a_{hwy} and a_{hwz} , shall be reported separately.

The evaluation of vibration exposure is based on a quantity that combines all three axes. This is the vibration total value, a_{hv}, and is defined as the root-sum-of-squares of the three components. If the magnitude of weighted vibration is equal in all three directions, the estimated vibration total value is the measured weighted value of one component multiplied by a factor of 1.7:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \tag{1}$$

In order to facilitate comparisons between daily exposures of different durations, the daily vibration exposure shall be expressed in terms of the 8-h energy-equivalent frequency-weighted vibration total value A(8):

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \tag{2}$$

where

T	is the total daily duration of exposure to the vibration a_{hv};
T_0	is the reference duration of 8 h (28800 s)

This "single-value" method has been standardized for convenience, and not because it is the best method. The guidance given in this standard is derived from the limited quantitative data available on the exposure-response relationship [1, 15]. Most of the measurements reported have been carried out applying this standard.

The daily vibration exposure, A(8), which is estimated to cause finger blanching in 10% of the exposed persons, is presented in Figure 2. The values are shown for group mean total (life-time) exposures of from one to ten years. This relationship does not predict the risk of finger blanching (VWF) occurring in any particular individual within a group.

The practical guidance for the measurement of hand-transmitted vibration at the workplace is given in the standard ISO 5349-2 [29].

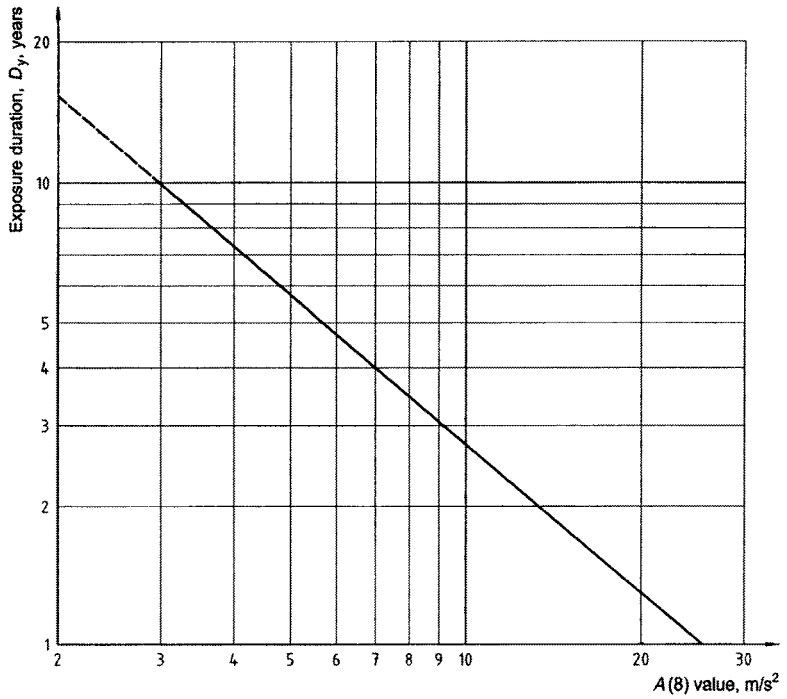

Figure 2. Vibration exposure for predicted 10% prevalence of vibration-induced white finger in a group of exposed persons [15].

The exposure-response relationship used in ISO 5349-1 contains many uncertainties and assumptions. The ISO 5349-1 model underestimates the risk of vibration-induced white finger [22]. The subjective estimation of the exposure time is often overestimated, and thus gives an overestimation of the risk [30]. The energy equivalent acceleration failed to predict the acute effects of vibration both during and after exposure to vibration. Both central and local vasoregulatory mechanisms are likely to be involved in the response of finger blood circulation to acute exposure to 125 Hz vibration [31].

The reproducibility of the ISO 5349 method in measuring hand-arm vibration was poor when the vibration of a chain saw and a hand mower was measured. An alternative method, in which at least four different measurement situations were used, had acceptable reproducibility [32].

1.1.3 Exposure and symptoms of dental personnel

High-speed drills and ultrasonic scalers expose to the hands of the users to high-frequency vibration, e.g. [33]. The symptoms and the prognosis of vibration injuries was studied by means of a questionnaire in 374 Swedish women who had reported an injury due to hand-arm vibration. Questions were asked about neurological and vascular symptoms in fingers and hands, decreased hand strength, tremor, and pain in the hands and neck. The accumulated vibration exposure was calculated for each woman on the basis of self-reported yearly and daily exposure to hand-arm vibration up to the recording of the injury. The vibration level of

the tools used was received from the former studies. The most common symptoms were numbness and loss of strength. Pain in the hands and symptoms from the neck/shoulders were also frequent complaints. Neurological symptoms of the hands and fingers were more frequent than vascular symptoms. The period of hand-arm vibration exposure before the first appearence of symptoms was on average 6.8 years. The incidence of vibration injury related to the number of women in certain occupation in some occupational groups is presented in Table 1, where is also the relative risk of getting a vibration injury related to the group of administrative personnel. The most common tools are also listed [10].

Table 1. Occupational group, most common tools, estimation of the incidence of vibration injuries and estimation of the relative risk of getting a vibration injury related to the group administrative personnel. The relative risk is complemented by 95% confidence intervals (CI) [10].

Group	Tools (examples)	Incidence (1000/year)	Relative risk (95% CI)
Administrative personnel	Lever	0.003	1.0
Agricultural workers	Lawn mower, hedge clipper, grinder	0.057	21 (9-50)
Cleaners	Scrubbing machine	0.016	6.2 (2.7-14)
Dental hygienists	High-speed grinding machine, handpiece, ultrasonic scaler	0.88	330 (150-710)
Dental nurses	Sander, drill	0.05	19 (7.2-49)
Dental technicians	Drill, vibrator	1.8	680 (320-1400)
Dentists	High-speed handpiece, ultrasound device	0.72	270 (130-570)
Drivers	Steering wheel, lever	0.15	56 (25-130)
Garment workers	Sewing machine, nail punch, impact wrench	0.5	190 (77-450)
Laboratory personnel	Test tube shaker	0.091	34 (13-88)
Metal workers	Grinder, screw drill, impact wrench, drill	0.42	160 (80-310)
Wood product assemblers	Sander, grinder, nut runner, nail punch, orbital sander	0.39	140 (68-310)

The exposure time of 10 dental hygienists during the use of ultrasonic scalers was quantified by measuring the daily duration of vibration. The daily exposure time was 0-50 min, the average time being 12 min. The self-assessed duration of exposure was clearly overestimated [33].

Work-related musculoskeletal disorders are commonly reported by dental hygienists, and the major risk factors are repetitive motion, pinch-grasp, force, vibration and prolonged awkward working positions [34].

The relationship between symptoms of musculoskeletal disorder and vibration in dental hygiene students was studied. A questionnaire was distributed to three intact students groups: those accepted for admission, those at the end of the first year, and graduating students at the end of second year. The survey was completed by 82 students, 77 female and 5 male. Students increased their use of ultrasonic instruments from 0.2 to 2.8 to 7.3 hours per week over the three years. Dental hygiene students with symptoms of numbness in the upper extremities used ultrasonic scalers a mean of 8.2 hours per week compared to 2.8 hours of use by students with no upper extremity numbness. Results indicate that musculoskeletal disorder symptoms may increase with the use of ultrasonic and/or manual instruments. The study also indicates the possibility that nerve injury may result from the use of vibrating instruments, although it is difficult to separate the effects of other musculoskeletal disorder risk factors from manual instrument use [35].

Early neuropathy in dental personnel exposed to high-frequency vibrations was evaluated. The exposed group consisted of 30 dental hygienists and 30 dentists, and the non-exposed group of 30 dental assistants and 30 medical nurses. The two groups exposed to vibration had significant impairments of vibrotactile sensibility, strength, and motor performance, as well as more frequent sensoneural symptoms. In the dentists there were significant associations between vibrotactile sensibility and strength, motor performance, superficial sensibility, and sensoneural symptoms. There was no increase of vascular symptoms of the hands in the groups exposed to vibration [36]. Ten female dentists with 10 years of work experience had a significantly higher sensation threshold of the fingers than the control group [37].

The difference between the dominant and nondominant hand in the perception of vibration, temperature, and heat pain was compared between 26 dentists with long-term exposure to high-frequency vibration and 18 with short-term exposure. Dentists exposed for many years had a high frequency of neurological symptoms, especially in the dominant hand. The symptoms were comparable to those described in the hand-arm vibration syndrome. The neurological symptoms of the dentists had some other pathogenic background than the corresponding symptoms in workers exposed to traditional vibrating tools [38]. In Minnesota (USA), 15 of 61 dental hygienists reported symptoms of tingling, numbness and/or pain in the fingers [39].

When 120 dental technicians, 111 women and 9 men, were examined, their most frequent subjective complaints were vertebral complaints, paraesthesia in the fingers, and pain in the joints of the upper extremities. The mean exposure period was 25 years. The authors recommended ergonomic interventions and replacing the instruments with exessive vibrations by those with lower levels of vibrations [40].

The vibration of altogether 80 handpieces used in a dental laboratory was measured during normal work. Four frequency weightings were used: weighted vibration according to standard ISO 5349-1986, and total unweighted vibrations up to 1250 Hz, 5000 Hz and 10 000 Hz. The highest vibration levels were measured in the frequency range of 100-10 000 Hz. The weighted vibrations determined according to the ISO 5349 standard were 0.35-5.6 m/s^2, and the median value was 0.5 m/s^2. The total unweighted acceleration levels were about 10-30 times higher. The material being worked did not have any effect on the vibration level. The

rated mean daily exposure time was about three hours [41]. The tactile perception of the users of these tools was not reduced. The prevalence of numbness was, however, higher in hands that were in contact with the vibrating handpiece [42]. Ten dental technicians exposed to high-frequency vibration had increased vibration thresholds and the limits for warming and cooling, and an increased difference in the digital nerve response to tactile and electric stimuli at the fingertip [43].

1.1.4 Hand-held tools

The vibration of hand tools must be declared according to the EC Machinery Directive [44]. The instruction handbook of the machine must contain the weighted rms acceleration value to which the arms are subjected, if it exceeds 2.5 m/s^2. If the accleration value does not exceed 2.5 m/s^2, this must be mentioned. Several machines, e.g. those for medical use used in direct contact with patients are outside the scope of this directive.

The weighted vibration for declaration purposes is measured according to appropriate test standards, e.g. [45, 46]. Tools are tested under conditions as appropriate for the type of tool and specified in the relevant Part 2 of the test standard. The requirements given in Part 2 either supplement or modify the requirements given in Part 1 to account for the particular hazards and characteristics of these specific tools. The measurement method of the vibration described in these standards is based on the standard ISO 5349-1.

The standard deviation of reproducibility was determined in a round-robin test for common hand tools such as rotary hammers, breakers, chisel hammers, impact drills and chain saws. 18 laboratories were involved in the investigations. The tests were carried out according to the respective international test codes. The results showed that even certified laboratories had great deviations and measurement errors. The machines with powerful impacts were most problematic [47]. According to field measurements, the declared vibration values of grinding machines [48] and road brakers [49] were not adequate for assessing the vibration exposure. More attention should be paid to the risks from common vibrating tools [50].

The test standards do not refer to all working situations of the tool in question. It is not intended that the values measured according to a relevant test standard are used for assessing human exposure to vibration. The practical guidelines for measuring human exposure to hand-transmitted vibration at work are given in ISO 5349-2 [29]. As an example of exposure level, the average vibration of grinders (n=74) was 4.2 m/s^2, and of hammers (n=32) 8.7 m/s^2 during normal work [51].

1.1.5 Measurement methods

Vibration measurement systems generally use accelerometers to detect the motion of the vibrating surface. In the selection of the accelerometer, the size, frequency response, sensitivity, thermal response, ease of calibration and compatibility with other signal conditioning will be major influencing factors [1]. In addition, the expected magnitude of vibration, the physical characteristics of the surface being measured, and the environment in which the accelerometer is to be used, are important factors. Various mounting methods have been developed to fix accelerometers to vibrating surfaces. In the standard ISO 5349-2 [29] four examples are presented: stud mounting, mounting by glue or cement, clamp connections, and hand-held adaptors.

The vibration signal from the accelerometer can be processed in a number of ways to achieve a measure of the frequency-weighted acceleration. A new method for the personal measurement of hand-arm vibration is to attach sensors to the hands [52]. When vibration transmitted to the operators of a sewing machine was measured, the accelerometers were glued directly to the workers´ fingernails [53].

In practical measurements of vibration, problems often arise from, e.g. fastening and the mass of the accelerometer, especially at high frequencies. Non-contact laser sensors are preferred for high-frequency vibration and shock applications. Laser Doppler Velocimeters (LDV) and Scanning Laser Vibrometers (SLV) are commercially available. They provide a voltage analogue of target vibration velocity.

In a basic LDV system, scattered light that has been Doppler-shifted by the vibrating target is mixed with a coherent reference beam and heterodyned on a photodetector as shown in Figure 3. This results in an optical beat at the detector at the difference frequency between the target and the reference beams. Frequency demodulation then produces a time-resolved analogue of the target vibration velocity [54].

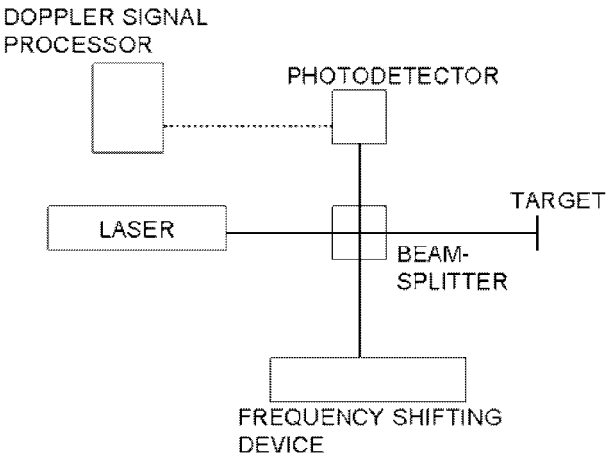

Figure 3. Schematic diagram of a Laser Doppler Velocimetry system [54].

The SLV consists primarily of a controller and a work station (for data decoding and manipulation) and a scanning head, combining a laser and an integral video camera. A low power laser beam is split into a reference beam and an object beam within the scanner head. The reference beam is internally reflected and the object beam is focused onto the oscillating target and then reflected back into the scanner head. The frequency of the reflected light is Doppler-shifted, the magnitude of the shift being proportional to the instantaneous velocity of the object. The reference beam and the Doppler-shifted object beam interfere within the scanner head. A photodetector records the interfered light and provides a voltage proportional to the velocity of the vibration [55].

The Scanning Laser Vibrometer technique has been successfully applied to analyze vibration transmitted to the hands of an operator of an agricultural machine working in a fixed position

[56]. Using Scanning Laser Vibrometry, the vibration pattern of a dental ultrasonic scaler tip can be accurately characterized [55, 57, 58]. A fibre optic vibrometer is an inexpensive alternative to commercial laser vibrometers for small-amplitude vibration measurements [59].

A laser vibrometer and capacitive sensor matrix were used to measure the distribution of hand-transmitted vibration and grip force at the hand-handle interface. The results showed a strong correlation between grip force, tool vibration, hand-arm vibration, and the onset of vascular disorders of the fingers [60].

A new instrument uses the laser Doppler principle to provide a voltage analogue of target vibration acceleration. An important advantage of this Laser Doppler Accelerometer (LDAc) is its ability to measure extremely high vibration accelerations and shocks. In LDAc, the "reference" beam and the target beam are both taken from the target itself, and the issue of maintaining path imbalance to within the coherence length of the laser now depends only on internal geometry. After being scattered from the target, the laser beam is amplitude-divided, and a path length imbalance is introduced between each half of the beam as shown in Figure 4 [54].

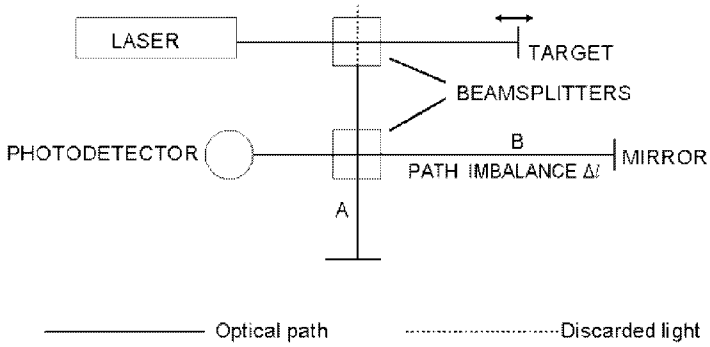

Figure 4. Schematic diagram showing the principle of a Laser Doppler Accelerometer [54].

Compared to LDV, the optical design is more complex, but the user is unaware of this, and the benefits are substantial. The LDAc principle is not only suitable for use with an inexpensive laser source and associated components, but its use is also simple for the vibration engineer who may be unfamiliar with laser technology. This is achieved by eliminating the requirement to match optical paths to maintain coherence, which can be restrictive in LDV, by using optical geometry in which the path lengths are inherently matched, regardless of the distance to the target.

1.2 Noise and ultrasound

1.2.1 Effects on man

Airborne sound in the hearing range can be divided into audio frequencies (20 Hz to approximately 10 kHz) and very high frequencies (10-20 kHz) [61]. High-frequency sound

which is not audible to the human ear is called ultrasound. Its frequency area is typically determined to be above 16 kHz or 20 kHz.

Exposure to noise can reduce hearing sensitivity permanently by damaging the sensory organs of the inner ear. This type of hearing damage can never be repaired.

The standard ISO 1999 specifies a method for calculating the expected noise-induced permanent threshold shift on the hearing threshold levels of adult populations due to various levels and durations of noise exposure [62]. This standard is based on statistical data and therefore shall not be used to predict or assess the hearing impairment or hearing handicap of individual persons. The measure of exposure to noise for a population at risk is the averaged A-weighted sound pressure level, $L_{Aeq,T}$, over an average working day, for a given number of years of exposure. This standard applies to audio-frequency (less than approximately 10 kHz) noise. The use of this standard for instantaneous sound pressures exceeding 200 Pa (140 dB relative to 20 μPa) and for higher sound frequencies should be recognized as extrapolation.

Since noise-induced hearing impairment is the result not only of occupational noise exposure, but of the total noise exposure of the population, it may be important to take non-occupational exposure into account.

For the purposes of the new European noise directive [63] the exposure limit values and exposure action values in respect of the daily noise exposure levels ($L_{EX,8h}$) are fixed at:

(a) exposure limit values: $L_{EX,8h}$ = 87 dB(A)
(b) upper exposure action values: $L_{EX,8h}$ = 85 dB(A)
(c) lower exposure action values: $L_{EX,8h}$ = 80 dB(A)

When applying the exposure limit values, the determination of the worker's effective exposure shall take account of the attenuation provided by the individual hearing protectors worn by the worker. The exposure action values shall not take account of the effect of any such protectors. Noise of the machines must be declared according to EC Machinery Directive [44]. The instructions must contain an equivalent continuous A-weighted sound pressure level in the user position, when this exceeds 70 dB(A); when this level does not exceed 70 dB(A), this fact must be indicated.

The non-auditory effects of noise are broad in scope. Noise affects both physical and mental well-being, and can be an accident risk when it masks communication or warning signals. When performance is considered, the effect of noise on attention or vigilance is critically dependant on the exposure level. Other effects are, e.g. annoyance, sleep disturbances, increased blood pressure, blood cholesterol and diastolic pressure [64]. It seems that a smaller difference between the high-frequency part and the low-frequency part of the noise spectrum is more annoying [65].

Occupational exposure to very high frequency noise and ultrasound has been studied in the 1960s. Exposed workers and researchers reported perceived annoyance, discomfort in the ears, a feeling of fullness in the ears, malaise, fatigue, nausea, vestibular dysfunction, tinnitus, and persistent headaches. There are a number of recommendations and risk criteria which deal specifically with very high frequency noise or ultrasound. There have been no reports showing systematic hearing loss trends associated with occupational exposure to very high-frequency noise. However, the recommended limits have two stated aims: to avoid subjective effects and to avoid hearing damage [61].

Maximum permissible levels (dB) for airborne ultrasound, issued by organisations or national governments are presented in Table 2 [61].

Table 2. Maximum permissible levels (dB) for airborne ultrasound.

Source	One-third octave band centre frequency (kHz)							
	10	12.5	16	20	25	31.5	40	50
International Labour Office (ILO)		75	85	110	110	110	110	110
International Radiation Protection Association (IRPA)				75	110	110	110	110
Health Canada			75	75	110	110	110	110
American Conference of Governmental Industrial Hygienists (ACGIH), ceiling values	105	105	105	105	140	145	145	145

Ultrasound is used widely for medical purposes. The group of examinees exposed to both ^{192}Ir and ultrasound had significantly more chromatid breaks, acentric fragments, and dicentric chromosomes, and had a significantly higher frequency of micronuclei than subjects exposed to ^{192}Ir only. The study suggests that the detected differences in the genome damage may be attributed to the action of ultrasound [66]. Individuals occupationally exposed to ultrasound may have an increased genotoxic risk [67]. The epidemiological evidence does not indicate any association between diagnostic ultrasound exposure during pregnancy and reduced birth weight, childhood malignancies or neurological development. However, a statistically significant association between ultrasound exposure and left-handedness among males has been found in three studies. Thus, there is still need for more research [68].

1.2.2 Exposure and symptoms in dentistry

High-speed drills, ultrasonic scalers and suction tubes are common noise sources in dentistry, e.g. [69, 70]. The purpose of a case-control study was to determine whether long-term ultrasonic noise exposure via the dental office environment is related to dental hygienists' hearing status. The sample consisted of 20 dental hygienists with a high ultrasonic usage rate and a matched group of 20 dental hygienists who had a low ultrasonic usage rate. Audiometric data were analyzed to determine whether the level of exposure to ultrasonic scaler noise in the dental office environment was significantly related to the hearing status of these dental hygienists. The results revealed that the right and left ears were not statistically different in hearing threshold levels, regardless of group status. However, there was a significant difference between the high ultrasonic and the low ultrasonic usage groups at 3000 Hz. Ultrasonic noise may in fact affect dental hygienists' hearing at 3000 Hz, but the loss of hearing observed at the higher frequencies may be attributed to other unidentified factors present in both groups [71].

The noise emitted by five high-speed dental air turbines was studied under different working conditions, and under all conditions the air turbines emitted frequencies which can cause hearing loss. The most significant frequency was 6860 Hz [72].

Noise and ultrasound spectra of high-speed dental air turbines were measured during idling (n=17) and during enamel cutting (n=6). The microphone was positioned 20 cm in front of the noise source. The results show that the audible spectrum may reach amplitudes which may be noxious. The ultrasound spectrum of a high-speed air turbine, in terms of both frequency and amplitude indicate potential noxious effects over a short- or long-term period [70].

The noise exposure of two dentists was measured during a workday using a sound level meter. The microphone position was approximately 18 cm from the dentists' ear. The rotating speed of the drills was determined with an accelerometer and a stroboscope. The total duration of drilling during workday was 109-115 min. Average noise level during drilling was 91 dB(A) and predominant frequency range was 6±2 kHz [73].

Sound levels were measured at four dental clinics and three dental laboratories. Virtually all noise levels at the dental clinics were below 85 dB(A) and were considered to be below the limit of risk of hearing loss. The noise levels in the dental laboratories were higher, in some cutting activities, steam cleaning, and sandblasting up to 90 dB(A), and in compressed air blasts the maximum was 96 dB(A). Technicians and other personnel who spend many hours in noisy dental laboratories may be at risk if they do not wear hearing protectors [74].

In order to estimate the risk of hearing-damage among dentists, and the extent of communication interference, sound levels were measured in clinical settings and in a pre-clinical laboratory. The results show that the risk of hearing damage is slight among dentists using modern equipment, and noise control of handpieces is necessary, so that error-free communication during dental procedures can be ensured [75].

Hearing of two generations of dentists, noise exposure of dentist during dental treatment of 12 patients, and noise spectrum of five high-speed turbine dental drills were studied. Hearing of dentists free from clear ear pathology was found good. There was no difference in hearing of 46 dentists, examined in 1973, and among whom there had been exposure to early noisier drills, as compared to hearing of 56 dentists of similar age and years in dentistry, examined in 1988 and who had only been exposed to quieter drills. The noise exposure level of dentist L_{Aeq} was 65 dB(A). The total measurement time was 4 h 50 min. Discrete peaks in the noise spectra of the drills were found at frequency range of approximately 6200-13 500 Hz. According to this study, dental drill noise is not and has never been a risk to dentists' hearing [76].

At frequencies of 4-8 kHz, the dentists tended to have higher hearing thresholds than expected [77]. Exposure to high-frequency noise from high-speed drills and other dental instruments does not appear to be harmful to one's hearing [69].

Use of laser in tooth preparations has been studied. The results showed that the high-speed drilling caused greater tooth vibration and had a frequency spectrum near the high sensitivity of hearing compared to the laser [78].

The noise level of dental instrumentation was measured in the studies reported, but the sound power of these instruments was not reported.

1.2.3 Measurement methods

The determination of A-weighted sound exposure is described in the standard ISO 1999 [62]. Methods for determining emission sound pressure levels at work station and other specified positions are described in standard ISO 11200 [79]. The sound power of the sound sources is determined using either a sound intensity method [80, 81], or a sound pressure method, e.g. [82].

Most test standards concerning the sound power measurements of hand tools, e.g. [45] are based on the sound pressure method described in the standard ISO 3744 [82]. This standard specifies a method for measuring the sound pressure levels on a measurement surface enveloping a noise source, in order to calculate the sound power level produced by the noise source. To facilitate the location of the microphone positions on the measurement surface, a hypothetical reference box shall be defined; this box is rectangular and covers the sound source. The shape of the measurement surface is either a hemisphere (Figure 5) or a rectangular parallelepiped (Figure 6). The microphone positions lie on the measurement surface of area S.

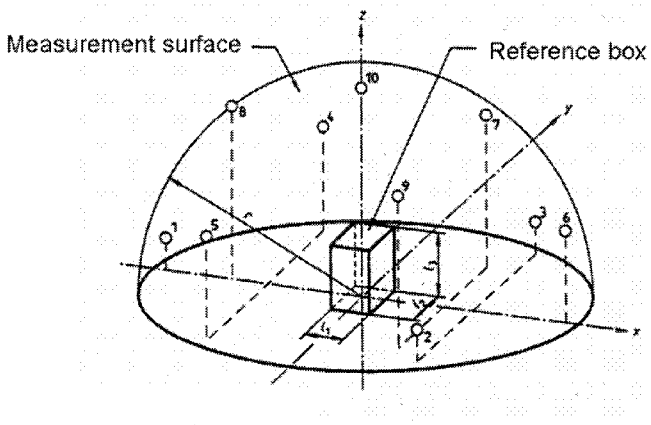

Figure 5. Microphone positions on the hemispherical surface [82].

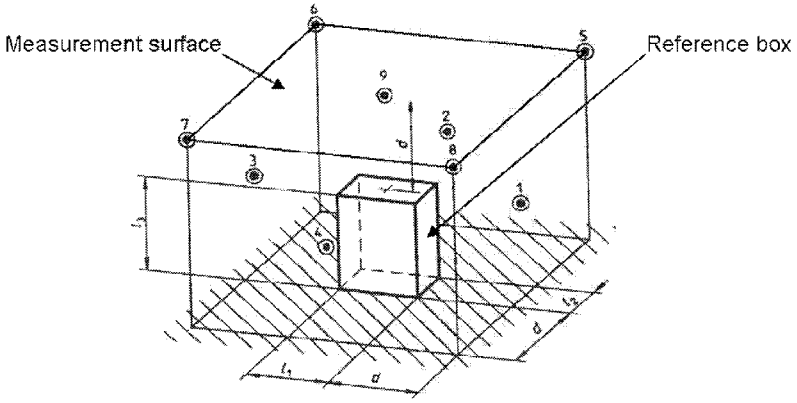

Figure 6. Microphone positions on the rectangular parallelepiped surface [82].

The sound pressure is measured in each microphone position and the sound power level L_W is calculated as follows:

$$L_W = \bar{L}_p + 10\lg\frac{S}{S_0}\,dB \qquad (3)$$

where $\bar{L}_p$ is average sound pressure level averaged over the measurement surface
S is area of the measurement surface, in square metres
$S_0 = 1\ m^2$

If needed, corrections are made for background noise and the test environment.

2 AIMS OF THE STUDY

Many dental instruments expose the users to high-frequency vibration and noise. Effects of high-frequency vibration on hands and fingers are not well known. Previous studies show that dental personnel has finger symptoms and high risk of getting a vibration injury. Measurements of vibration exposure of dentists have not been reported. Laser method gives a new possibility to make high-frequency non-contact vibration measurements. Noise levels during dental treatment may be harmful. Sound powers of dental instruments have not been measured.

The aims of this study were to evaluate the exposure of dental personnel to high-frequency vibration and noise, and to study the feasibility of some measurement methods to assess the exposure.

The detailed objectives of this study were:

- to measure vibration of dental drills according to standard ISO 5349 in laboratory conditions and during dental treatment (Chapters 2 and 3)

- to measure high-frequency vibration of dental drills in laboratory conditions and during dental treatment (Chapters 2 and 3)

- to evaluate the occurrence of dentists´ hand symptoms perceived as vibration-related (Chapter 3)

- to compare traditional with non-contact vibration measurement methods for dental drills (Chapter 3)

- to make comparison measurements of weighted and high-frequency vibration between dental drills and common hand tools (Chapter 4)

- to determine sound power and ultrasound levels of dental equipment in laboratory conditions (Chapter 5)

- to measure noise and ultrasound exposure of dentists during dental treatment (Chapter 6)

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CHAPTER 2
VIBRATION OF DENTAL HANDPIECES

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1 ABSTRACT

The vibration of new (n=4) and used (n=16) dental handpieces was tested in three directions during idling. In addition, work was simulated by drilling on plastic plate with all new and five used handpieces. The weighted vibration according to standard ISO 5349:1986 and the total acceleration of high frequency vibration ("ultravibration") in the frequency range of 1.43-11.06 kHz were analyzed. Neither the water and air injection nor the grip force of fingers had any significant effect on the vibration level. The work simulation did increase the vibration of the handpieces, and the vibration became more broadband. The weighted accelerations were plainly below the hazardous acceleration determined in ISO 5349 and ACGIH-TLV. The vibration spectra of the handpieces contained powerful vibration at high frequencies, but the effects of this ultravibration and exposure during work are not well known.

2 INTRODUCTION

Dental personnel are exposed to high frequency vibrations, and neurological findings among them have been reported [1-4]. Symptoms of tingling, numbness, and/or pain in hands were reported by 15 of 58 dental hygienists [5]. The sensation threshold of fingers was significantly higher among 10 female dentists with 10 years of experience than among the control group [6]. Among 120 dental technicians, pathological motor conduction in the nervus medianus was found in 13 persons. Carpal tunnel syndrome was acknowledged in 4 individuals as an occupational disease [7].

The ISO standard 5349 [8] describes the "exposure-response relationship" between white finger latency and the mean acceleration level of the tool in the one-third-octave bands of 6.3-1250 Hz. This risk prediction model contains numerous uncertainties, such as variations in individual susceptibility and other relevant factors, variations in work methods, and uncertainty in determining total effective exposure [9]. The influence of ageing on vibration levels of dental handpieces is not well known.

The aims of the study were to evaluate the vibration of new and used dental handpieces according to ACGIH-TLV [10] and the standard ISO 5349, and to measure the high-frequency vibrations of these handpieces.

3 MATERIALS AND METHODS

Two new and six used micromotor handpieces, and two new and 10 used air-turbine handpieces were tested in the Acoustics Laboratory of Kuopio Regional Institute of Occupational Health, Finland. The numbering of the handpieces is shown in Table 1.

Table 1. Numbering of handpieces

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Type	M	M	T	T	M	M	M	M	M	M	T	T	T	T	T	T	T	T	T	T

M = micromotor handpiece; T = air-turbine handpiece.

Handpieces 1-4 were new and 5-20 were used. The rotation speed of the micromotor was 40 000 rpm, and the rotation speed of air turbine was 300 000-400 000 rpm. During all tests, the bit of the air-turbine handpiece was a Meisinger 835009 and the bit of the micromotor handpiece was a Meisinger 1012 US 3 RA (Hager & Meisinger GmbH, Germany). The handpieces were lubricated after every hour of running according to the manufacturer's instruction. After lubrication, a running-in period of one minute was used.

The vibrations were measured in three directions. The accelerometer was fastened with a stud to the adapter, which was glued with cyanoacrylate glue to the testing position of the handpiece; see Figure 1. The mass of the adapter was 1.3 g and the mass of the stud 0.2 g. The influence of the grip force of the fingers on the vibration of the handpiece was tested using pressing forces of 0 N, 4 N, 15 N and 25 N. The pressing force was measured with a Force Sensing Resistor FSR 151 AS (International Electronics & Engineering). In addition, the influence of air blasting and water spraying on the vibration of the handpiece was tested. The influence of the measurement position on the vibration results was tested also. These preliminary tests were carried out during idling. The measuring instruments were the accelerometer B&K 4393 (Brüel & Kjaer, Naerum, Denmark), the conditioning amplifier B&K 2635, the real-time frequency analyzer B&K 2133 and the calibration exiter B&K 4294.

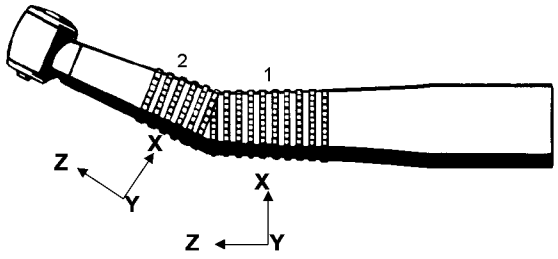

Figure 1. Location of measurement positions 1 and 2 and measurement directions.

The root mean square (rms) vibration was analyzed in the 1/24-octave bands in the frequency range of 5.7 Hz-11.06 kHz, and the sampling frequency was 1 Hz. The total number of samples was 60 during idling and 15 during drilling in all directions. The weighted vibration according to standard ISO 5349 and the total acceleration of high frequency vibration "ultravibration" in the frequency range of 1.43-11.06 kHz also were analyzed.

The vibration of each handpiece was tested during idling. Normal work was simulated by drilling on polyacetal plate with all new and five used handpieces. The size of the plate was 420 mm x 150 mm x 11 mm. During idling and drilling, the water spray was adjusted to the maximum value. The preliminary tests showed that vibration results measured in position 2 sufficiently represent the vibration of the handpiece, and thus the tests were carried out using this position.

4 RESULTS

The results are presented in acceleration (m/s^2) or acceleration level (dB), re 10^{-6} m/s^2. The effect of the grip force of the fingers on the vibration of the handpiece is shown in Figure 2, and the effect of air blasting and water spraying on the vibration of the handpiece in Figure 3. An example of the influence of the measurement position on the vibration result is shown in Figure 4.

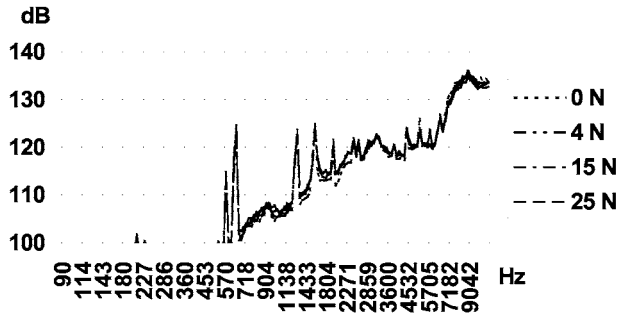

Figure 2. The effect of the grip force of the fingers on the vibration of the micromotor handpiece, measurement position 1, direction x.

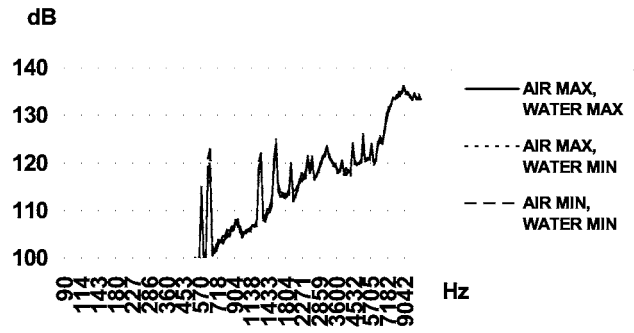

Figure 3. The effect of air blasting and water spraying on the vibration of the micromotor handpiece, measurement position 1, direction x.

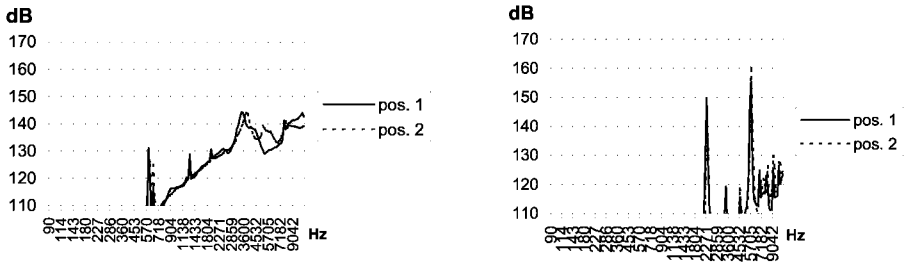

Figure 4. The influence of measurement position on vibration results of micromotor handpiece (number 1, left) and air-turbine handpiece (number 4, right) in y-direction.

The average vibration spectra of new and used micromotor handpieces during idling and drilling are presented in Figures 5 and 6. Consequently, the average vibration spectra of new and used air-turbine handpieces during idling and drilling are presented in Figures 7 and 8.

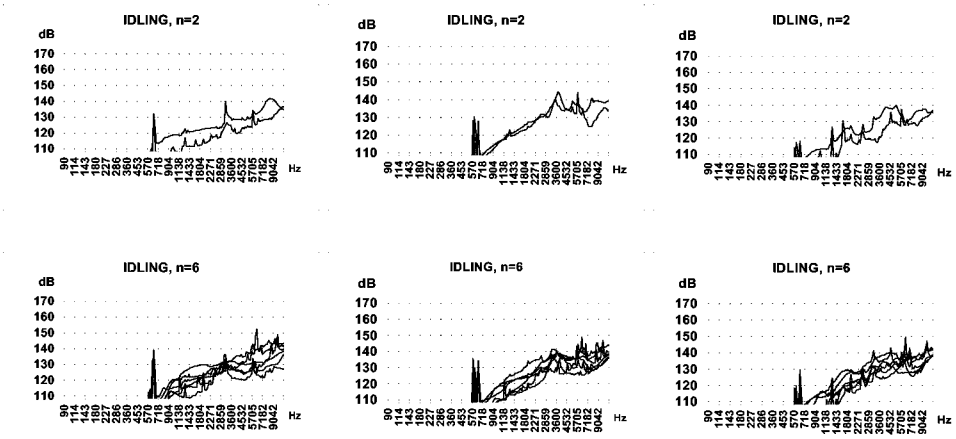

Figure 5. The average vibration spectra of new (upper) and used (lower) micromotor handpieces during idling in x-, y- and z-directions.

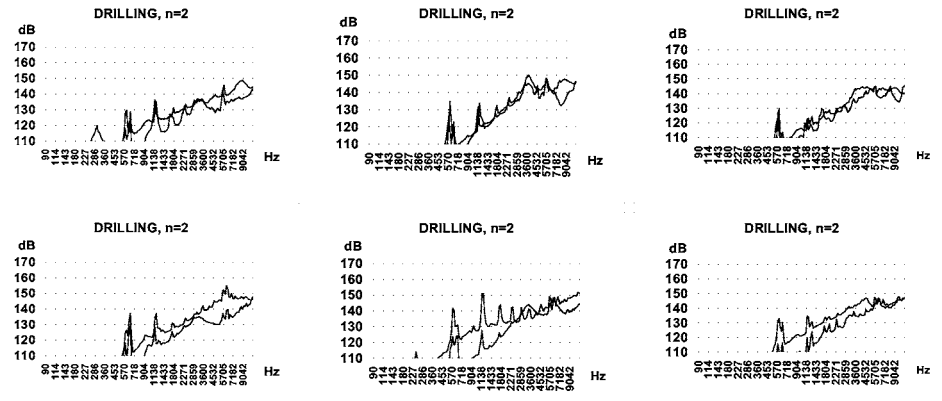

Figure 6. The average vibration spectra of new (upper) and used (lower) micromotor handpieces during drilling in x-, y- and z-directions.

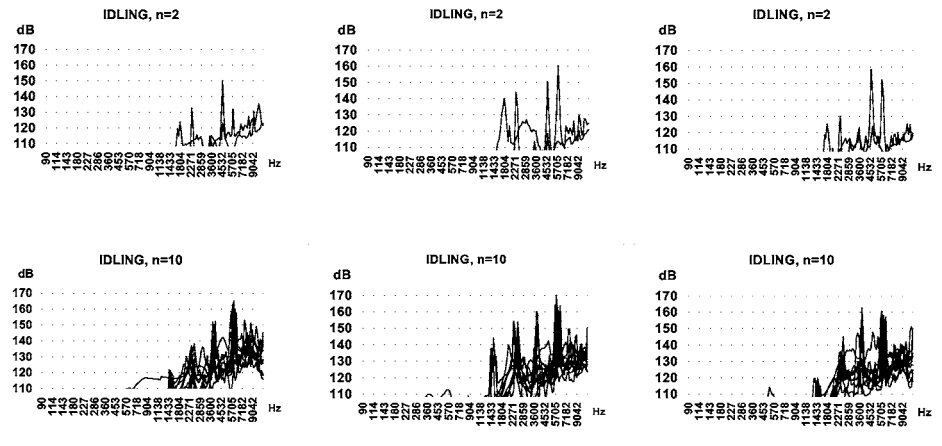

Figure 7. The average vibration spectra of new (upper) and used (lower) air-turbine handpieces during idling in x-, y- and z-directions.

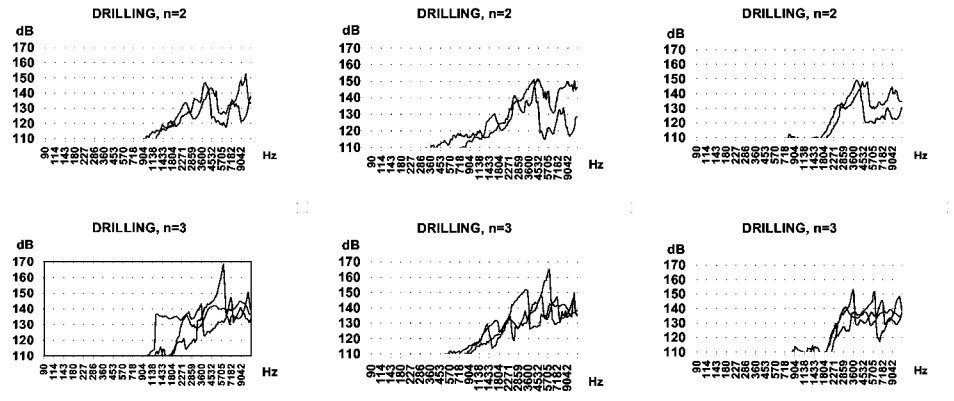

Figure 8. The average vibration spectra of new (upper) and used (lower) air-turbine handpieces during drilling in x-, y- and z-directions.

The weighted vibration in the frequency range of 6.3-1250 Hz according to standard ISO 5349, and ultravibration in the frequency range of 1.43-11.06 kHz are presented in Table 2.

Table 2. Weighted vibration and ultravibration in the frequency range of 1.43-11.06 kHz.

Drill no.	Type	Weighted acceleration m/s^2		Ultravibration m/s^2	
		idling	drilling	idling	drilling
1	M	0.1	0.2	66	160
2	M	0.1	0.1	44	130
3	T	<0.01	0.06	98	140
4	T	<0.01	0.09	110	250
5	M	0.1	*	29	*
6	M	0.2	*	40	*
7	M	0.1	0.1	65	140
8	M	0.2	*	82	*
9	M	0.2	*	46	*
10	M	0.2	0.8	98	180
11	T	<0.01	*	170	*
12	T	<0.01	*	320	*
13	T	<0.01	*	200	*
14	T	0.06	0.2	70	120
15	T	<0.01	0.03	110	640
16	T	<0.01	*	340	*
17	T	<0.01	*	190	*
18	T	<0.01	*	99	*
19	T	0.1	*	120	*
20	T	0.02	0.08	210	180

M = micromotor handpiece; T = air-turbine handpiece.
* Not measured.

5 DISCUSSION

Neither the water and air injection nor the grip force of fingers had any significant effect on the vibration level of the handpieces. During idling, the weighted vibration of used micromotor handpieces was on average twice as high as that of the new ones. The weighted vibration of new and used air-turbine handpieces was approximately in the same class of magnitude. Powerful components in the spectra of micromotor handpieces in the frequency range of 500-700 Hz coincide with the maximum rotation speed of the micromotor. In the vibration spectra of air-turbine handpieces, there are high levels in the frequency of approximately 5700 Hz, which coincides with the typical rotation speed of air turbines.

Drilling did increase the vibration of handpieces, and the vibration became more broadband. The weighted accelerations were plainly below the hazardous acceleration determined in the ACGIH-TLV and ISO 5349. During drilling, the ultravibration was one- to sixfold compared with idling.

The vibration spectra of the handpieces contain powerful vibration at high frequencies, but the effects of this ultravibration are not well known. To explain the harmfulness of the vibration of the handpieces, the influence of the high-frequency vibration on fingers, and the vibration exposure during real work should be studied.

6 ACKNOWLEDGEMENTS

Financial support for this work was provided by the Finnish Work Environment Fund.

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CHAPTER 3
HAND-ARM VIBRATION EXPOSURE OF DENTIST

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Submitted

1 ABSTRACT

The use of dental handpieces exposes the dental personnel to high-frequency vibration. Dentists have been shown to have a high frequency of finger-related and other upper limb symptoms and a high prevalence of osteoarthrosis in the distal interphalangeal joints. The vibration of 22 dental handpieces was measured during normal work with accelerometer. The weighted vibration according to standard ISO 5349-1 and the total acceleration of high frequency vibration ("ultravibration") in the frequency range of 1600-10000 Hz were analyzed. In order to compare non-contact vibration measurement method for dental handpieces, vibration of 12 handpieces was measured during idling with Portable Digital Vibrometer and simultaneously with the accelerometer. The weighted vibration of air-turbine handpieces during working were 0.3-1.6 %, compared with the action value of the the Vibration Directive of EU, and weighted vibration of micromotor handpieces consequently 10-37 %. The vibration spectra of the air-turbine handpieces showed that most part of the vibration energy of these handpieces existed in the frequency range above 1250 Hz. Both vibration measurement methods gave highly similar values. A group of 295 female dentists aged 45-63 years responded to a questionnaire on working conditions, lifestyle, and health. High level of cumulative exposure to vibration during work history as well as a high body mass index may increase the risk of frequent finger symptoms of dentists.

2 INTRODUCTION

The use of dental handpieces exposes the dental personnel to high-frequency vibration. It has recently been shown that the vibration of dental handpieces is powerful in the frequency range above 1250 Hz [1]. The daily exposure action value for hand-arm vibration shall be according to EC-vibration directive [2] 2.5 m/s^2. Vibration exposure measurements of dentists during normal work have not been reported.

There is little information on the physiological and health effects of the use of dental handpieces. Dentists have been shown to have a high frequency of finger-related and other upper limb symptoms [3, 4] and a high prevalence of osteoarthrosis in the distal interphalangeal joints [5]. The prevalence of symptoms consistent with carpal tunnel syndrome in the dominant hand among dentists was higher than in the general population [6].

The vibration exposure in dentistry is a possible risk factor for the development of neurological and circulatory disturbances in the hands and related hand symptoms [7, 8]. In Sweden, the risk of women reporting a work-related vibration injury was by far the highest among dentists and other dental personnel [9]. A pilot study to determine the relationship between vibration and musculoskeletal symptoms in dental hygiene students indicated that

musculoskeletal symptoms may increase with the use of ultrasonic and/or manual instruments [10].

The aims of this study were to measure vibration of dental handpieces during normal clinical work, compare non-contact method with traditional method in vibration measurement of dental handpieces, and to evaluate the occurrence and risk factors of hand symptoms perceived as vibration-related among dentists.

3 MATERIALS AND METHODS

3.1 Vibration measurements

The vibration of 22 dental handpieces was recorded during normal work. The measuring equipment were the accelerometer B&K 4393 (Brüel & Kjaer, Denmark), the conditioning amplifier B&K 2635 and the DAT-recorder Sony PC208A (Sony, Japan). The accelerometer was fastened with a stud to the adapter, which was glued with cyanoacrylate glue to the testing position of the handpiece, see Figure 1. The mass of the adapter was 1.3 g and the mass of the stud 0.2 g.

The recorded signals were analyzed in the laboratory with the real-time frequency analyzer B&K 2133 in 1/3-octaves in the frequency range of 6.3-10 000 Hz. The weighted vibration according to standard ISO 5349-1 [11] and the total acceleration of high-frequency vibration "ultravibration" in the frequency range of 1600-10 000 Hz were also analyzed. The measuring time (total drilling time) of one handpiece included the whole drilling time required for the dentist working with one patient.

In order to compare non-contact vibration measurement method for dental handpieces, vibration of 12 handpieces was recorded during idling with Portable Digital Vibrometer PDV-100 (POLYTEC GmbH, Germany), and the accelerometer B&K 4393. Vibrometer PDV-100 utilizes laser doppler velocimetry (LDV) technology. For laser measurements, three measurement positions were at different grip positions of the handpiece and one at the end of the accelerometer, see Figure 2. The recorded signals were analyzed in the laboratory with the real-time frequency analyzer B&K 2133. The averaging time was 4 s. Velocity spectra measured with the laser method were transformed to acceleration spectra using formula

$$a = 2\pi f v \qquad (1)$$

where

a	is acceleration
f	is frequency
v	is velocity, measured with laser method

From the accleration spectra, the weighted vibration a_w according to standard ISO 5349-1 and the total acceleration of high-frequency vibration "ultravibration" in the frequency range of 1600-10 000 Hz were analyzed.

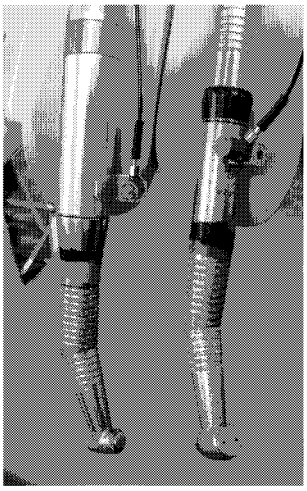

Figure 1. Fastening of the accelerometer. Micromotor handpiece on the left and air-turbine handpiece on the right.

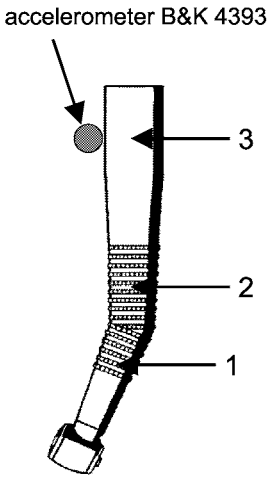

Figure 2. Vibration measurement positions using laser method.

3.2 Questionnaire study

A group of 295 female dentists aged 45-63 years randomly selected from the register of the Finnish Dental Association using the place of residence (Helsinki or its neighbouring cities) as an inclusion criterion responded to a questionnaire on working conditions, lifestyle, and health. It was inquired: "Do you feel that vibration of handpieces causes or aggravates your finger symptoms? (1= not at all, ..., 5 = very often or continuously)". The questionnaire also included items on anthropometric measures, handedness, daily activities that require repetitive hand or wrist use, seniority, and occupational exposure at present and during work history, including information on average weekly working time and the proportion of time spent in different work tasks (six tasks defined) during four 10-year age periods since age 25. Participation in the study was voluntary and based on informed consent. The Hospital District of Helsinki and Uusimaa Ethics Committee for Research in Occupational Health and Safety approved the study proposal.

Using the questionnaire data, first, the amount of hours per week spent in dental filling and root treatment during the past 12 months was calculated. Second, the total time (hours) during work history spent in dental filling and root treatment was calculated using the following formula:

$$[(Pd1*Wh1)*Y1 + (Pd2*Wh2)*Y2 + (Pd3*Wh3)*Y3 + (Pd4*Wh4)*Y4]* 46 \qquad (2)$$

where

Pd1 – Pd4	is the proportion of dental filling and root treatment in the dentist's daily work during four 10-year age periods
Wh1 – Wh4	is the average weekly working time (hours) during four 10-year age periods
Y1 – Y4	is the number of work years during four 10-year age periods
46	is the average number of working weeks during a year (an assumption).

Finger grip strength of both hands was evaluated with the Martin Vigorimeter (Gebrüder Martin GmbH & Co. KG, Germany) and measured in kilopascals (kPa). The test was administered by a researcher trained for the purpose during the clinical examination session. Grip strength was measured between the thumb pulp and the pulps of the second and third digits. Subjects were asked to make two maximal contractions. Verbal encouragement was given. If the readings were not within <10% of each other, further contractions were undertaken. Once repeatable, only the maximum contraction was taken to represent the maximal grip strength.

Body mass index (BMI) [weight (kg) per height squared (m^2)] was calculated based on self-reported height and weight at the age of 25 years and weight measured during the clinical examination session. BMI was put to tertiles for analyses.

The mean age of the dentists was 54 ± 6 years and they had been on average 26 ± 8 years in the current occupation.

4 RESULTS

4.1 Vibration measurements

Measured handpieces and acceleration of vibration during normal work are presented in Table 1. The handpieces were produced by KaVo (Dentale Medizinische Instrumente, Germany). The measuring time varied from 0.2 to 4.5 minutes.

Table 1. Handpieces and measuring results. Letter T means air-turbine handpiece, and M micromotor handpiece.

Identification of the handpiece	Measuring time	ISO 5349 weighted vibration	Ultravibration
	min	m/s^2	m/s^2
T1	0.4	0.01	100
T2	1.4	0.01	80
T3	0.2	0.01	200
T4	3.7	0.01	100
T5	0.8	0.02	80
T6	0.2	0.04	40
T7	1.1	0.03	80
T8	0.7	0.01	40
T9	0.5	0.01	50
T10	0.8	0.01	100
M1	1.5	0.4	9
M2	1.3	0.3	10
M3	2.5	0.4	6
M4	2.1	0.3	10
M5	1.8	0.3	8
M6	3.4	0.9	10
M7	1.1	0.3	10
M8	0.9	0.3	9
M9	1.7	0.2	20
M10	1.5	0.7	3
M11	2.3	0.3	30
M12	4.5	0.3	30

The vibration spectra during normal work are in Figures 3 and 4. The acceleration of vibration is presented in dB ref. 1 $\mu m/s^2$.

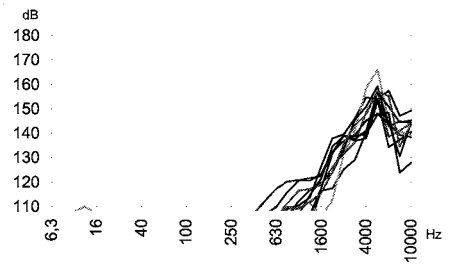

Figure 3. Vibration spectra of the air-turbine handpieces (n=12).

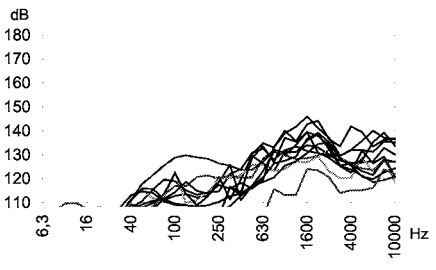

Figure 4. Vibration spectra of the micromotor handpieces (n=10).

Comparison of the vibration measurement results during idling are presented in Figure 5. Weighted vibration a_w and ultravibration in the frequency range of 1.6-10 kHz are analyzed. In the legends, BK means the result measured with the accelerometer, and PDV means vibration of the end of the accelerometer, measured with laser method.

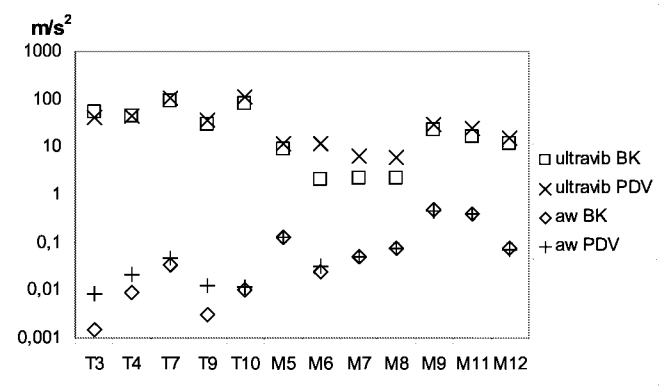

Figure 5. Comparison of results measured with accelerometer and laser method during idling.

Vibration measurement results of the handpiece in measurement positions 1-3 (see Figure 2), measured with laser method during idling are presented in Figure 6.

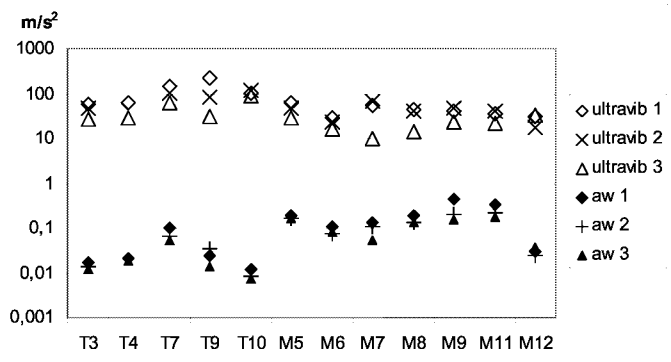

Figure 6. Laser measurement results in the measurement positions 1-3 during idling.

Comparison between results during normal work and idling, measured with accelerometer is presented in Figure 7.

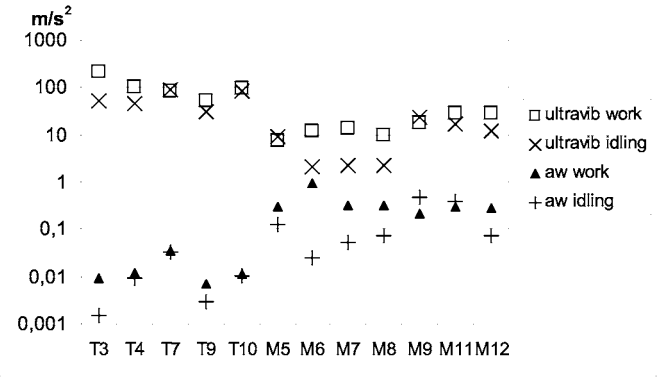

Figure 7. Comparison between results during normal work and idling, measured with accelerometer.

4.2 Questionnaire results

About one half of the dentists (51.8%, n=153) did not report any finger symptoms related to the use of vibrating tools, 12.2 % (n=36) experienced symptoms sometimes and only 1.7% (n= 5) continuously. The frequency of the finger symptoms positively correlated with age, current BMI and the total time during work history spent in dental filling and root treatment (Table 2). Finger grip strength was inversely associated with symptoms.

Table 2. Pearson correlation coefficients between finger symptoms due to vibration and other variables.

Variables	r	p-value
Age	0.11	0.06
Seniority (years in occupation)	0.09	0.12
BMI at age of 25 years (kg/m^2)	0.05	0.36
Current BMI (kg/m^2)	0.13	0.03
Dominant hand's grip strength (kPa)	-0.23	< 0.005
Non-dominant hand's grip strength (kPa)	-0.22	< 0.005
Average working hours per week during the past 12 months	-0.07	0.21
Average hours per week spent for dental filling and root treatment during the past 12 months	0.04	0.46
Total time during working period spent for dental filling and root treatment (hours)	0.17	0.004

For further analyses the frequency of finger symptoms was classified in three categories: no symptoms (1), infrequent symptoms (2, 3) and frequent symptoms (4, 5). The distribution of hours per week during the past 12 months, and during work history, spent in dental filling and root treatment by finger symptom category is given in Table 3.

Table 3. Distribution of hours per week and during work history spent in dental filling and root treatment by finger symptom category. Mean ± SD.

	Average hours per week in dental filling and root treatment during the past 12 months	Total time during work history in dental filling and root treatment (hours)
No finger symptoms	10.5 ± 9.1	18500 ± 9900
Infrequent symptoms	10.0 ± 8.4	20200 ± 10200
Frequent symptoms	12.3 ± 8.5	23500 ± 9400
p-value*	0.32	0.017

*p-value for one way ANOVA

The total work history in dental filling and root treatment was associated with finger symptom frequency. The dentists with frequent finger symptoms had spent on average more working time during the week for dental filling and root treatment than others, although the difference was not statistically significant.

The results of a logistic regression analysis allowing for age, seniority and hand grip strength showed that a high level of cumulative exposure to vibration during work history and a high BMI increased the risk of finger symptoms (Table 4). Cumulative exposure to vibration was associated with a two-fold risk of occurrence of finger symptoms (OR 1.92, 95% CI: 1.03-3.6).

Table 4. Predictors of occurrence (present/absent) of finger symptoms perceived as related to use of vibrating tools. Logistic regression analysis. Adjusted odds ratios (OR) and their 95% confidence intervals (CI). Covariates in the model are age, seniority, hand grip strength and smoking.

Variables		OR	95% CI
Average weekly work time (hours) in dental filling and root treatment during the past 12 months			
	Low	1.0	
	Medium	1.50	0.83-2.71
	High	1.06	0.56-2.00
Total time during work history in dental filling and root treatment (hours)			
	Low	1.0	
	Medium	1.46	0.80-2.68
	High	1.92	1.03-3.60
Current BMI (kg/m^2)			
	Low	1.0	
	Medium	1.57	0.85-2.91
	High	3.00	1.44-6.25

5 DISCUSSION

The measured weighted vibrations of air-turbine handpieces during working were 0.3-1.6 %, compared with the action value of the Vibration Directive of European Union, and weighted vibration of micromotor handpieces consequently 10-37 %. The vibration spectra of the air-turbine handpieces show that most part of the vibration energy of these handpieces exists in the frequency range above 1250 Hz.

It can be seen in Figure 5 that the traditional method and the laser method gave highly similar values. The dental treatment work did not permit fastening of the accelerometer to the grip position of the handpiece. According to measurement results obtained in different grip positions (see Figures 2 and 6), the weighted vibration level was approximately the same in all three positions. Ultravibration results in the measurement position 3 were in all excepting one case slightly lower than the results in positions 1 and 2. However, the position of the accelerometer was sufficient to describe the vibration of the handpiece during idling. Figure 7 shows that the vibration measurement results during idling do not in all cases describe the vibration during working.

The mesurements were carried out in dental clinic during a normal workday, and therefore there was not much time to perform extra non-contact vibration measurements. This study shows however, that the laser method can be applied in vibration measurements of dental handpieces during idling. Under laboratory conditions, the laser method may be applicable also during simulated work. The disadvantages of traditional vibration measurement methods are e.g. possible errors concerning the mass and fastening of the accelerometer. These are avoided using non-contact methods. In order to develop standardized vibration test methods for dental handpieces, more research and method development are needed.

Our data imply that vibration exposure in dentistry could increase the risk of frequent finger symptoms that are perceived as vibration-related. Current exposure (during the past 12 months) to vibration (dental filling and root treatment work) was not thus associated, while a high level of cumulative exposure during work history was. This would mean, either, that there is a latency time for such symptoms to appear, or, that dentists with finger symptoms tend to reduce their work time exposing the fingers to vibration. High BMI was also associated with finger symptoms. Previous studies by Kouyoumdjian et al. [12] showed that high BMI is associated with the severity of carpal tunnel syndrome. The mechanism of such an association remains to be elucidated.

6 ACKNOWLEDGEMENTS

The authors wish to thank Tuomo Meriläinen, Chief Dental Officer of Kuopio Social and Health Center for arranging the possibility to make vibration measurements in the dental clinic. The Finnish Work Environment Fund is acknowledged for financial support.

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CHAPTER 4
HIGH-FREQUENCY VIBRATION OF DENTAL LABORATORY HAND TOOLS COMPARED TO COMMON HAND TOOLS

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Submitted

1 ABSTRACT

Dental technicians use regularly different hand-held motor-operated tools and therefore hand-transmitted vibration exposure is common in dental laboratories. Hand and finger dysfunctions and high relative risk of getting a vibration injury have have been reported among dental technicians. The vibration spectra of handpieces used in dental laboratories contain high-frequency components, but the effects of this "ultravibration" are not well known. The aims of the study were to evaluate the vibration of dental laboratory hand tools and some common hand tools, e.g. drills, grinders and hammers according to EC-directive and the standard ISO 5349-1, and to measure high-frequency vibration of these tools. The vibration of dental laboratory hand tools was tested during seven different work stages. The vibration of 15 different electric motor-operated hand tools was tested in laboratory conditions according to appropriate test standard. The weighted vibration according to standard ISO 5349-1 and the total acceleration of high frequency vibration ("ultravibration") in the frequency range of 1.6-10 kHz were analyzed. The measuring instruments were the accelerometer B&K 4393, the conditioning amplifier B&K 2635, the real-time frequency analyzer B&K 2133 and the calibration exiter B&K 4294. The weighted accelerations of dental laboratory hand tools were 0.5-3 m/s^2, and of the common hand tools 1-18 m/s^2. High-frequency vibration levels (ultravibration) were 30-210 m/s^2 and 3-870 m/s^2, respectively. The vibration spectra of the hand tools contained powerful vibration at high frequencies. The vibration of the tool did not depend on the input power.

2 INTRODUCTION

Dental technicians use regularly different hand-held motor-operated tools and therefore hand-transmitted vibration exposure is common in dental laboratories. Hand and finger dysfunctions have been reported among dental technicians [1-3]. The relative risk of getting a vibration injury was 680 times greater for dental technicians related to the group administrative personnel [4]. The vibration spectra of handpieces used in dental laboratories contain high-frequency components [5], but the effects of this "ultravibration" are not well known [6].

The ISO standard 5349-1 [7] describes the exposure-response relationship between white finger latency and the mean acceleration level of the tool in the 1/3-octave bands of 6.3-1250 Hz. This risk prediction model contains numerous uncertainties, for example, variations in individual susceptibility and other relevant factors, variations in work methods, and uncertainty in determining total effective exposure [6, 8].

According to the EC-vibration directive [9] the daily exposure limit value for hand-arm vibration standardised to an eight-hour reference period shall be 5 m/s^2; and the daily exposure action value shall be 2.5 m/s^2.

The aims of the study were to evaluate the vibration of dental laboratory hand tools and some common hand tools, e.g. drills, grinders and hammers according to EC-directive and the standard ISO 5349-1, and to measure high-frequency vibration of these tools.

3 MATERIALS AND METHODS

Seven types of processing were tested during normal dental laboratory work. Three micromotor and one air-turbine drills were used, age of 6-12 years. The rotation speed of the drills were 25 000 rpm, 50 000 rpm and 250 000 rpm, respectively.

The accelerometer was fastened with a stud to the adapter, which was glued with cyanoacrylate glue to the holding position of the hand tool. The mass of the adapter was 1.3 g and the mass of the stud 0.2 g. The measuring instruments were the accelerometer B&K 4393 (Brüel & Kjaer, Naerum, Denmark), the conditioning amplifier B&K 2635, the real-time frequency analyzer B&K 2133 and the calibration exiter B&K 4294. Measuring direction was x as described in ISO 5349-1. The root mean square (rms) vibration was analyzed in in one-third octave bands in the frequency range of 6.3 Hz-10 kHz, and the averaging time was 1 s. The total number of samples was 60. The weighted vibration according to standard ISO 5349-1 and the total acceleration of high frequency vibration "ultravibration" in the frequency range of 1.6-10 kHz were also analyzed.

Vibration of 15 different electric motor-operated hand tools was tested in laboratory conditions according to appropriate test standard [10, 11] in the frequency range of 6.3-1250 Hz. In addition, high-frequency vibration in the frequency range of 1.6 -10 kHz of these tools was tested.

4 RESULTS

The results are presented in acceleration (m/s^2) or acceleration level (dB), re 10^{-6} m/s^2. The weighted vibration in the frequency range of 6.3-1250 Hz according to standard ISO 5349-1, and ultravibration in the frequency range of 1.6-10 kHz are presented in Tables 1 and 2.

Table 1. The weighted vibration and ultravibration measurement results of dental laboratory hand tools. Drill type M means micromotor drill, A means air-turbine drill.

Measure-ment no.	Drill	Tool	Processing object	ISO 5349 weighted vibration m/s^2	Ultravibration m/s^2
1	M1	Fabric reinforced disc ∅40 mm	Prosthesis, working of acrylic	1.5	50
2	M1	Hard metal fresar HF 251	Prosthesis, working of acrylic	3	210
3	M1	Abrasive paper band	Prosthesis, working of acrylic	2	30
4	M1	Rose drill 016	Prosthesis, working of acrylic	1	120
5	M2	Fabric reinforced disc ∅40 mm	Prosthesis, working of cobalt chromium	0.5	80
6	M2	Hard metal fresar H79 (EF)	Prosthesis, working of cobalt chromium	1	120
7	A	Diamond head	Grinding of porcelain tooth	0.5	60

Table 2. The weighted vibration and ultravibration measurement results of common hand tools.

Measure-ment no	Type of tool	Rated input W	ISO 5349 weighted vibration m/s^2	Ultravibration m/s^2
8	Impact drill	750	10	870
9	Impact drill	590	15	800
10	Impact drill	550	18	470
11	Orbital sander	200	2	58
12	Disc grinder	2400	2	40
13	Disc grinder	650	5	170
14	Angle grinder	600	6	560
15	Pipe cutter	1400	1	30
16	Hammer	1240	16	25
17	Hammer	950	9	3
18	Hammer	750	5	90
19	Hammer drill	1140	14	280
20	Rotary hammer	850	8	30
21	Nibbler	400	2	30
22	Jig saw	740	7	80

The average one-third octave spectra of the vibration of the tools are presented in Figures 1-5.

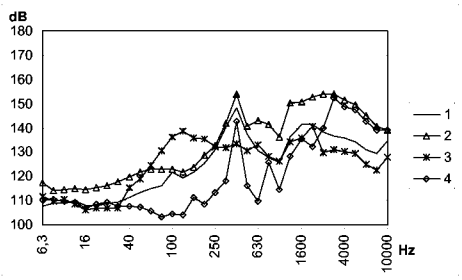

Figure 1. The average vibration spectra. of dental laboratory hand tools, measurements 1-4.

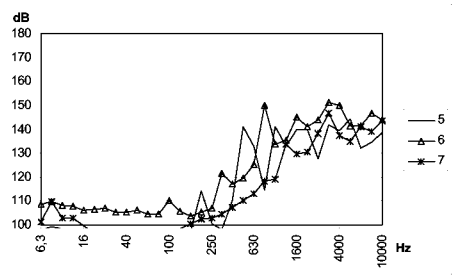

Figure 2. The average vibration spectra of dental laboratory hand tools, measurements 5-7.

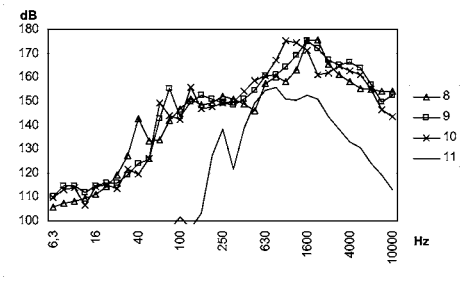

Figure 3. The average vibration spectra of common hand tools, measurements 8-11.

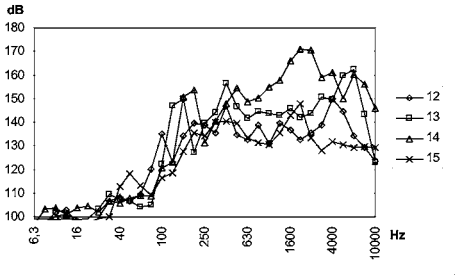

Figure 4. The average vibration spectra of common hand tools, measurements 12-15.

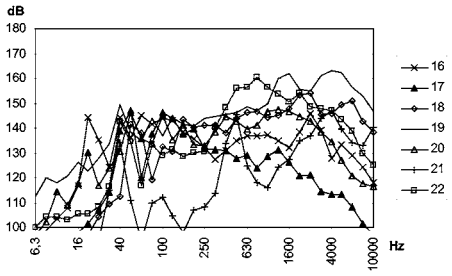

Figure 5. The average vibration spectra of common hand tools, measurements 16-22.

5 DISCUSSION

Weighted vibration of dental laboratory hand tools was 0.5-3 m/s^2. High-frequency vibration levels (ultravibration) were 30-210 m/s^2 and thus 16-170 times greater than the weighted vibration. The highest vibration values were measured at the fresar, measurement nr. 2. Powerful component in the vibration spectra in measurements 1, 2 and 4 in the one-third octave band of 400 Hz coincides with the rotation speed of the drill.

The measurements were made in one direction only, so the results presented here are underestimates of vibration total value a_{hv}. Assuming that the magnitude of weighted vibration is equal in all three directions, the estimated vibration total value according to the standard ISO 5349-1 is the measured weighted value of one component multiplied by factor 1.7. Therefore exposure action value of EC-directive 2.5 m/s^2 is exceeded in measurements 2 and 3.

The measured vibration accelerations of the dental laboratory hand tools are at same order of magnitude as measured earlier [5]. Vibration exposure of dental technician depends on the type and condition of the drill and tool used. The measurements were made in one direction because of technical restrictions. The type of working and direction of feed force of the tool changed continuously, and therefore one direction measurement gave acceptable mean value

of vibration. On grounds of the measurement results presented in this study, and noticed risk getting a vibration injury [4], technical vibration control measures are necessary for dental laboratory hand tools.

Weighted vibration of acceleration of the common hand tools was 1-18 m/s^2 and ultravibration respectively 3-870 m/s^2 (0.3-100 times greater than the weighted vibration). The measurement results show however, that there are wide variations between different tools. The tool nr. 17 had more efficient high-frequency damping than others, see Figure 5. The vibration of the tool did not depend on the input power, and so it seems that technical measures and the design of the tool are important factors concerning the vibration control.

There are only few reports concerning high-frequency vibration of hand tools. In this study, high frequencies of tools were measured systematically. The number of tools tested was small, and therefore the results presented here are suggestive. However, the results show that ultravibration is very common and is emitted by many types of tools. The effects of ultravibration on hands and fingers are under consideration and not well known. Therefore much more research is needed in order to explain the exposures and effects of high-frequency vibrations.

6 ACKNOWLEDGEMENTS

The authors wish to thank Mr Heikki Hiippala from Vaasan Hammas, Finland, for arranging possibility to study vibration in their dental laboratory.

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CHAPTER 5
HIGH-FREQUENCY NOISE IN DENTISTRY

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Published in AIHA Journal, 2002;63:231-233. Reprinted here with kind permission from Taylor & Francis.

1 ABSTRACT

Earlier studies have revealed that dentists have higher hearing thresholds than expected. The aim of this study was to evaluate the noise levels of current dentistry equipment under very controlled conditions. This noise study was carried out in the Acoustics Laboratory of Kuopio Regional Institute of Occupational Health, the background noise of which is about 0 dB(A). Working noise was simulated by drilling a polyacetal plate. During drilling and idling, the noise of the handpieces was measured over a reflecting plane on the hemisphere surface, the radius of which was 0.3 m, and 10 noise samples were picked for each handpiece. The average sound pressure level and the sound power level of the devices were calculated applying the standard ISO 3744. The measurement and analysis were done in the one-third octave bands of 25-80 000 Hz. The measuring instruments used were the B&K 4135 microphones, the B&K 2633 preamplifiers, the B&K 2811 multiplexer and the B&K 2133 real-time analyzer with the ZT 0318 high-frequency expansion unit. During the simulated work, the average A-weighted sound pressure level of the new and old handpieces was 76-82 dB(A), that of the power suction tube 77 dB(A), the saliva suction tube 75 dB(A) and the ultrasonic scaler 83 dB(A). The average ultrasound level of the ultrasonic scaler was 107 dB at the one-third octave band of 25 000 Hz.

2 INTRODUCTION

Micromotor handpieces, air-turbine handpieces, ultrasonic scalers and sucking tubes are common sources of noise in dentistry.

A pure tone, air-conduction, audiometric evaluation of 137 dentists and 80 physicians was made. Dentists were found to have a higher hearing threshold, especially at 4000 Hz, than the physician control group. In addition, right-handed dentists had greater hearing loss in the left ear than in the right ear, ostensibly relating to the proximity of noise sources. The physicians had no statistically significant difference in hearing between the left and right ears [1]. In 1973 the pure tone audiograms of 68 dentists were taken. These dentists had practiced dental work for a period of not less than 10 years. A follow-up study was carried out in 1988. At the frequencies of 4, 6, and 8 kHz, dentists tended to have higher hearing thresholds than expected [2]. However, some studies have shown no significant differences concerning dentists' hearing [3, 4]. The risk of hearing damage is slight when using modern equipment; however, control is nevertheless necessary for error-free communication during dental procedures [5].

Lately, the use of high-speed micromotor handpieces has increased. Their rotation speed does not change when the drilling resistance changes.

The aim of this study was to evaluate the noise levels of current dentistry equipment under very controlled conditions.

3 METHODS

The noise study was carried out in the Acoustics Laboratory of Kuopio Regional Institute of Occupational Health. Two new and 6 used high-speed micromotor handpieces and 2 new and 10 used high-speed air-turbine handpieces were studied. W&H handpieces (W&H Dentalwerk Bürmoos GmbH, Austria) and KaVo handpieces (KaVo Dentale Medizinische Instrumente GmbH, Germany) were used for the study. New suction tubes and a new ultrasonic scaler also were studied.

To measure the idling noise of the handpieces, they were placed over a reflecting surface in the vertical position so that the bit was at a distance of 1 mm from the surface.

Working noise was simulated by drilling a polyacetal plate, the dimensions of which were 15 mm, 150 mm and 420 mm. When drilling with micromotor handpieces, the Meisinger 1012 US 3 RA bit was used and with air-turbine handpieces, the Meisinger 835009 bit was used.

During drilling and idling, the noise of the handpieces was measured over a reflecting plane on the hemisphere surface, the radius of which was 0.3 m, and 10 noise samples were picked for each handpiece. The working noise of the new ultrasonic scaler and the new suction tubes also was measured in a similar way. The average sound pressure level and the sound power level of the devices were calculated applying the standard ISO 3744 [6]. In addition, the sound power level of the air piping noise was measured applying the standard ISO 9614 [7].

In principle, the sound power level of the device does not depend on the measuring distance from the source, and, therefore, it provides a reasonable comparison value for the noise of the equipment. Figure 1 shows the sound power level measurement of a handpiece.

The measuring instruments used were the B&K 4135 microphones (Bruel & Kjaer, Naerum, Denmark), the B&K 2633 preamplifiers, the B&K 2811 multiplexer and the B&K 2133 real-time analyzer with the ZT 0318 high frequency expansion unit. The B&K 4220 pistonphone was used to calibrate the equipment.

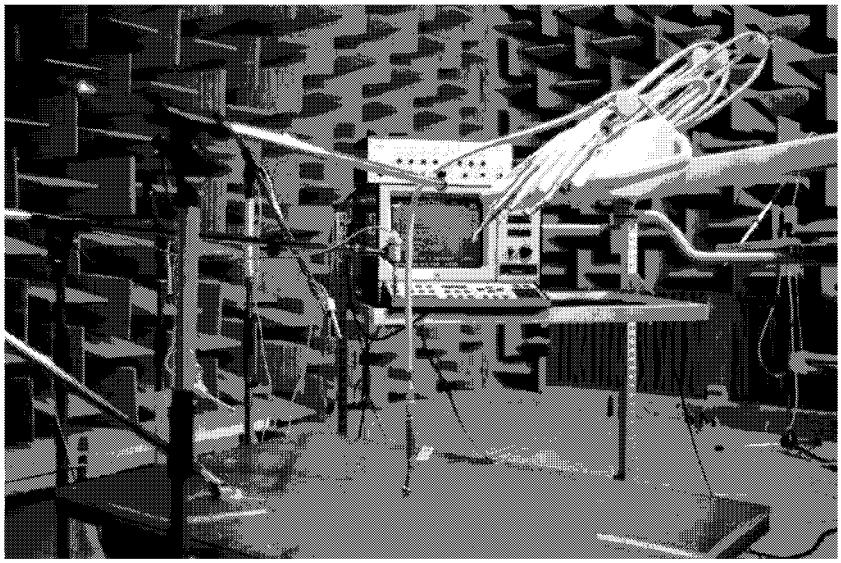

Figure 1. The sound power level measurement of a handpiece.

4 RESULTS

The average sound pressure level of the idling noise of the new high-speed micromotor handpieces and the new high-speed air-turbine handpieces in the one-third octave bands of 25-80 000 Hz were measured.

Durng idling, when the water spray was turned off and the air pressure adjusted to its maximum value, the average A-weighted sound pressure level of the new and old handpieces (n=20) was 65-76 dB(A). The studied handpieces are presented in detail in Table 1.

Table 1. Summary of the A-weighted sound power levels of the working noise and strongest one-third octave band levels in A-weighted sound power spectra.

Device	New handpieces		Old handpieces		Power suction tube	Saliva suction tube	Ultra-sonic scaler	Piping noise
Number of devices	n=2 (M)	n=2 (T)	n=6 (M)	n=10 (T)	n=1	n=1	n=1	n=1
L_{WA} (dB)	75-77	74-75	74-75	75-80	75	73	81	59
Most powerful one-third octave bands of L_{WA} spectra (kHz)	5-16	2-16	4-16	2-16	1.6-2	3.15 and 6.3-10	10-12.5	

M = micromotor handpieces; T = air-turbine handpieces.

During drilling, when both the water spray and the air pressure were adjusted to their maximum value, the average A-weighted sound pressure level of the new and old handpieces was 76-82 dB(A). During the simulated work the average A-weighted sound pressure level of the power suction tube was 77 dB(A), the saliva suction tube 75 dB(A), and the ultrasonic

scaler 83 dB(A). During drilling the average ultrasound levels of the handpieces were below 90 dB in all one-third octave bands of 20 000 to 80 000 Hz. The average ultrasound level of the ultrasonic scaler was 107 dB at the one-third octave band of 25 000 Hz.

Table 1 provides a summary of the working noise. The noise caused by the compressed air of the piping is also shown. To facilitate the comparison of the noise of the equipment, the results have been given as the A-weighted sound power levels L_{WA} because, in principle, this is not dependent on the measuring distance. The most powerful one-third octave bands of the A-weighted sound power level spectra are also presented in Table 1. The noise of the piping has been measured at a different distance than the noise of the other equipment simply because it was not possible to install the pressure piping on the reflecting plane. The measurement surface for the other equipment was so chosen that the measured average A-weighted sound pressure level was about 2.5 dB greater than the corresponding A-weighted sound power levels.

5 DISCUSSION

In some cases the A-weighted sound pressure levels of drilling of the old air-turbine handpieces were over 80 dB(A), as was the case for the ultrasonic scaler. The average ultrasound level of the handpieces was below 90 dB in all the one-third octave bands of 20 000 to 80 000 Hz. The average ultrasound level of the ultrasonic scaler at the one-third octave band of 25 000 Hz was 107 dB. This is close to the American Conference of Governmental Industrial Hygienist's limit value of 110 dB [8]. To evaluate the risk of hearing damage, the long-term noise exposure of dental care personnel during normal working days should be studied.

There were no great differences in noise between the old and new handpieces; however, the new micromotor handpieces were slightly noisier than old ones, and the new turbine handpieces were slightly quieter than the old ones. Wider study is needed to be able to draw any general conclusions on the noisiness of new and old handpieces.

6 ACKNOWLEDGEMENTS

The authors wish to thank Esko Hokkanen from Plandent Ltd. for arranging the use of the study dental care equipment. Financial support was provided by the Finnish Work Environment Fund.

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CHAPTER 6
NOISE LEVEL AND ULTRASOUND SPECTRA DURING BURRING

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Published in Clinical Oral Investigations, 2002;6:133-136. Reprinted here with kind permission from Springer-Verlag.

1 ABSTRACT

The aim of this study was to evaluate the noise spectra of current dentistry equipment during normal work at the dental clinic and in the laboratory. In the study, noise was measured during the dental treatment of seven patients at a dental clinic and also in the acoustics laboratory, where working noise was simulated by drilling a polyacetal plate. All samples were analyzed in audible and ultrasonic areas in the one-third octave bands of 25-80 000 Hz. The measuring instruments used were the B&K 4135 microphones, the B&K 2633 preamplifiers, the B&K 2811 multiplexer and the B&K 2133 real-time analyzer with the ZT 0318 high-frequency expansion unit. In the in situ measurements, the A-weighted sound pressure level was occasionally over 85 dB(A), and the equivalent continuous A-weighted sound pressure level, L_{Aeq}, was 76 dB(A). The noise level was most powerful in the one-third octave band of 40 000 Hz, where it was 74 dB. In laboratory measurements, the noise levels of the air-turbine and the micromotor handpieces (n=16) were also most powerful in the one-third octave band of 40 000 Hz, where they were 80-89 dB. The L_{Aeq} of the different micromotor handpieces (n=6) varied between 76 dB(A) and 77 dB(A), and the L_{Aeq} of the turbine handpieces (n=10) varied between 77 dB(A) and 82 dB(A). The noise of the drills is most powerful in the high frequencies, so using hearing protectors, it is possible that speech communication improves because the protectors attenuate high frequencies more than low frequencies. The very light protectors give sufficient protection against the drilling noise.

2 INTRODUCTION

Micromotor handpieces and air-turbine handpieces are common sources of noise in dentistry.

A pure tone air conduction audiometric evaluation of 137 dentists and 80 physicians was made. Dentists were found to have a higher hearing threshold, especially at 4 000 Hz, than the physician control group. In addition, right-handed dentists had greater hearing loss in the left ear than in the right ear, ostensibly relating to the proximity of the noise source. The physicians had no statistically significant difference in hearing between the left and right ears [1]. In 1973, the pure tone audiograms of 68 dentists were taken. These dentists had practiced dental work for periods of not less than ten years. A follow-up study was carried out in 1988. At the frequencies of 4, 6, and 8 kHz, dentists tended to have higher hearing thresholds than expected [2]. However, studies do exist according to which no significant differences were found concerning their hearing [3, 4]. The risk of hearing damage is slight when using modern equipment; however, control is nevertheless necessary for error-free communication during dental procedures [5].

According to the noise measurements near the operator's ear at four dental clinics, the maximum noise level was 88 dB(A). This maximum was caused through use of an ultrasonic scaler. The noise of other equipment was below 75 dB(A). The measurements were made with a precision sound level meter [6]. When seventeen turbines were studied, in some cases, during idle rotation at a distance of 0.2 m from the turbine drills, the peak values of the ultrasonic level reached 115 dB at the frequency of 47 000 Hz [7].

The International Standard ISO 1999 sets out the relationship between occupational noise exposure, expressed in terms of equivalent continuous A-weighted sound pressure level, L_{Aeq}, and the percentage of the workers that may be expected to exhibit an increased threshold of hearing amounting to 25 dB or more, averaged over the three frequencies 500, 1 000 and 2 000 Hz solely as a result of the noise exposure. For instance, exposure to an L_{Aeq} of 85 dB(A) over a period of ten years causes hearing impairment to 6 % of exposed workers, and exposure to an L_{Aeq} below 80 dB(A) carries no risk of hearing impairment [8].

Lately, high-speed micromotor handpieces have been increasingly taken into use. Their rotation speeds do not change when the drilling resistance changes.

According to an EEC directive [9], machinery must be accompanied by instructions, including the L_{Aeq} at the workstations, where this exceeds 70 dB(A). However, machinery for medical use used in direct contact with patients is excluded from the scope of this directive.

The aim of this study was to measure and analyze the noise spectra of current dentistry drills in the one-third octave bands of 25-80 000 Hz during normal work at the dental clinic and in the laboratory under very controlled conditions.

3 MATERIAL AND METHODS

The noise study was conducted during the dental treatment of seven patients at a dental clinic and in the acoustics laboratory of Kuopio Regional Institute of Occupational Health, Finland.

In the in situ measurements, the stable microphone was installed at a distance of 1.2 m from a bit of the drill when it was in the patient´s mouth. For the distance correction, at the beginning, noise was measured during drilling simultaneously at the place the stable microphone and at a distance of 0.3 m from the bit of the drill, close to dentist's ear. The samples of the both measurements were analyzed in the one-third octave bands of 25-80 000 Hz. The correction was made in all one-third octave bands so that the spectra difference was added to the spectrum measured at the distance of 1.2 m from the bit. During the noise measurement, one dentist saw seven patients, and 7000 1-s samples were collected. The root-mean-square (rms) value was analyzed for each sample. The variation of A-weighted sound pressure level and the equivalent continuous A-weighted sound pressure level, L_{Aeq}, were calculated. The average sound pressure spectrum in the one-third octave bands of 25-80 000 Hz was also calculated from the 7000 samples. The dentistry equipment studied was produced by KaVo (Dentale Medizinische Instrumente, Germany) and W&H (Dentalwerk Burmoos, Austria). During burring, many different kinds of bits were used.

In the laboratory, where the background noise is about 0 dB(A), the noise of handpieces was measured by drilling a polyacetal plate. During the measurements, the water spray and the air pressure of the air turbines were adjusted to their maximum values. The rotation speed of the

micromotor was about 40 000 rpm and that of the air turbine was 300 000-400 000 rpm. The noise of the handpieces was measured over a reflecting plane on the hemisphere surface, the radius of which was 0.3 m. The noise samples were picked from ten positions on the hemisphere surface, and altogether 150 1-s samples were collected for each handpiece. The rms value was analyzed for each sample in the one-third octave bands of 25-80 000 Hz, and the average was calculated. The dental clinics sent handpieces for use in the laboratory measurements. The handpieces were produced by KaVo and W&H. During drilling with micromotor handpieces, the Meisinger 1012 US 3 RA bit was used and with air-turbine handpieces, the Meisinger 835009 bit was used. A summary of the handpieces studied in the laboratory is shown in Table 1.

Table 1. Summary of the handpieces used in the laboratory measurements.

Number of handpieces	Device	Manufacturer	Type
2	Micromotor	KaVo	20 LN
1	Micromotor	KaVo	20 LH
3	Micromotor	W&H	956 LT
2	Air-turbine	KaVo	630 B
5	Air-turbine	KaVo	640 B
3	Air-turbine	W&H	898

The measuring and analyzing instruments used were B&K 4135 microphones, B&K 2633 preamplifiers, the B&K 2811 multiplexer and the B&K 2133 real-time analyzer with the ZT 0318 high-frequency expansion unit. The B&K 4220 pistonphone was used to calibrate the equipment.

4 RESULTS

Figure 1 shows the variation of the A-weighted sound pressure level during the dental treatment of seven patients. This level was occasionally over 85 dB(A), and the L_{Aeq} was 76 dB(A). The spectrum in the one-third octave bands of 25-80 000 Hz is presented in Figure 2. The noise was most powerful in the one-third octave band of 40 000 Hz, where it was 74 dB.

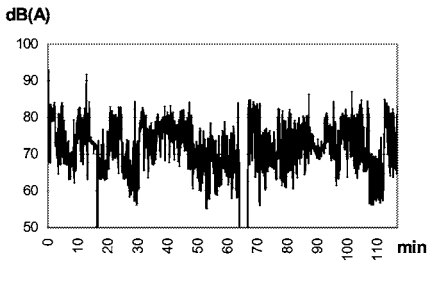

Figure 1. Variation of A-weighted sound pressure level during the dental treatment of seven patients.

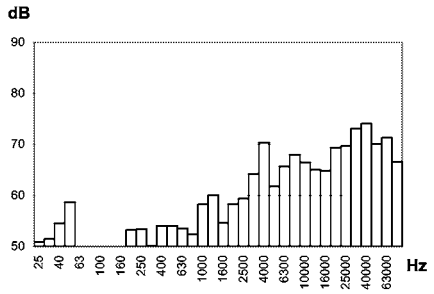

Figure 2. Average linear noise spectrum during the dental treatment of seven patients.

The results of the laboratory measurements are presented in Figures 3 and 4. The spectra of the air-turbine handpieces (n=10) in the one-third octave bands of 25-80 000 Hz are shown in Figure 3. Figure 4 shows the spectra of the micromotor handpieces (n=6). The noise of the air turbines was most powerful in the one-third octave band of 40 000 Hz, where the levels were 83-89 dB. The noise of the micromotor drills was also most powerful in the one-third octave band of 40 000 Hz, where the levels were 81-84 dB. The L_{Aeq} of the micromotor handpieces varied between 76 dB(A) and 77 dB(A), and the L_{Aeq} of the turbine handpieces varied between 77 dB(A) and 82 dB(A).

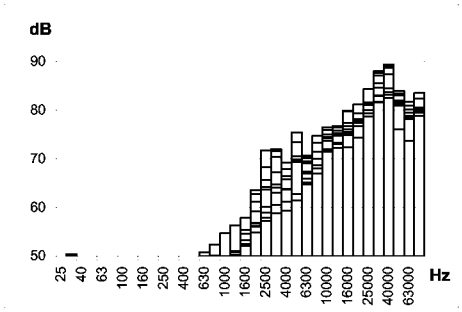

Figure 3. Average linear noise spectra of air-turbine handpieces (n=10).

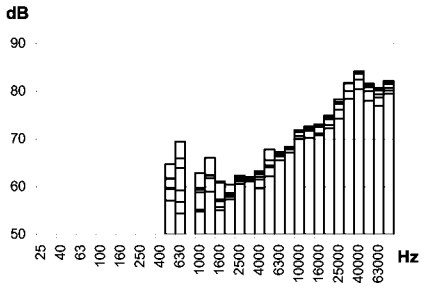

Figure 4. Average linear noise spectra of micromotor handpieces (n=6).

5 DISCUSSION

During the dental treatment of seven patients, the L_{Aeq} was 76 dB(A). According to ISO 1999 standard, exposure to L_{Aeq} below 80 dB(A) carries no risk of hearing impairment [8]. The ultrasonic scalers were not used during treatments. The noise level of the ultrasonic scaler can essentially be 88 dB(A) [6], and so the use of scalers can increase the L_{Aeq}. Therefore it would be important to start a wide study to evaluate the exposure of dentists to noise in the audible and ultrasonic areas when ultrasonic scalers are also used.

In the laboratory measurements, the L_{Aeq} of the turbine handpieces were 1-5 dB(A) higher than the L_{Aeq} of the micromotor handpieces.

The noise levels of the drills were most powerful in the one-third octave band of 40 000 Hz and, in the laboratory measurements, these levels were 4-15 dB higher than in the in situ measurements. In the one-third octave bands of 5 000-20 000 Hz, the levels were 0-15 dB higher in the laboratory measurements than in the in situ measurements. The differences between the in situ and the laboratory measurement results could be caused by the fact that, in the in situ measurements, the drilling and the water spray occurred mainly in the patient's mouth, which probably strongly absorbs high-frequency noise. The in situ measurements also included pauses. In addition, different kinds of handpieces were used during the in situ and laboratory measurements, and the drilling noise in the laboratory did not correspond exactly enough to the normal working conditions.

The ultrasonic levels were clearly below the American Conference of Governmental Industrial Hygienists (ACGIH) limit values of 105-115 dB in the one-third octave bands of

20 000-50 000 Hz [10]. This was because the ultrasonic scalers were not used during measurements.

The laboratory measurements were done at a distance of 0.3 m from the noise source, and the measurement results of the dental clinic were corrected so that they also corresponded to the measurement results at a distance of 0.3 m from the source. If the measurement distance from the source had been 0.15 m, the measurement results would have been about 6 dB greater. Further, it is problematical that, because medical machinery used in direct contact with patients is excluded from the scope of the "machinery directive", handpiece producers are not obliged to declare the noise levels of the drills at the operator's position.

6 ACKNOWLEDGEMENTS

The authors wish to thank the Finnish Work Environment Fund for providing financial support. Also we are grateful to Mr Esko Hokkanen from Plandent Ltd, Finland, for arranging for the use of the study dental care equipment, and to Mr Heikki Hiippala from Vaasan Hammas, Finland, for arranging possibilities to study dentistry noise in their dental clinic.

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CHAPTER 7
GENERAL DISCUSSION

1 HAND-ARM VIBRATION

The weighted vibration of dental handpieces measured according to standard ISO 5349-1 [1] varied in this study from <0.01 m/s^2 to 0.9 m/s^2. The vibration spectra of the handpieces contain powerful vibration at high frequencies (1 600-10 000 Hz), which are above the frequency range of ISO 5349-1. The effects of this ultravibration on hands and fingers are not well known. The highest ultravibration acceleration was measured in air-turbine handpieces, in which the weighted vibration values were the lowest. The measured vibration accelerations of the tools of dental technician were at same order of magnitude as measured earlier [2]. The vibration of common hand tools varied widely. The weighted vibration values did not predict magnitudes of ultravibration. A summary of weighted vibration and ultravibration measurements is given in Table 1.

Table 1. Summary of weighted vibration (ISO 5349-1) and ultravibration (1 600-10 000 Hz) measurements in this study.

Tool	n	Weighted vibration m/s^2	Ultravibration m/s^2
Air-turbine handpieces			
- laboratory measurements	12	<0.01 - 0.2	70 - 640
- during normal work	10	0.01 - 0.04	40 - 200
Micromotor handpieces			
- laboratory measurements	8	0.1 - 0.8	30 - 180
- during normal work	12	0.2 - 0.9	3 - 30
Dental technician´s tools	7	0.5 - 3	30 - 210
Common hand tools	15	1 - 18	3 - 870

The measurements were made in one direction only, so the results presented here are underestimates of vibration total value a_{hv}. Assuming that the magnitude of weighted vibration is equal in all three directions, the estimated vibration total value according to the standard ISO 5349-1 is the measured weighted value of one component multiplied by a factor of 1.7. Therefore the exposure action value of the EC directive 2.5 m/s^2 [3] was exceeded in two of the seven tools of the dental technician. The weighted vibration of the dental handpieces multiplied by a factor of 1.7 remained below 2.5 m/s^2. Uncertainty in the assessment of the vibration exposure of the dentist arises from, e.g. the relative importance of different axes of vibration, exposure time and influence of finger-grip force.

In this study, the total daily duration of exposure to the vibration was not measured and therefore the 8-h energy-equivalent frequency-weighted vibration total value could not be determined.

Vibration exposure level of dentist is low, determined according to standard ISO 5349-1 and compared to European legislation. However, the relative risk of getting a vibration injury is higher among dental personnel than other occupational groups [4]. The questionnaire data of this study imply that exposure to vibration in dentistry may increase the risk of frequent finger symptoms that are perceived as vibration-related. Current exposure (during the past 12 months) to vibration (filling of cavities and root treatment) was not associated with finger

symptoms, whereas a high level of cumulative exposure during one's work history was. This would mean, either, that there is a latency time for such symptoms to appear, or, that dentists with finger symptoms tend to reduce the time they spend on work tasks that expose the fingers to vibration. High BMI was also associated with finger symptoms, which is in agreement with previous studies [4, 5]. The mechanism of such an association remains to be elucidated.

The effects of hand-transmitted vibration are not restricted to vascular effects and VWF. It seems that non-vascular symptoms of fingers are more common than vascular symptoms among dental personnel [6, 7], and also among other occupational groups [4]. It is possible, that women are more susceptible to vibrations than men, but this question requires more research [4, 8]. Knowledge of the injurious effects of vibration on hands and fingers is not complete. The vibration exposure standards and the limit values do not predict the risk of injury occurring in any particular individual within a group. It is difficult to propose a comprehensive method for the evaluation of vibration exposure and risk assessment. The risk prediction model presented in the standard ISO 5349-1 is a compromise based on considerable extrapolation, derived from limited quantitative data on VWF, and subjective sensations at low and medium frequencies. It does not take into account all the factors contributing to injury, e.g. the effects of vibration on the bones, joints, nerves and muscles. Its shortcomings have been discussed also earlier, e.g. [9-11]. It is evident that frequency weighting and the risk prediction model in evaluating hand-transmitted vibration should be modified.

In most test methods of vibration response or determination of the dynamic response of the hand-arm system, palm gripping is used, and in only few studies were fingers exposed, e.g. [12-14]. When dental drills and other small and light tools are used, gripping involving only the first three fingers of the dominant hand is the most usual. Instead of "hand-arm transmitted vibration", "finger-transmitted vibration" should be studied when the vibration of dental drills or other small vibrating tools is considered. The problems encountered are, e.g. defining the location of the origin of the axes of the coordinate system, orientation of the axes, frequency range and frequency weighting. If a vector sum is determined, the weighting factor of three directions must be given.

The dynamic properties of the fingers are not well known, and when interaction between the fingertip and the vibrating tool was simulated, a steel plate was often used as a contact surface, e.g. [14]. However, when dental instruments are used, the contact surface of the tool typically has a cylindrical form, which produces a high local pressure in the fingertip. The nature of a dentist's work, when instruments are used in the mouth of the patient, sets high demands to the accuracy of positioning and orientation of the instruments. The extremely high concentrating on the working, the mass of the tool, and the local muscle tension of the hand-arm may increase the grip force, and thus the transmission of vibration to the fingers may be greater. There is need for a redesign of the dental instruments in order to improve the ergonomics, e.g. making the diameter larger to reduce the grip force [8].

The interior of small-diameter tubings in dental unit waterlines are sites of biofilm formation e.g. [15, 16]. This is a reason to connect the water supply of dental handpieces to the cold water tap, which may lower the temperature of the handpiece. The low temperature of instruments may be one factor which possibly has an effect on work-related symptoms in dentistry.

Ultrasonic instrumentation may be employed for descaling tooth surfaces, root canal preparation and in apcal surgery. It is therefore possible that drilling may be replaced by ultrasonic technology [17], and this may increase the high-frequency vibration exposure of dental personnel [8].

Traditional accelerometer methods are still used most for determining the vibration of hand tools. The laser method, which has been applied in the present work, has many advantages compared with traditional methods. E.g. it is possible to avoid problems concerning the mass and fastening of the accelerometer. The mass of dental handpieces is small, typically about 50-100 g, and therefore it is necessary to consider the effect of the mass of the accelerometer on the result of the vibration measurement. If the total mass of the accelerometer and mounting system is small compared to the mass of the tool (less than 5%), the effect can be ignored according to the standard ISO 5349-2 [18].

The use of non-contact measurement devices has been recommended especially for high-frequency vibration, e.g. [19]. Laser method has been succesfully applied to characterize the vibration pattern of dental ultrasonic scaler tip, e.g. [20]. According to this study, the laser method can be used to measure the vibration of dental handpieces during idling. The measurement equipment is portable and measurement is fast, because time-consuming fastening of the accelerometer is not needed. The dynamic and frequency ranges are wide enough for these applications. The laser method is more practical especially in the high-frequency area, in which the problem concerning reliable fastening of the accelerometer is critical. When the vibrations between handpieces, or between parts of the instruments, are compared, laser-based measurements are easy to perform. The feasibility of the laser method to measure vibration of the nails should be studied.

The laser method measures the vibration component perpendicular to the surface; this means that the vibration components parallel to the surface can not be measured. The laser method can be applied only during idling of most hand tools. During normal work, the movements of the tool and masking of the operator prevent non-contact measurements, and also triaxial non-contact vibration measurements are very problematic to perform. Therefore, the traditional accelerometer method is often the only possible means of determining vibration during normal work. In order to develop a standardized vibration measurement method for dental handpieces, more research and method development are needed.

2 NOISE AND ULTRASOUND

Air-turbine and micromotor handpieces, suction tubes and ultrasonic scalers are common noise sources in dental care. In this study, the sound power levels of these instruments were tested systematically in laboratory conditions. The methods described in the standards ISO 3744 and ISO 9614 were applicable to these tests. The sound power level L_W of the device does not depend on the measurement distance from the source, nor on the acoustical environment, and therefore it provides a reasonable comparison value for the noise emitted by the equipment.

During the dental treatment of seven patients, the L_{Aeq} was 76 dB(A), which exceeds the declaration value of the EC Machinery Directive [21]. Variations of noise level were wide, which may increase the annoyance of the noise. The A-weighted noise exposure level of a dentist can occasionally be over 80 dB(A), which is the lower exposure action value of the

new European noise directive [22]. Ultrasonic scalers were not used during the treatments. The noise level of an ultrasonic scaler can essentially be 88 dB(A) [23], and so the use of scalers can increase the L_{Aeq}. Therefore it would be important to start an extensive study to evaluate the exposure of dentists and other dental personnel to noise in the audible and ultrasonic areas, also when ultrasonic scalers are used.

In the laboratory measurements, the L_{Aeq} of the air-turbine handpieces was 1-5 dB(A) higher than the L_{Aeq} of the micromotor handpieces. The noise levels of the handpieces were most powerful in the one-third octave band of 40 000 Hz and, in the laboratory measurements, these levels were 4-15 dB higher than in the in situ measurements. In the one-third octave bands of 5 000-20 000 Hz, the levels were 0-15 dB higher in the laboratory measurements than in the in situ measurements. The high-frequency noise level of air-turbine handpieces measured in laboratory conditions exceeded in the one-third octave bands of 16-20 kHz the maximum permissible levels determined by IRPA and Health Canada [24]. The noise levels were lower during dental treatment. The differences between the in situ and the laboratory measurements might be due to the fact that, in the in situ measurements, the drilling and the water spray were confined mainly to the patient's mouth, which probably strongly absorbs high-frequency noise. The in situ measurements also included pauses. In addition, different kinds of handpieces were used during the in situ and laboratory measurements, and the drilling noise in the laboratory did not correspond sufficiently to the normal working conditions.

When disturbances in communication and other non-auditory effects of noise are taken into account, it is important to reduce workers' noise exposure. Technical noise control measures are, e.g. the designing of less noisy handpieces and improving the acoustics of rooms. As the noise is most powerful at the high frequencies, using hearing protectors may improve speech communication because the protectors attenuate high frequencies more than low frequencies. Even the very light protectors give sufficient protection against noise.

3 CONCLUSIONS

Based on the results of the present study, the following conclusions can be drawn:

- Vibration exposure level of dentist is low, determined according to standard ISO 5349-1 and compared to European legislation.

- The vibration spectra of the dental handpieces contain powerful vibration at high frequencies (1 600-10 000 Hz), which are above the frequency range of ISO 5349-1. The effects of this ultravibration on hands and fingers are not well known.

- Vibration exposure of dentist may increase the risk of frequent finger symptoms that are perceived as vibration-related.

- Frequency weighting and the risk prediction model based on ISO 5349-1 in evaluating hand-transmitted vibration should be modified.

- Laser method is applicable to vibration measurements of dental handpieces during idling. The dynamic and frequency ranges are wide and problems concerning the mass and fastening

of the accelerometer are avoided. Triaxial non-contact vibration measurements are problematic to perform.

- Many hand tools used in dentistry and also many common hand tools expose the users to ultravibration. Weighted vibration values do not predict magnitudes of ultravibration.

- In the determination of the sound power level of dental handpieces, suction tubes and ultrasonic scalers, the methods described in standards ISO 3744 and ISO 9614 can be applied.

- Dental treatment exposes the dental personnel to high-frequency noise and ultrasound. Technical noise control measures are recommended. If hearing protectors are used, even the very light protectors are sufficient.

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