Measuring tooth vibrations induced during cavity preparation with time-averaged holography and its influence on near vision acuity in dentists

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The aim of this study was to quantify vibrations and their influence on visual acuity. The study consisted of two parts, laboratory and clinical. Time-averaged holographic interferometry (TAHI) method was used in laboratory for measuring the amplitude of tooth vibrations induced by dental handpiece. The amplitudes of tooth vibrations were measured for the three diameters and three speeds. The larger diameter coupled with increasing speed resulted in greater vibration amplitudes, whereby a maximum amplitude of less than one micrometer was detected. For quantifying the natural visual acuity for the corresponding tooth vibrations, we have used the clinical condition approach with miniaturized Snellen optotype as an assessing tool. Central visual acuity did not display variance in visual acuity at rest or under load. Results indicate that the vibrations induced during cavity preparation are not sufficient to negatively affect visual acuity of dentists.

Keywords: Tooth vibration, Dental handpiece, Visual acuity, Dentistry, Time-averaged holographic interferometry

INTRODUCTION

Improper posture, repetitive movement, lasting mechanical strain and vibrations are listed as biomechanical causes of professional risk in dental medicine. Mechanical vibrations in dental medicine are caused by operation of various machinery containing moving parts. Main sources of mechanical vibration are air-driven vibrating instruments, low- and high-speed hand-held extensions and ultrasonic devices. Mechanical vibrations can affect the patient through upper extremities, causing changes in vasculature, nervous and bone-skeletal system. Four parameters are important when considering harmful effects of vibrations: direction of vibration influence, duration of exposure, level of vibrations, and frequency of vibration sensitivity.¹,²

Various methods and appliances have been proposed for measuring vibrations in research of dental work like Portable Digital Vibrometer³, Laser Doppler Vibrometry (LDV)⁴, Scanning Laser Vibrometer⁵ and other force transducer analyzers.

Time-Averaged Holographic Interferometry (TAHI) is a method suitable for analyzing the modal structures of object vibrations because it turns vibrations into a fringe pattern visible in the recorded hologram.⁶,⁷

Although there are more studies looking into the influence of vibration forces on physical health of dentists, the influence of those same vibrations on the near visual acuity is only sporadically investigated.

Visual acuity plays an important role in dentists’ vision, which requires fine discrimination of detail in oral cavity in daily clinical routine. Dental competence requires good perceptual and visual skills for judging position, distance and the size of the object, as well as various shapes, in a small operating field. Using rotating instruments in everyday dental work, causing vibrations of the tooth surface and possible consequential structural changes in a tooth, could cause deterioration of the central visual acuity and thus not precise enough dental treatment.

So far, the TAHI was not used to measure vibrations generated in the tooth by using rotating dental instruments. The aim of this study was to: 1. investigate such possibility by evaluating a procedure based on the TAHI and by comparing the obtained results with those available in literature and to: 2. investigate possible influence of tooth vibrations induced with dental handpiece on near visual acuity in dentists under simulated clinical conditions.

MATERIALS AND METHODS

The study consists of two parts. The first part of the study included quantitative measurements of vibrations by applying the time-averaged holographic interferometry (TAHI) method at the Coherent Optics Laboratory, Institute of Physics, Zagreb. Second part of the study was testing the near visual acuity under simulated clinical conditions, examined in the group of dental students without corrections.

The study was approved by the Ethics Committees
of the School of Dental Medicine, University of Zagreb (approval No. 05-PA-26-6/2015). All procedures were conducted in accordance with the recommendations of the Declaration of Helsinki.

**Part one: laboratory study vibrations with TAHI**

We constructed an experimental system, shown in Fig. 1, consisting of a coherent source of light (He-Ne laser, MKS Instrument, Newport, USA, 25 mW, wavelength of 632 nm), a fixation press including a sample carrier, a charge coupled device (CCD) detector connected to a computer, and an instrument for mechanical cavity preparation (Maillefer NiTi system, Dentsply Tecnika, Ballaigue, Switzerland) with a micromotor with 16:1 of torque (WD-75 M, W&H Dentalwerk Bürmoos, Bürmoos, Austria). The sample carrier is a three-jaw lathe chuck which allows certain flexibility in fixing the samples. An extracted molar with a cavity was used as a sample. The extracted molar was cemented within the sample carrier (Figs. 2a, 2b and 2c). To emulate the real conditions, a rubber o-ring was inserted between two parts of the sample carrier. This allowed the movement and vibration occurring while drilling the enamel and the dentine to become more natural. Three speeds of the micromotor —100/450/800 rpm—, and three diameters of the carbide drills, 1.0, 1.6, and 2.3 mm, were used to vibrate the tooth. The micromotor was affixed to the frame of the fixation press in such a way that the carbide drill of the micromotor was placed along the entire front surface of the cavity. One series of measurements by holographic interferometry of mechanical vibrations of the tooth in performing a restoration consisted of ten measurements and determination of the position and the size of the deformation: Tooth still, tooth being excited with a 1.0 mm carbide drill at 100/450/800 rpm, tooth being excited with a 1.6 mm carbide drill at 100/450/800 rpm, and tooth being excited with a 2.3 mm carbide drill at 100/450/800 rpm.

The fringe pattern is mathematically described by the magnitude of the zero-order Bessel function of the first kind (\(|J_0 (x)|\)), where the argument \(x\) is equal: \(x=(4\pi/\lambda)h\), and where \(\lambda\) is wavelength of the laser and \(h\) is the vibration amplitude. Thus, the appearance of fringes indicates the position where the vibrations occur while the number of fringes reveals the vibration amplitude.

The amplitude of vibration \(h\) can be calculated from the argument of the zero-order Bessel function, \(h_n=\lambda/(4\pi)\lambda_n\), where \(h_n\) is the amplitude produced by the \(n\)-th dark fringe. Thus, the zeros of the Bessel function, \(x_1=2.4, x_2=5.5, x_3=8.7,\) etc., can be used to calculate the vibration amplitudes experimentally obtained by the TAHI method.

**Part two: visual acuity clinical study**

The study group consisted of 21 students of the School of Dental Medicine University in Zagreb who volunteered to participate in the study, with normal eye status and visual acuity of 1.0. The participants’ age was between 21 and 25 years of age. Before they were included in the study, their ophthalmology status was established in an ophthalmological practice, and all of those with any ophthalmological condition that may affect the vision were excluded. Refraction status was examined by refractometry, and measured at up to +/-0.50 Daph=+1.00 Dcyl ax 90, and at the Snellen Chart (Optotype) 1.0. Near vision was examined by standard Jäger tables and had to be measured at 1.0 at a distance of 30 to 40 cm. After the basic inclusion and exclusion criteria were met, every subject was informed about the project and had to provide written consent.

For examination of visual acuity, a miniature...
Snellen Chart was created. An A4 model of the Snellen Chart was produced in high resolution, printed out, then copied on to a 35 mm B/W microfilm in the central Photolaboratory of Croatian State Archive. A microfilm camera, Zeutschel Documator was used. It was reduced to the minimum possible 28.5× compared to the starting A4 format of the Snellen high resolution chart. The miniature Snellen chart for examination of dentists’ visual acuity in close-up work was 5.2×2.8 mm in size. Size of the optotypes ranged from 0.05 to the largest at 0.6 mm (Fig. 3).

The study was conducted on a dental phantom, where a miniature Snellen chart was affixed at the bottom of first class cavity in a molar (Fig. 4). The subject was seated in a working chair, upright, with full surface of both feet planted on the ground, knees situated below and elbows at level with the jaw of the dental phantom. The smallest optotype that the subject was able to read was registered as the near visual acuity.

The value of visual acuity was recorded by decimal graduation as between 0.1 to 1.0 (or as a percentage of 10% to 100% of visual acuity), using universal mathematical values in quantifying visual acuity. The participants’ natural near visual acuity was examined at rest and under load. The load simulated clinical conditions in a dental office, using three drill of different diameter (1.0, 1.6, 2.3) at three speeds (100, 450, 800 rpm). The lightning of the room and the work zone lightning ranged from 250 to 500 lux meters. The light task area was lit by a 60 W surgical light bulb.

Before conducting the differential analysis, the normality of data distribution was tested. Shapiro-Wilk test was used to discard the null hypothesis of data normality (p<0.05). Since the data did not follow a normal distribution, non-parametric statistical tests were used for their analysis. Descriptive statistics included a calculation of arithmetic means with appropriate standard deviations and coefficients of variation.

RESULTS

Laboratory one: TAH Vibrations Measurements

The holograms were first recorded using the device shown in Fig. 1 and then reconstructed applying the DigiOpt laboratory software (Institut für Algorithmen und Kognitive Systeme, Karlsruhe, Germany).

As a general conclusion, it was found that coarser drills in larger diameters and higher-speed frequencies induced more fringes. Photographs show a series...
Table 1 Visual acuity without and under the load

| Variable   | N  | Mean | SD  | Minimum | Maximum |
|------------|----|------|-----|---------|---------|
| VSC        | 21 | 0.56 | 0.055 | 0.5     | 0.6     |
| V1.0/100   | 21 | 0.56 | 0.055 | 0.5     | 0.6     |
| V1.0/450   | 21 | 0.56 | 0.055 | 0.5     | 0.6     |
| V1.0/800   | 21 | 0.52 | 0.084 | 0.4     | 0.6     |
| V1.6/100   | 21 | 0.56 | 0.055 | 0.5     | 0.6     |
| V1.6/450   | 21 | 0.56 | 0.055 | 0.5     | 0.6     |
| V1.6/800   | 21 | 0.54 | 0.055 | 0.5     | 0.6     |
| V2.3/100   | 21 | 0.56 | 0.055 | 0.5     | 0.6     |
| V2.3/450   | 21 | 0.56 | 0.055 | 0.5     | 0.6     |
| V2.3/800   | 21 | 0.50 | 0.071 | 0.4     | 0.6     |

VSC –visual acuity without correction at rest; V1.0/100 –visual acuity turbine 1.0 rpm 100; V1.0/450 –visual acuity turbine 1.0 rpm 450; V1.0/800 –visual acuity turbine 1.0 rpm 800; V1.6/100 –visual acuity turbine 1.6 rpm 100; V1.6/450 –visual acuity turbine 1.6 rpm 450; N –sample size; Mean –arithmetic mean; SD –standard deviation of interferograms obtained from different speed frequencies and different drill diameters. Figures 5a, 5b and 5c show the smallest size drills dimension of 1.0 mm, at rotation speeds of 100/450/800 rpm, Figs. 5d, 5e and 5f show the middle size drills of 1.6 mm at rotation speeds of 100/450/800 rpm, Figs. 5g, 5h and 5i show the largest drill of 2.3 mm at 100/450/800 rpm. In Figs. 5f, 5h, and 5i dark fringes are emphasized by lines with numbers indicating the corresponding deformation in micrometers i.e., deformation is constant along each line or fringe. Obviously, number of fringes increases with the size of drill diameter and increased frequency. Smaller diameter drills, at lower frequencies, produced almost not a single clearly visible fringe. Smaller diameters at higher frequencies, as well as larger diameters even at lower frequencies, produced only one, barely visible fringe (Figs. 5b, 5e and 5g). Number of fringes increases to maximum number of 3 at higher frequencies and larger drills (Figs. 5f, 5h and 5i). The three visible fringes are the highest number of fringes we managed to obtain by measurement, which result in less than 1 µm amplitude of vibrations.

**Part two: visual acuity**

Statistical analysis included results of 21 subjects, 13 females and 8 males, of average age of 23.8 years. Average value (standard deviation) of visual acuity using natural vision, at a distance of 300–400 mm (VSC) at rest, was 0.56 (0.05). The results on visual acuity in rest and visual acuity with load showed no statistical significant difference. All values at rest and under load are shown in Table 1. The age and sex of the subjects had no influence on near visual acuity.

**DISCUSSION**

The results of the study provide valuable information about the near vision acuity in simulated clinical conditions. Unassisted average near visual acuity in our study, at rest or under load, was recorded at 0.56 (56%) of the total of 1.00 (100%). There was no statistically significant difference between measurements of the two working modes. Our results are in concordance with the Weingarten research on students of dental medicine, measuring visual acuity and neck angulation, with and without magnification aids. In other studies, authors were using the miniaturized eye charts to test dentists and dental hygienists, where the detection of detail was measured in dimensions of the smallest structure detected, and varied by a magnitude of 250–300% independent of age or place of work/practice. The results were not similar with the findings of our study. Smaller pattern, and generally uniform young age of the subjects in our study with good visual acuity, could explain such a result and uniform distribution of the visual acuity results. Reduction of near visual acuity takes place with age, and especially after the fortieth year. This is also the reason for our group to comprise younger subjects, and for the visual acuity to be uniform when considered from the perspective of age.

Studies showed that when self-assessing their eyesight, the dentists generally believe their vision to be good. In all studies it was confirmed that this is not the case including our results. Near visual acuity, which was 0.56 in our study, cannot be compared to real life conditions, because the real conditions in which the dentists work tend more towards microscopic levels. If a person had a measured central visual acuity of 1.0, that person would not need the assistance of magnifying aids.
Therefore, the best support in everyday detailed work are the head lenses and magnification instruments. There are numerous articles confirming the benefits of working with head gear\textsuperscript{15-19,21} which requires getting used to. A general recommendation is to introduce magnification instruments and adaptation to working with them as a subject in dental schools. These devices may be introduced as early as the pre-clinical phase of dentistry degree programs. That would allow students to develop their professional motor skills with a magnified field.

Series of variables define details recognition like size, luminance, contrast and glare. Also working distance, light source and visual aids are some of defined variables that dentist can accommodate to their needs. Intraoral light is a variable that depends on a few other conditions, such as the intraoral mirror position, test location and possible light reflection\textsuperscript{22}. All these variables were optimized in our research, so they had no impact on the results. The acuity measured was sufficient for everyday dental work, such as removing plaque or caries, or doing a filling. However, that was not sufficient for procedures requiring high degree of precision for success, such as prosthetics, endodontics or any kind of high precision aesthetic dentistry.

Published studies and scientific research on near visual acuity in dental clinical conditions show lack of standardized optotypes and protocols\textsuperscript{20}. For that reason, Patel et al. developed tables to enable easier comparison of results in measurements of visual acuity\textsuperscript{15} which we used so we could compare our results with others. Some new studies measure differentiation of detail as visual performance, measuring detail differentiation supported by other parameters such as the size of the observed object, lighting, light contrast, and glare. Such measurements are supplements to measuring central visual acuity, certainly not a replacement\textsuperscript{14,19}.

Measuring the vibrations of the tooth caused by a dental handpiece by a new method — TAHI, as far as we were able to ascertain, was done for the first time. The results obtained indicated that the vibrations caused by the dental handpiece during cavity preparation are not sufficient to influence visual acuity. Central visual acuity is determined by the minimal angle where the eye can still see two dots as separated. This visual angle is called the Minimum Angle of Resolution or minimum separable. In an emmetropic eye, this angle is one angle minute, corresponding to the size of 4 microns. This matches the size of the base of a single retinal cone and is the unit for visual acuity. In order for two points to be seen as separated, at least two cones must be stimulated, between which there must be an unstimulated cone\textsuperscript{24}.

TAHI measurement of vibrations for the largest diameter and at the highest frequency produced three fringes which were calculated to a total of 1 micron. This is not enough to induce or influence stimulation of the eye. This result leads us to conclude that the vibrations created during dental restoration process in the course of everyday dental work are not sufficient to reduce visual acuity of dentists, as compared to visual acuity at rest.

There are not that many articles dealing with measuring vibrations at a tooth while using dental handpiece (which is the dental hand tool most commonly used). Most studies are focused on implantology and influence of vibrations on bone and implants structure, or measuring vibrations caused by endodontic instruments, which are coarser and whose mode of operation and method of force transfer differs from one that we investigated\textsuperscript{25-29}. Scant research was concerned by influence and transfer of vibration onto the tooth structure while there were various methods and investigations mostly to measure force of vibration transfer onto the hand of the dentist\textsuperscript{3,29}. This is what encouraged us to conduct this study and measure vibrations with this highly sensitive technology. The result we obtained was smaller than 4 micrometers, which was in agreement with the Poole et al., who measured vibrations of five dentals high-speed turbines and two speed-increasing handpieces with a scanning laser vibrometer (SLV)\textsuperscript{30}.

So far no studies have reported use of TAHI for measuring tooth vibrations induced by dental handpiece. TAHI as a method for measuring vibrations in dentistry was successfully used to measure with great precision a degree of shrinkage of various dental materials\textsuperscript{31-33}. This method was also used to measure vibrations created by axial forces during dental implant procedures\textsuperscript{29}, and static load of the mandibula in test animals\textsuperscript{34,35}. Displacements of human maxillary central incisors was successfully measured to an accuracy of 0.05 µm\textsuperscript{36}. TAHI was used for precision management in prosthetics, to measure dimensional stability of metal-ceramic prostheses\textsuperscript{37,38}.

Lots of research in various scientific fields over the past sixty years successfully investigated changes of dimension caused by various forces. All of them showed TAHI as a very precise method suitable for measuring fine vibrations. This innovative study can be used in the future as a starting point in development of visual aid for dentists during all condition clinical work in all age group of dentists.

CONCLUSION

It is demonstrated that two related approaches, introduced by this study, can be successfully used to quantify the visual acuity in dentistry under simulated clinical conditions. However, the obtained results indicate that tooth vibrations are in general of low amplitude and thus presumably with no influence on the visual acuity for operators with normal vision. Although near visual acuity decreases in dentists during life time, we assume that it depends on other variables in dentists work which still needs to be investigated.

DISCLOSURE STATEMENT

The undersigned author transfers the copyright over this manuscript Measuring Tooth Vibrations Induced During Cavity Preparation with Time-averaged Holography and its Influence on Near Vision Acuity in Dentists to Dental Materials Journal in case the
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