Ultrasonic Scaler Oscillations and Tooth-surface Defects
S.C. Lea, B. Felver, G. Landini and A.D. Walmsley
J DENT RES 2009 88: 229
DOI: 10.1177/0022034508330267

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What is This?
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INTRODUCTION

Dental ultrasonic scalers are used for the removal of plaque and calculus from tooth surfaces. A recent review has suggested that ultrasonic scalers produce clinical outcomes similar to those achieved with manual instruments (Walmsley et al., 2008). Ultrasonic scaler units are popular due to their ease of use, efficiency, and the various probe designs available for accessing different anatomical areas. The primary mechanism by which ultrasonic scaler systems remove adherent material on tooth surfaces is through the mechanical chipping action of the oscillating scaler probe when in contact with the tooth surface. However, the oscillating probe may also cause damage to the tooth surface, especially in areas where visibility is limited, and over-instrumentation may occur.

In vitro studies that assess the effect of power-driven instrumentation rely on either instrumentation of the tooth until it is deemed to be clean and smooth (Cross-Poline et al., 1995; Busslinger et al., 2001; Kawashima et al., 2007), or scaling of the tooth or root surface for a defined time or number of strokes (Flemmig et al., 1997, 1998a,b; Schmildlin et al., 2001; Folwaczny et al., 2004; Jepsen et al., 2004). Instrumentation of the tooth until it is clean or smooth is operator-dependent, and such studies do not accurately record the operational characteristics of the ultrasonic scalers (such as load and contact angles used). Over-instrumentation of the surface may be the end result in such studies, although this type of study is more clinically realistic.

Controlling the operating conditions to include contact loads, duration of instrumentation, and generator power setting will lead to improved standardization. Other factors, such as the amount of water flowing over the scaler probes to cool them during treatment (Lea et al., 2004), have a significant effect on probe performance (Lea et al., 2008) and should be factored into such measurements. Since there is no standardized method for evaluating root surface damage, debate has focused on which type of instrument, namely, magnetostrictive or piezoelectric, causes the greater amount of tooth damage. It is commonly suggested that magnetostrictive and piezoelectric instruments produce different modes of probe vibration. Piezoelectric probes are thought to be driven to oscillate in a primarily longitudinal manner, whereas magnetostrictive instruments are thought to have a more elliptical motion. However, recent research has suggested that both designs of instrument oscillate with a similar elliptical pattern (Lea et al., 2009). Laser vibrometry and metrology offer the opportunity to study tooth damage from ultrasonic scaling in a reproducible manner.

In this work, we aimed to investigate the degree of tooth damage caused by magnetostrictive (Slimline) and piezoelectric (P-style) ultrasonic scaler probes and relate it to an increased understanding of how the probes oscillate. Our null hypothesis states that tooth-surface defects, resulting from instrumentation with dental ultrasonic scalers, do not depend upon whether the scaler probe is magnetostrictive or piezoelectric.

ABSTRACT

Damage to tooth root surfaces may occur during ultrasonic cleaning with both piezoelectric and magnetostrictive ultrasonic scalers. It is unclear which mechanism causes more damage or how their mechanism of action leads to such damage. Our null hypothesis is that tooth-surface defect dimensions, resulting from instrumentation with ultrasonic scalers, are independent of whether the scaler probe is magnetostrictive or piezoelectric. Piezoelectric and magnetostrictive ultrasonic scaler probes were placed into contact against polished dentin samples (100 g/200 g). Resulting tooth surfaces were evaluated with a laser metrology system. Ultrasonic instrumentation produced an indentation directly related to the bodily movement of the probe as it made an impact on the surface. Load, generator power, and probe cross-section significantly affected probe vibration and defect depth/volume. Defect dimensions were independent of generator type. Magnetostrictive probes oscillated with greater displacement amplitudes than piezoelectric probes, but produced similar defects. This may be due to the cross-sectional shape of the probes.

KEY WORDS: periodontology, ultrasonic scaler, vibration, performance, laser vibrometry, laser profilometry, tooth-surface damage.

DOI: 10.1177/0022034508330267

Received July 15, 2008; Last revision September 22, 2008; Accepted November 24, 2008
and related to the resulting tooth-surface defects. The 3D vibration characteristics during instrumentation to be recorded with a laser vibrometer (Polytec GmbH, Waldbronn, Germany). This enabled vibration analysis of the scaler probes were performed with a PSV 400-3D laser vibrometer. Measurements were repeated for all power settings.

The load between the scaler probe and the tooth was then increased to 200 g, and the same procedure was repeated at high power. The load between the tooth surface and the scaler probe was approximately 10 degrees. The contact angle between the scaler probe and the tooth was increased to 200 g, and the load between the tooth surface and the scaler probe was approximately 10 degrees. The contact angle between the scaler probe and the tooth was increased to 200 g, and the load between the tooth surface and the scaler probe was approximately 10 degrees.

The output of the load cell was connected to a computer, which continuously recorded the load in one-second increments. The scaler probe and the tooth were brought into contact with each other until a load of 100 g was established. The contact angle between the tooth surface and the scaler probe was approximately 10 degrees. The tooth root was then instrumented for 10 sec at low power. This was repeated to produce 10 indentations for that load/generator power setting. The same procedure was repeated at high power. The load between the scaler probe and the tooth was then increased to 200 g, and the measurements were repeated for all power settings.

While in contact with the tooth surfaces, three-dimensional vibration analyses of the scaler probes were performed with a PSV 400-3D laser vibrometer. This enabled the 3D vibration characteristics during instrumentation to be recorded and related to the resulting tooth-surface defects.

**MATERIALS & METHODS**

To assess the tooth-surface defects produced following instrumentation with ultrasonic scalers, we prepared tooth samples in a manner similar to that used in a previous investigation (Jepsen et al., 2004). Extracted human molar teeth (collected with the donors’ informed consent and in accordance with UK guidelines on the use of human tissues) were washed and sterilized, and any soft tissue remnants were removed. The tooth crowns were removed with a bone saw, and the remaining of the teeth were hemisected to produce 2 dentin surfaces upon which instrumentation could be performed. The samples were cast in resin, leaving the cut surfaces exposed. Once the resin had set, teeth were ground with P800 followed by a finer P1200 paper and polished (1-μm diamond paper).

Three magnetostrictive scalers (Slimline) driven by a Cavitron Select SPS generator (Dentsply, York, PA, USA) and 3 piezoelectric (P) scalers driven by a miniMaster generator (EMS, Nyon, Switzerland) were selected (Fig. 1). The generators used are designed to drive the scaler probes with a nominal oscillation frequency of 30 kHz. The Cavitron unit has a dial to control power (with no incremental markings to indicate power or dial position), and so a voltmeter was connected across the generator power unit of the system, enabling the generator power settings to be relocated more precisely. The miniMaster ultrasonic generator has buttons which allow for accurate power selection and required no further modification. The water flow rate over both scalers was constant and required no further modification. Scaler probe oscillations comprise a series of nodes and antinodes along their length (Fig. 2).

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The first resin-embedded tooth sample was mounted next to the scaler tip in the load-measuring system, which included a Model 13 low-profile (1000 g) compression load cell. This load cell gave a voltage output which was directly proportional to the applied load. The output of the load cell was connected to a computer, which continuously recorded the load in one-second increments.

The scaler probe and the tooth were brought into contact with each other until a load of 100 g was established. The contact angle between the tooth surface and the scaler probe was approximately 10 degrees. The tooth root was then instrumented for 10 sec at low power. This was repeated to produce 10 indentations for that load/generator power setting. The same procedure was repeated at high power. The load between the scaler probe and the tooth was then increased to 200 g, and the measurements were repeated for all power settings.

While in contact with the tooth surfaces, three-dimensional vibration analyses of the scaler probes were performed with a PSV 400-3D laser vibrometer (Polytec GmbH, Waldbronn, Germany). This enabled the 3D vibration characteristics during instrumentation to be recorded and related to the resulting tooth-surface defects.

**RESULTS**

Vibration displacement amplitude data were recorded for all the probes operated under all operating conditions. Probe vibration displacement amplitude data were plotted as a function of position along the length of the scaler probe (Fig. 2a). In such graphs, positive and negative vibration displacement amplitudes relate simply to vibration toward (positive) and away from the camera of the laser vibrometer system. The zero displacement amplitude line (i.e., the x-axis) represents the position of the scaler probe in its unactivated state. Scaler probe oscillations comprise a series of nodes and antinodes along their length (Fig. 2).

The tooth-surface defects, caused by instrumentation with the ultrasonic scaler probes, were successfully evaluated by the laser metrology system (Figs. 2b, 2c). From the resulting images, the defect depth and volume were recorded and plotted as a function of the instrumentation conditions used (Fig. 2).

The maximum vibration displacement amplitude data were also plotted against the tooth surface defect data/operating parameter (Fig. 3).

Overall, magnetostrictive probes 1 and 2 produced significantly greater vibration displacement amplitudes than the piezoelectric probes (p < 0.0011). Magnetostrictive probe 3 showed no significant difference compared with any of the piezoelectric probes (p > 0.05). There were no significant differences in the vibrations of any of the piezoelectric probes tested (p = 1.000).

Magnetostriuctive probe 1 produced significantly deeper defect depths than magnetostrictive probe 2 (p = 0.002) and both piezoelectric probes 2 and 3 (p < 0.018), and also produced significantly greater defect volumes than all of the piezoelectric probes (p < 0.024). However, over the range of loads and powers tested, there was no significant difference in the defect depths produced by any of the other probes (p > 0.154), and no significant differences in any of the defect volumes (p > 0.153).

**Surface Defect Assessment**

A TuCaan Yxiris 4000 WL/CL 3D metrology system (TaiCaan Technologies Ltd., Southampton, UK) was used in “laser profilometry” mode for non-invasive evaluation of the tooth surface topography, following instrumentation. The system consists of a precision sensor in the Z-axis, with an XY-axes movable stage, allowing for scanning areas of up to 25 mm x 25 mm with a resolution of 100 nm in both the X and Y axes. The movable stage is mounted on a granite support structure, which provides vibration damping. The system’s laser spot size is 2 μm, and it has a resolution of 10 nm. In turn, each of the tooth samples was mounted on the stage of the profiler, and a standard scan area of 15 mm x 12 mm (resolution, 401 x 401 points) was centered over the central region of the sample with an integrated CCD camera microscope. Each scan took approximately 1 hr to perform.

**Statistical Analysis**

Data were analysed with SPSS v15.0 (SPSS, Chicago, IL, USA). The significance of variations in tip vibration displacement amplitude, defect depth, and defect volume under various load conditions and generator power settings was tested by univariate analysis of variance (General Linear Model) and multiple post hoc comparisons (Tukey test). Probability values smaller than 0.05 were considered statistically significant.
For a given load, increasing generator power significantly increased magnetostrictive probe defect depths \((p < 0.0001)\) and volumes \((p < 0.03)\), except for magnetostrictive probe 3 at 100 g \((p = 0.096)\). For the piezoelectric probes, increasing generator power significantly increased defect depth \((p < 0.0001)\) and volume \((p < 0.041)\). Increasing power was shown to increase all magnetostrictive and piezoelectric probe vibration displacement amplitudes significantly \((p < 0.0001)\).

Increasing load (at a given power setting) generally led to an increase in defect depth and volume, except for magnetostrictive probe 2 \((p > 0.172)\), magnetostrictive probe 1 at high power \((p > 0.685)\), or magnetostrictive probe 3 (defect volume, low power, \(p = 1.000)\). Increasing load significantly increased the defect depths and volumes for the piezoelectric probes \((p < 0.040)\), except piezoelectric probe 3 \((p = 1.000)\). Load significantly reduced the vibration displacement amplitude of magnetostrictive probe 3 \((p < 0.001)\). Load did not significantly affect any of the other probes’ vibration displacement amplitudes \((p > 0.211)\).

**DISCUSSION**

**The Defect Shape**

The nature of scaler probe oscillations, between the free end (or tip) of the probe and the first nodal point, is to ‘sweep out’ a triangular area. The tooth defects produced in this study were triangular or ‘tear-drop’-shaped when viewed orthogonally, but, when viewed in cross-section, this area was almost cone-shaped, deeper in its center, becoming shallower toward its periphery. This may be explained by considering the elliptical nature of the tip vibration at this point (unpublished observations).

**Defect Dimensions**

Over the range of loads and powers tested, there were no significant differences in the defect depths and volumes produced by any of the probes \((p > 0.153)\), except magnetostrictive probe 1, which produced significantly greater defect depths and volumes than the piezoelectric probes. Therefore, our null hypothesis (that tooth-surface defects, resulting from instrumentation with dental ultrasonic scalers, do not depend upon whether the scaler probe is magnetostrictive or piezoelectric) was accepted.

The defect depths and volumes for the 2 classes of instrument are demonstrated graphically and are related to the maximum displacement amplitudes of the probes. These results are interesting because, for probes of the same type, displacement amplitude is shown to correlate well with the defect depth and volume. Increases in probe vibration result in greater defect depths and volumes and *vice versa*. This occurred for both styles of probe (piezoelectric and magnetostrictive).

Comparisons between the different probe designs showed that this relationship was not true. The magnetostrictive probes generally showed greater vibration displacement amplitudes over the range of powers and loads tested, and yet there were almost no differences between the defect depths and volumes for the 2 classes of instrument are demonstrated graphically and are related to the maximum displacement amplitudes of the probes. These results are interesting because, for probes of the same type, displacement amplitude is shown to correlate well with the defect depth and volume. Increases in probe vibration result in greater defect depths and volumes and *vice versa*. This occurred for both styles of probe (piezoelectric and magnetostrictive).

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**Figure 2.** Relating the oscillations of the scaler probes to the tooth-surface defects. (a) Plotting the maximum vibration along the length of the scaler probes (values shown are the mean of 10 readings ± 1 standard deviation) demonstrates how the characteristic triangular defects observed on the tooth surfaces, following instrumentation with (b) magnetostrictive and (c) piezoelectric probes, are created. The scales provided in (b) and (c) indicate the height above or depth below the polished dentin surface ‘zero’ level (measured in millimeters).
and volumes produced by the piezoelectric and magnetostrictive probes. Since magnetostrictive and piezoelectric scaler probes oscillate in a similar elliptical fashion (unpublished observations), it might therefore be expected that the magnetostrictive probes would, at least theoretically, produce greater defect depths and volumes. This may not be the case, due to the actual shapes of the probes in cross-section. The piezoelectric probe has relatively flat sides and is close to rectangular in cross-section, with corners near its working edge. In comparison, the magnetostrictive probe is circular in cross-section, with rounded sides. It is suggested that the more rounded sides of the magnetostrictive probe therefore

Figure 3 (a-b). Maximum vibration displacement amplitudes of the magnetostrictive probes plotted as a function of instrumentation condition and plotted with (a) instrumentation defect depth and (b) instrumentation defect volumes (data shown are the average of 10 readings ± 1 standard deviation).
dug into the surface of the dentin less effectively than the piezoelectric probes. This resulted in both types of probe producing a similar degree of damage, despite the differences in vibration displacement amplitude.

Though the magnetostrictive instruments were shown on this occasion to produce the same degree of dentin damage, despite their larger vibrations, this is not to suggest that the magnetostrictive instrument is a better device, since it is less likely to damage tooth surfaces. These results may also imply that, in the case of calculus removal, piezoelectric probes remove as much material as magnetostrictive probes, but with less vibration magnitude. This obviously warrants further investigation, since the

Figure 3 (c-d). Maximum vibration displacement amplitudes of the piezoelectric probes plotted as a function of instrumentation condition and plotted with (c) instrumentation defect depth and (d) instrumentation defect volumes [data shown are the average of 10 readings ± 1 standard deviation].
results observed on these polished dentin surfaces may not necessarily directly translate to the removal process for calculus.

The results of this work may also be used to explain why so many studies have produced conflicting results on the subject of which type of instrument (magnetostrictive or piezoelectric) produces more tooth-surface alteration or damage. A similar study evaluated tooth-surface defects following instrumentation by 4 different designs of ultrasonic scaler probes: magnetostrictive (Slimline and TFI-10) and piezoelectric (P and A) (Jepsen et al., 2004). This study had well-controlled parameters, such as load and generator power. It concluded that the magnetostrictive inserts used resulted in both the least damage (Slimline) and the greatest damage (TFI-10) in terms of both defect depth and volume. However, during the course of this study, only one probe of each design was investigated, and, therefore, the study did not take into account the variability between probes that has been observed in this present study or in previous studies (Lea et al., 2003a,b, 2006, 2009).

In this current investigation, if magnetostrictive probe 1 alone had been investigated against any of the piezoelectric probes, the conclusions of this study would have been that magnetostrictive probes oscillate with greater vibration displacement amplitude and cause significantly greater defect depths and volumes than piezoelectric probes. Using more than one sample probe in an investigation is something which is commonly overlooked (Jotikasthira et al., 1992; Flemming et al., 1998a,b; Khosravi et al., 2004; Sato et al., 2004; Rühling et al., 2005; Kawashima et al., 2007) and should be considered in any future investigations. Whether the variability observed between tips has clinical significance is still to be ascertained, but should be factored into future in vitro and in vivo studies.

Load was shown to have a significant effect on magnetostrictive probe 3, the only probe whose vibration displacement amplitude was significantly decreased when the load was increased from 100 g to 200 g. Again, if this had been the sole magnetostrictive instrument evaluated, the study’s conclusions would have been very different. The loads used were selected to be similar to those both used in other root-surface investigations (Flemming et al., 1998a,b; Busslinger et al., 2001) and commonly used in other laser vibrometry investigations.

In normal usage, an ultrasonic scaler would be expected to be in contact with either enamel (supra-gingivally) or cementum (sub-gingivally) rather than dentin. Dentin was used in the current study, since it is slightly softer than the other surfaces previously mentioned and therefore more likely to make a usable defect which we could measure. It was also used so that our results would be more comparable with those of another study (Jepsen et al., 2004) that also utilized polished dentin surfaces, thereby facilitating better inter-study comparisons. Further work to investigate the effect of powered instrumentation on cementum surfaces would be of merit.

Despite magnetostrictive probes oscillating with greater displacement amplitudes than piezoelectric probes, there were few differences in the resulting defect depths and volumes. Since both have been shown to oscillate in a similar elliptical pattern, the cause may be due to the cross-sectional shape of the probes. Power and load had a significant effect on probe vibration and on the resulting defect depth/volume. This effect was independent of generator type (magnetostrictive or piezoelectric). The scaler probe oscillation patterns were successfully used to account for the shape of the defect resulting from tooth instrumentation.

ACKNOWLEDGMENT

This work was funded by a research grant from the UK EPSRC (No. GR/T22551/01).

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