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Letter to the Editor

Assessing the vibrations of dental ultrasonic scalers

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1. Introduction

1.1. Ultrasound in dentistry

Ultrasound has been used in dentistry for almost 50 years [1]. The main use of ultrasonics in dentistry has been in relation to the scaling of teeth using ultrasonic scalers. In spite of people brushing their teeth, the bacterial plaque may mineralize, leading to calculus (tartar) formation. This is a tenacious deposit that cannot be removed by brushing and may lead to periodontal disease. An ultrasonic generator is used to drive a scaler insert (Fig. 1), which has a metal probe that mechanically chips such deposits off the teeth. A variety of scaler insert probes have been designed to aid this process, based on conventional hand instruments (Fig. 2).

Ultrasonic scalers operate at frequencies between 25 and 30 kHz. The method of ultrasound generation most commonly used in dental generators is magnetostriction, although piezoelectric generators are also available. Ultrasonic scalers remove plaque and calculus by the mechanical chipping action of the scaler probe in contact with the tooth surface. Other processes that may aid this removal are the production of cavitation and acoustic micro-streaming which occurs within the cooling water supply which flows over the scaler probe to the treatment site [2–4]. Cavitation produces large shock waves that disrupt the deposits and the shear forces associated with acoustic micro-streaming aid this process.

Although the use of these instruments is widespread in dentistry the vibrational motion of scaler insert probes is not fully understood. Previous assessment of the oscillation of these instruments was performed by directing a beam of light onto the tip of a scaler probe which, when reflected off a scratch on the surface, resulted in a pinpoint of light [5,6]. This pinpoint of light became elongated into a thin bright line when the apparatus was operated, the length of the line indicating the excursion of the probe tip. However, this is a time-consuming procedure that does not allow detailed visualization of the probe movement or accurate measurement of its displacement amplitude.

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Fig. 1. A dental ultrasonic scaler insert showing the metal probe used for tooth debridement.

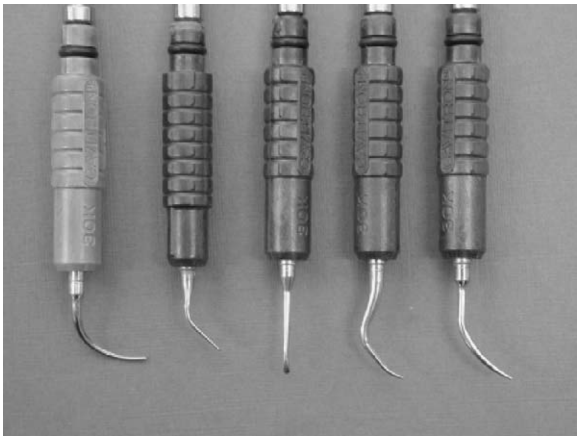

Fig. 2. A selection of dental ultrasonic scalers including (L–R): Slimline, TFI-3, TFI-1, TFI-1000 and TFI-10 (courtesy of Dentsply, York, PA, USA).

The use of laser vibrometers to analyze the vibrations of solid bodies has, in many situations, replaced the use of accelerometers or other forms of surface contacting sensors, due to the non-intrusive nature of the instrument. The technique is particularly useful where surfaces may be easily damped. By employing this technology, the vibration characteristics of dental scaler probes may be studied in detail. Better understanding of the operational characteristics of scaler probes and ultrasonic generators may aid manufacturers in designing and improving the equipment presently available and give clinicians a better understanding of how the equipment operates most efficiently.

2. Scaler insert measurements

2.1. Experimental setup

The scanning laser vibrometer performs measurements on vibrations along the axis of the laser and so this determines the initial setting up of the equipment. The scanner head of the laser vibrometer not only contains the laser and corresponding optics for data collection, but also a video camera. The output of the video camera is displayed on the monitor of the workstation. A virtual measurement grid, consisting of a mesh of scan points, was superimposed on the video image of the target scaler probe. This grid is fully adjustable in size, shape and point density and is used to guide the laser beam over the surface of the probe.

When performing a scan, the laser beam takes between 1 and 512 measurements (user defined) at the first scan point in the grid. The average of these measurements is then calculated and the laser beam moves to the next point in the grid where the process is repeated. All measurements taken must be in phase with each other (i.e. the target object must be at the same stage in its vibration cycle when all measurements are taken) and to accomplish this, a reference signal is used. The reference signal employed varies according to the target object under investigation. In the case of the ultrasonic scaler inserts, the reference signal is produced via a coil with an iron core. This is placed next to the scaler handpiece (which also contains a coil). Through mutual induction, current changing in one coil (the primary) can induce an e.m.f. in a neighbouring coil (the secondary). The mutual inductance, M (in henrys), of the two coils is given by

$$M = \frac{-\varepsilon_s}{\mathrm{d}I_p/\mathrm{d}t},$$

where ε_s is the induced e.m.f. in the secondary coil (reference signal) when the rate of change of current in the primary coil (the scaler handpiece) is $\mathrm{d}I_p/\mathrm{d}t$. The e.m.f. induced in coil 2 is therefore proportional to the rate of change of current in the first coil. A trigger level is set, at a certain percentage of the reference signals maximum amplitude (on the upward or downward phase of the signal) and the SLV performs a measurement each time this level is reached.

A series of dental scaler inserts were fixed in position with their probes facing the scanning laser vibrometer. Scans were performed to assess the longitudinal vibration of the scaler probes whilst operated in air and without the cooling water flowing over them at a medium generator power setting.

3. Results

3.1. Data display

The system measures the vibration velocity from which it calculates the displacement amplitude and acceleration, which are then stored in the data manipulation system. Animation of the vibration is made possible and the data may be presented in several ways. Two of the most informative ways are by superimposing the data over a captured video image of the target object (Fig. 3) or as an animated 3-D mesh (Fig. 4a–d). A colour-graded scale indicates the magnitude of the vibration velocity/displacement as well as the direction of the motion, relative to the scanner head. By superimposing data over the scaler probes it is possible to determine the location of any nodal positions as well as points of maximum displacement.

Fig. 3. Scanning laser vibrometer scan of a TFI-3 magnetostrictive scaling tip (Dentsply Preventive Care, York, PA, USA). Vibration data are superimposed upon a video image of the insert probe.

3.2. Initial observations

The ability of the scanning laser vibrometer to be used for analyzing the vibrations of ultrasonic scaler insert probe vibrations is demonstrated in Fig. 4a–d, which shows a P-style probe at different stages in its vibration cycle. It is also possible to compare the mode shapes of different designs of insert probe including a TFI-10 insert (Fig. 5a–c) and a TFI-3 insert (Fig. 6a–c) to determine which have the greatest displacement amplitude and which, therefore, may be the most effective for calculus removal.

4. Discussion

The vibration patterns of dental ultrasonic scaler probes are difficult to assess, due to their high frequency of oscillation and small associated displacement amplitudes. Previous work, using the reflection of light, gave an indication that different designs of scaler tips and ultrasonic generators performed differently from each other [5,6].

Since the introduction of the ultrasonic scaler, research has focussed on the effectiveness of the instrument and its effects on the root surface during contact. Until now, it has not been possible to fully characterize the movement of the scaler probe and so many previous research findings have not been able to relate the movement of the probe to the resulting clinical effect. Due to the light

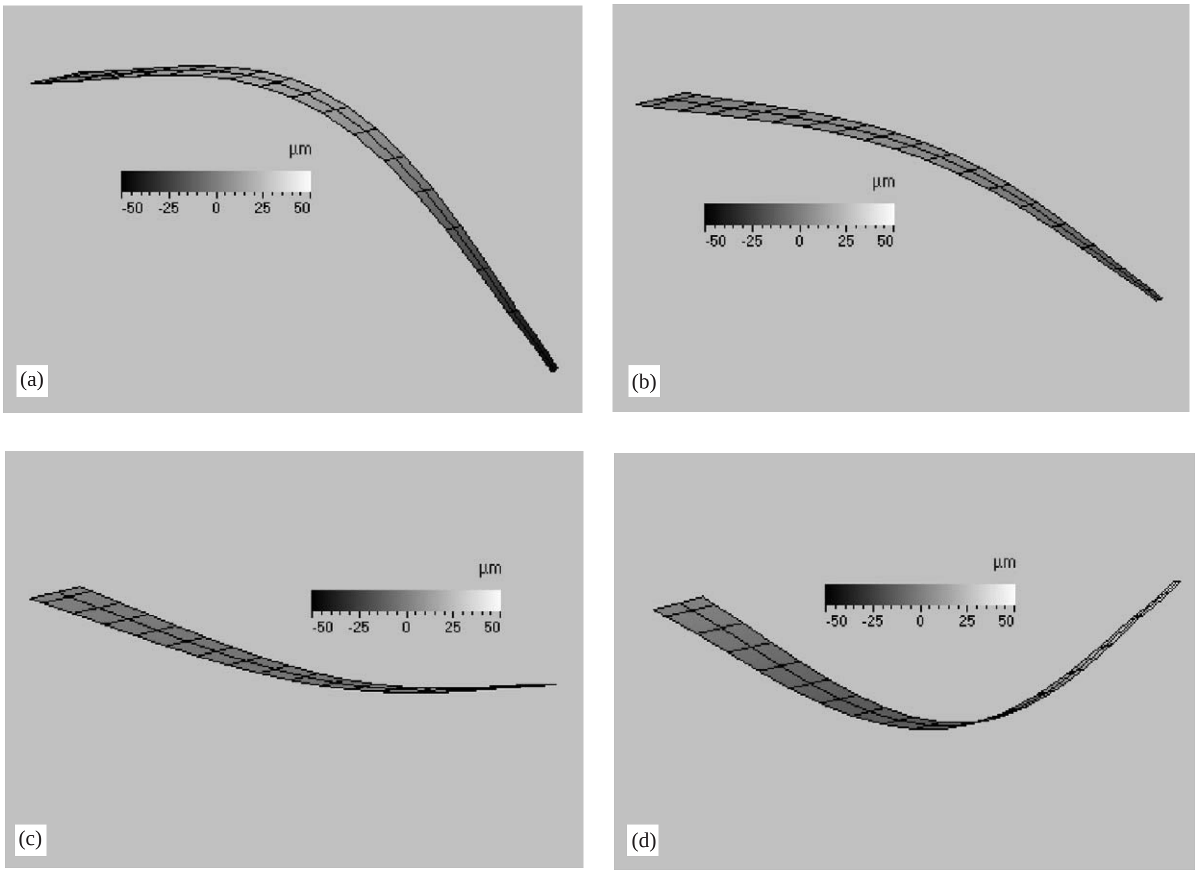

Fig. 4. (a-d) 3-D mesh animations of a P-style scaler probe, oscillating with frequency 29.50 kHz, at different stages in its vibration cycle.

weight of scaler probes, small contact loads can cause alterations in their vibration patterns. Contacting sensors, such as accelerometers would, therefore, affect their vibrations and this is why the non-contacting nature of the scanning laser vibrometer makes it ideal for the assessment of the vibrations of these instruments.

Using the scanning laser vibrometer, it was possible to determine the fundamental frequency of vibration of any dental scaler probe and then study the vibrations of the probe at this frequency. Area scans over the front surface of the probe reveal information on velocity and displacement amplitude. From this information the points of minimum and maximum vibration (i.e. nodes and antinodes) can be observed, enabling evaluation of possible probe fatigue points.

Performing unloaded vibration measurements on scaler probes (i.e. in air) can give a guide as to the performance of the generators driving the inserts and also to the way in which the inserts respond to changes in power. Research by Flemmig et al. [7,8] and Busslinger et al. [9] investigated the differences between piezoelectric and magnetostrictive scalers during contact with tooth surfaces. It was found that surfaces instrumented with a piezoelectric scaler resulted in a rougher tooth surface, which was not observed with magnetostrictive scalers [7]. This may be due to

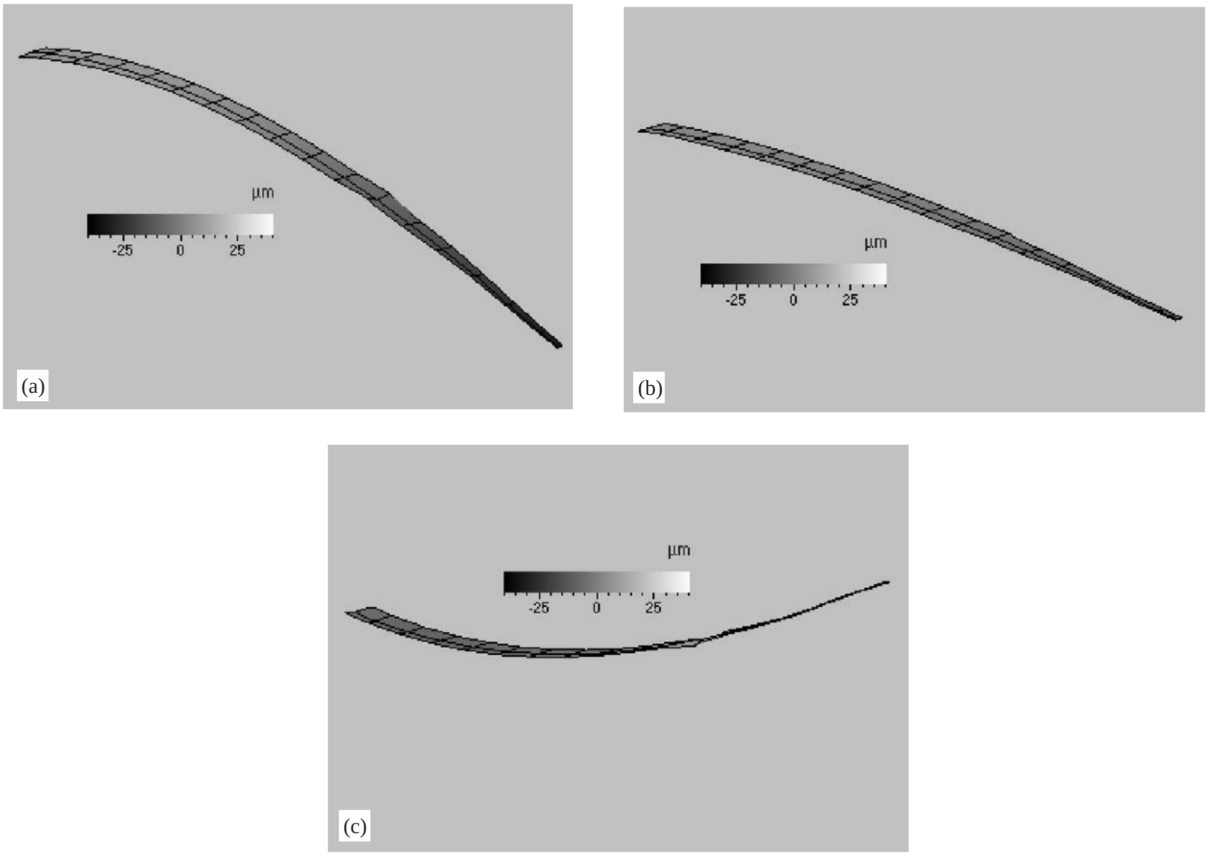

Fig. 5. (a-c) 3-D mesh animations of a TFI-10 scaler probe, oscillating with frequency 29.13 kHz, at different stages in its vibration cycle.

differences in the oscillatory patterns of magnetostrictive and piezoelectric probes under loading. The application of a load, as well as the point of contact along the length of the probe, may affect the vibration patterns. Presently, work is underway to characterize the motion of the probes when they are in contact with teeth, in-vitro.

5. Conclusion

The scanning laser vibrometer allows one to study, in detail, many of the vibrational characteristics of dental ultrasonic scaler tips. Information such as vibration velocity and frequency of oscillation may be measured and displayed rapidly. From the velocity data, the displacement amplitude of the scaler tips may be calculated. The ability to superimpose data over a video image of the target object allows the observation of nodes and anti-nodes along the length of the probe surface. The 3-D mesh display facility enables the motion of the probe to be viewed at much reduced velocities, making the visualization of probe motion much easier to understand and study.

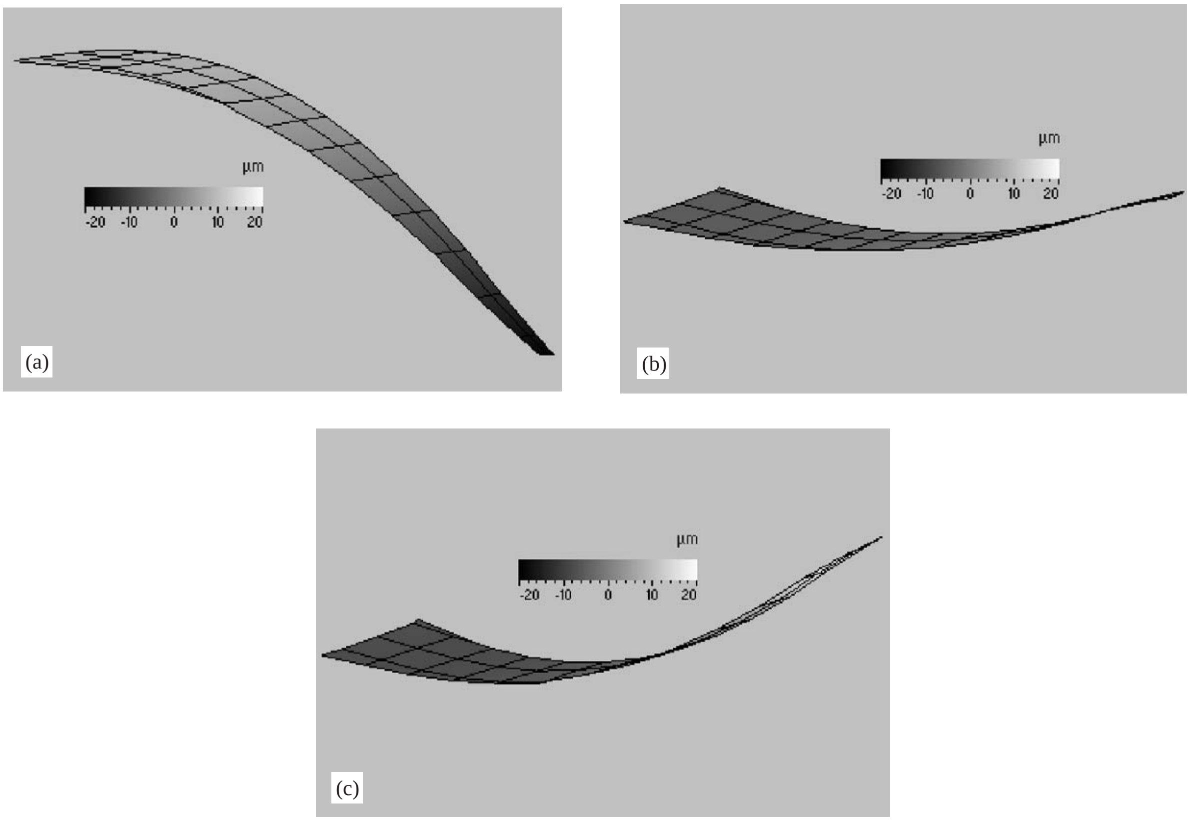

Fig. 6. (a-c) 3-D mesh animations of a TFI-3 scaler probe, oscillating with frequency 28.75 kHz, at different stages in its vibration cycle.

The use of the scanning laser vibrometer for assessing dental ultrasonic scalers is still at an early stage of development. However, the preliminary work reported here has demonstrated that the SLV may be a useful tool for assessing dental ultrasonic scaler probe motion and further work is underway to characterize this motion more precisely. The use of load cells to measure the force being applied to the tooth, by the scaler probe, will hopefully allow the vibrations of probes to be measured, under differing amounts of force and at different probe/tooth contact angles. The effect of water flow on probe vibration will also be investigated.

More knowledge, as regards the motion of the probes (in loaded and unloaded environments), will allow one to better understand how ultrasonic scalers work. This may ultimately lead to aiding the design of more effective instruments for clinical use.

Acknowledgements

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