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Three-dimensional analyses of ultrasonic scaler oscillations

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Abstract

Background: It is stated that the oscillation patterns of dental ultrasonic scalers are dependent upon whether the instrument is of a magnetostrictive or piezoelectric design. These patterns are then linked to differences in root surface debridement in vitro.

Material and Methods: Piezoelectric (A, P) and magnetostrictive (Slimline, TFI-3) ultrasonic scalers (three of each) were evaluated, loaded (100 g/200 g) and unloaded with a 3D laser vibrometer. Loads were applied to the probe tips via teeth mounted in a load-measuring device.

Results: Elliptical motion was demonstrated for all probes under loaded and unloaded conditions. Loading flattened the elliptical motion along the length of the probe. Unloaded, Slimline tip 1 was significantly different to tips 2 and 3 ($p<0.0001$). There were no differences between the A-tips ($p>0.207$). All TFI-3 tips were different to each other ($p<0.0001$). P-tips 1 and 2 were different to each other ($p=0.046$). Loaded, Slimline tips were different to each other ($p<0.001$). There were no differences between the P probes ($p>0.867$). Generator power increased all Slimline and P tip vibrations ($p<0.0001$).

Conclusions: Probe oscillation patterns are independent of ultrasound production mechanism and are dependent upon probe shape and generator power. Loaded probes oscillated with an elliptical pattern.

Key words: performance; periodontology; ultrasonic scaler; vibration

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Introduction

An evaluation of the oscillations of powered instruments used in dentistry has been performed previously using the detection of light reflected from an oscillating tip. This technique was used to evaluate the longitudinal vibrations of ultrasonic scalers (Walmsley et al. 1986) as well as to investigate the oscillations of sonic scalers (Gankerseer & Walmsley 1987, Kocher & Plagmann 1997). More recently, the oscillations of dental ultrasonic scaler probes have been measured using scanning laser vibrometry. This technique provides a more detailed insight into the ways in which ultrasonic probes oscillate than was possible using the reflection of light and has demonstrated that the oscillations of scaler probes are variable (Lea et al. 2003a, b). This variability can occur whether the probes oscillate freely (in air) or, more importantly, when contacting a surface under simulated clinical loading.

Previous assessment of probe performance has been performed primarily in a single plane along the longitudinal axis of the scaler instrument (Lea et al. 2003a, b, 2004, 2006). However, probe motion is liable to be more complex and will comprise some lateral motion. During correct usage, it is this lateral vibration that impacts into the tooth surface removing deposits and potentially damaging tooth surfaces.

Many articles state that scaler probes driven by piezoelectricity have a longitudinal oscillation with little or no lateral motion and that magnetostrictive instruments produce elliptical probe motion (Flemmig et al. 1998, Drisko et al. 2000, Oda et al. 2000, Sato et al. 2004, Arabaci et al. 2006, Guentsch & Preshaw 2008). The differences in oscillation patterns between the two classes of instrument (magnetostrictive and piezoelectric) are then linked to differences in root surface debridement in vitro.

Laser vibrometry has made evaluating the oscillation characteristics of ultrasonic scaler probes a rapid process, providing a more detailed understanding of the way in which factors such as load and wear affect scaler vibrations and performance (Lea et al. 2003b, 2006). The introduction of a three-dimensional (3D) scanning laser vibrometer enables the simultaneous evaluation of ultrasonic probe motion in both the longitudinal and lateral axes.

The aim of this study was to analyse, using 3D laser vibrometry, the vibration

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characteristics of a range of dental ultrasonic scaler probes, driven by magnetostrictive and piezoelectric mechanisms.

Material and Methods

The following ultrasonic scaler systems were selected for this study (Table 1). For each system, two different styles of scaler probe were selected, including the P and A style probes for the piezoelectric generators and the TFI-3 and Slimline instruments for the magnetostrictive generators. Three of each probe design were used. The scaler ''probe'' and ''tip'' are defined (Table 1) for clarification

The analysis of scaler probe motion was initially performed under unloaded conditions. Subsequently, the P and Slimline instruments were selected for further evaluation under simulated clinical loading. These probes were specifically chosen for their universal use (sub and supragingival application), their popularity amongst clinicians as well as being the best selling instruments of both manufacturers.

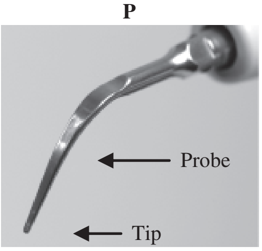
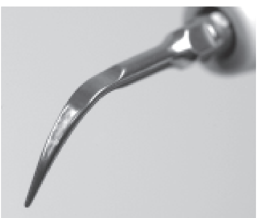
Unloaded measurements

The 3D vibration analyses of the scaler probes were performed using a PSV 400-3D laser vibrometer (Polytec GmbH, Waldbronn, Germany). This system enabled probe vibrations in the longitudinal and lateral planes to be performed simultaneously.

In turn, each scaler was fixed in place, such that its probe was vertical and clearly visible to the three cameras of the laser vibrometer system. A measurement grid was superimposed over the image of the scaler probe (as viewed on the vibrometer screen). This was used to guide the system's lasers over the probe surface. Generator power settings were set to either low or high and the scaler probe operated. Vibrometer scans were performed on the oscillating probes, for all combinations of generator, power and probe design. For each probe design/generator power setting combination, 10 repeat vibrometer measurement scans were performed.

The power control dial of the SPS Select ultrasound generator (EMS, Nyon, Switzerland) does not enable accurate relocation of the power setting between measurements. Therefore, a voltmeter was attached to the power output of the SPS Select generator. The voltage output ranged between 0.03 V (low power) to 10.10 V (high power) and these were the voltages used to indicate low and high power during the investigation. The MiniMaster generator (Dentsply, York, USA) had button controls for power setting and required no further modification. Throughout the investigation, a constant water flow rate of 20 ml/min. was utilized.

Table 1. The ultrasonic systems used in the present study

Scaler probe design	Details
P 	Piezoelectric 30 kHz MiniMaster generator *Manufactured by*: EMS, Nyon, Switzerland
A 	
Slimline (FSI-SLI-10S) 	Magnetostrictive 30 kHz SPS Select generator *Manufactured by*: Dentsply, York, USA
TFI-3 	

Tips were selected to enable the effect of tip shape on vibration pattern to be evaluated.

Loaded measurements

Tooth preparation

Molar teeth were washed and any soft tissue remnants removed. The tooth crowns were then removed using a bone saw and the remainders of the teeth hemisected to produce two surfaces for instrumentation. Alcohol was used to dehydrate any remaining water and eliminate any bacteria before setting the samples in resin such that the cut surface of each tooth half was at the surface of the sample. Once the resin had set, P800 silicone carbide grinding paper was used to expose the dentine surface, followed by a finer P1200 paper and finally the samples were polished.

Resin-embedded tooth samples were mounted next to the scaler probes in a load-measuring system, which included a Model 13 low profile (1,000 g) compression load cell (Sensotec, Columbus, OH, USA). 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 that continuously recorded and logged the load in 1 s 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° and contact was made at the free end (final 1 mm) of the oscillating probe. The tooth root was then instrumented for 10 s at low power (0.03 V). The same procedure was repeated at high power (10.10 V). The load between the scaler probe and the tooth was then increased to 200 g and the measurements repeated for all power settings.

The ''true'' scaler probe maximum vibration displacement amplitudes (*D*) were calculated, by the computer system, from the lateral (*X*) and longitudinal (*Z*) vibration displacement amplitudes, using the formula:

$$D = \sqrt{X^2 + Z^2} \qquad (1)$$

where *X* is the lateral vibration displacement amplitude of the scaler probe and *Z* is the longitudinal vibration displacement amplitude. Values for true displacement amplitude, *D*, were determined for all scaler probes under all power and load-operating conditions.

Statistical analysis

Data were analysed using SPSS 12.0 for Windows (SPSS Inc., Chicago, IL, USA). The significance of variation in true tip displacement amplitude, *D*, under various load conditions and generator power settings was tested using univariate analysis of variance (ANOVA) (General Linear Model) and using multiple post hoc comparisons (Tukey test) at a significance level of $p<0.05$, with the dependent variable being displacement amplitude.

Results

Plots were produced to demonstrate the vibration patterns which occurred at the free, unconstrained end of the ultrasonic scaler probes (Fig. 1). These were produced by analysing the displacement amplitude values at the tip of the instrument at various phases of the scaler probes oscillation cycle (20° phase increments).

To investigate the effect of load (100 and 200 g) on the oscillations of the probes, the P and Slimline instruments were investigated further. Plots of probe vibration were again produced for the tip of the instruments (Fig. 2).

Vibration data along the length of the probes were investigated under unloaded and loaded conditions for the Slimline and P-tips (Fig. 3).

Unloaded instruments

The 3D vibration displacement amplitude values for all unloaded scalers were plotted (Fig. 4). There were no significant differences between Slimline tips 2 and 3 ($p = 0.908$), but tip 1 was significantly different to both tips 2 and 3 ($p<0.0001$). There were no significant differences between the A-tips ($p>0.207$). All TFI-3 tips were different to each other ($p<0.0001$). P-tips 1 and 2 were significantly different to each other ($p = 0.046$), although there were no differences between tips 1 and 3 or tips 2 and 3 ($p>0.300$).

Increasing generator power from low to high significantly increased the displacement amplitude for all instruments tested ($p<0.0001$).

Loaded instruments

The 3D vibration displacement amplitude values for both loaded scalers were plotted (Fig. 5). Considering all power (low and high) and load (unloaded, 100 and 200 g) combinations, the Slimline probes all produced significantly different vibration displacement amplitudes to each other ($p<0.001$). Conversely,

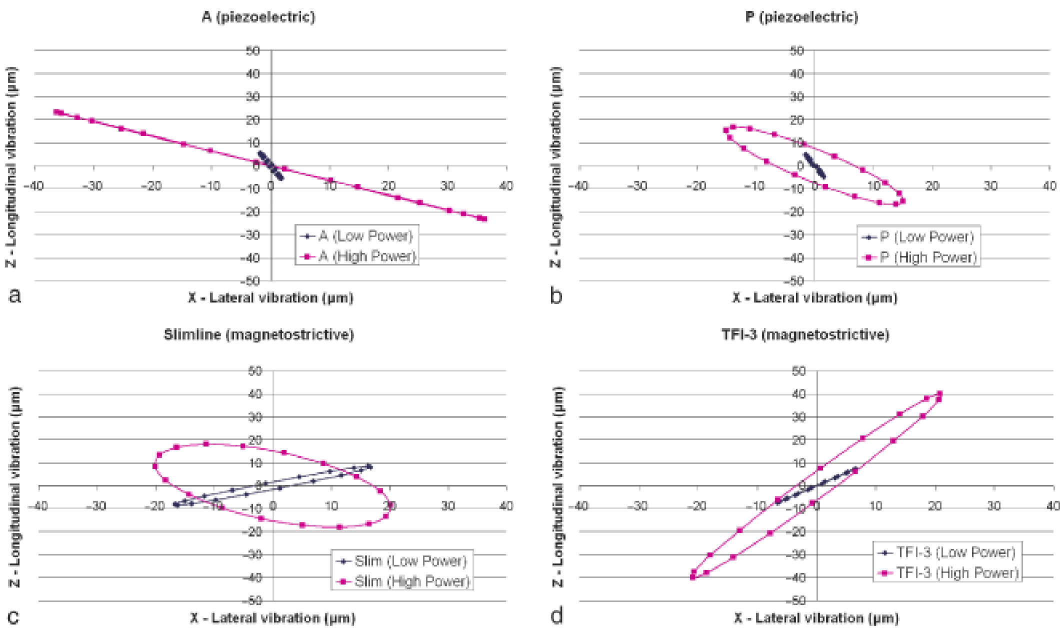


Fig. 1. Plots showing the typical probe vibration patterns (at the unconstrained tip) of different designs of ultrasonic scaler probes, unloaded, under high and low generator power settings. For all probe designs, the elliptical nature of the probe oscillation is revealed. Instruments investigated include (a) A and (b) P style probes (piezoelectric driven) and (c) Slimline and (d) TFI-3 (magnetostrictive driven). Axes show probe displacement amplitudes (measured in μm).

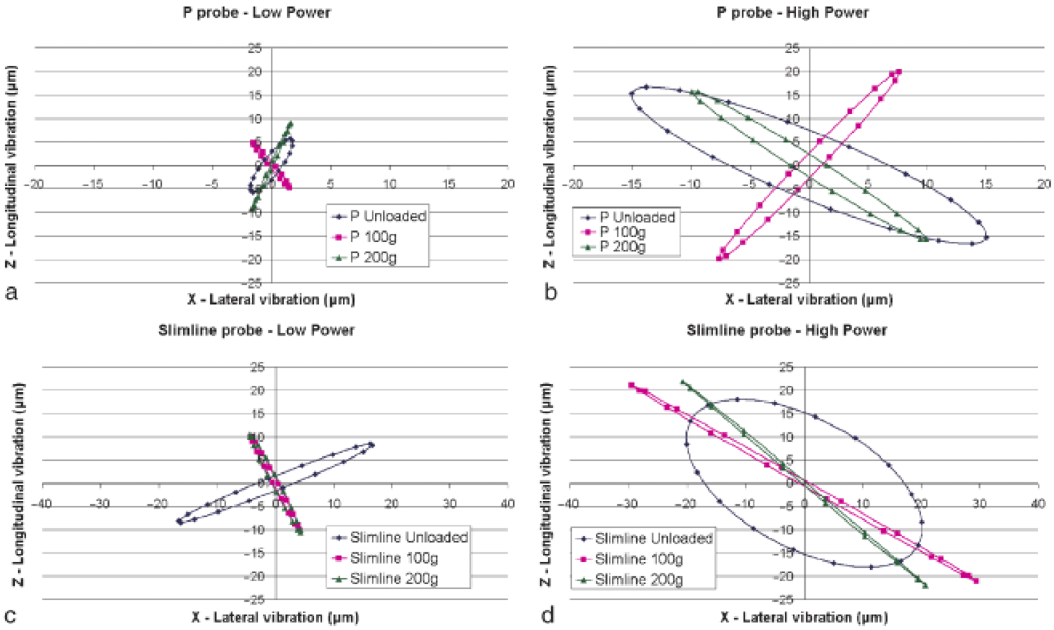


Fig. 2. Typical vibration patterns of loaded and unloaded P and Slimline probes (high and low generator powers). Both probe designs demonstrate elliptical motion under load. Plots show P probe at (a) low power and (b) high power and Slimline probe at (c) low power and (d) high power. Axes show probe displacement amplitudes (measured inμm).

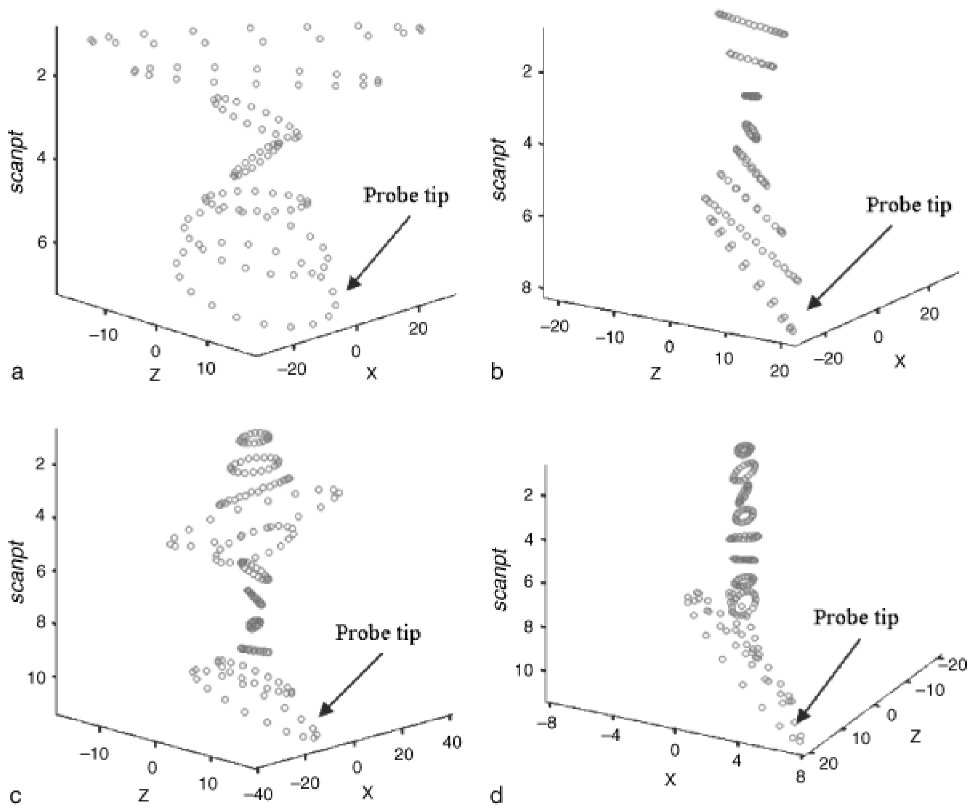


Fig. 3. Three-dimensional vibration profiles plotted for a Slimline (a) unloaded and (b) 100 g load and a P probe under (c) unloaded and (d) 100 g load-operating conditions. For each chart, the lowest ellipse depicts the oscillation pattern observed at the free end or tip of the scaler probe.

there were no significant differences between any of the P probes ($p > 0.867$).

Generator power had a significant effect (for a given load), with increases in power significantly increasing all Slimline and P probe vibration displacement amplitudes ($p < 0.0001$). Load had less of an effect on probe vibration displacement amplitude than generator power. Increasing load from 100 to 200 g only affected the vibration displacement amplitude of Slimline probe 3

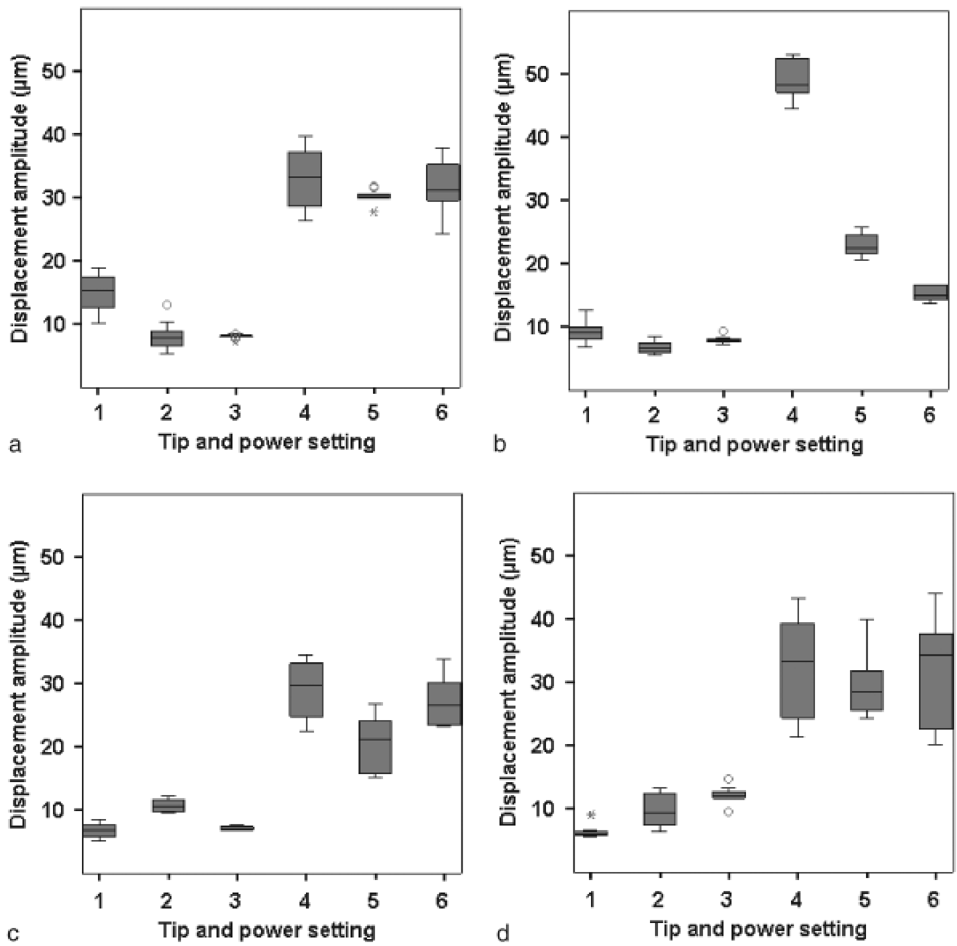


Fig. 4. Three-dimensional or true displacement amplitudes for all unloaded scalers were plotted, at both low and high power settings, for (a) Slimline, (b) TFI-3, (c) P and (d) A probes. Each *X*-axis increment represents a probe and its power setting where increments 1, 2 and 3 are probes 1, 2 and 3 at low power and increments 4, 5 and 6 are tips 1, 2 and 3 at high power (respectively).

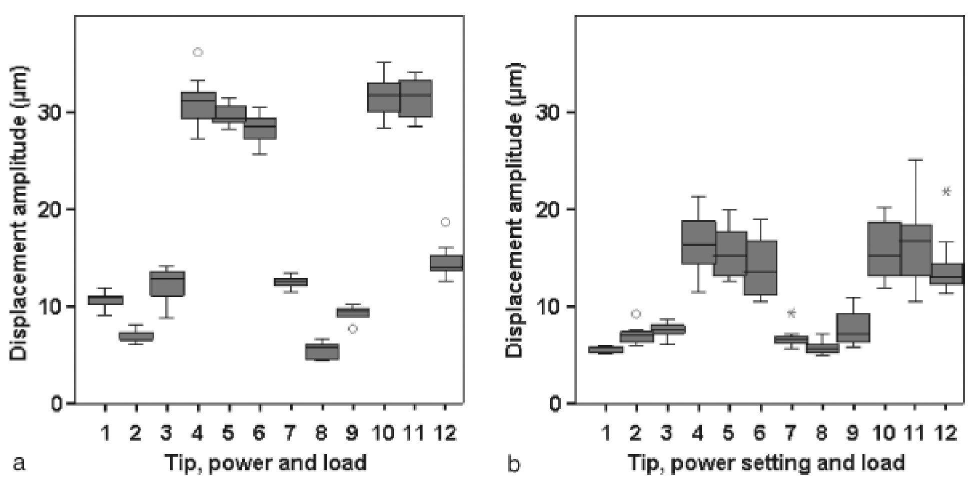


Fig. 5. Three-dimensional or true displacement amplitudes for both the Slimline and P scalers, under loaded conditions and at both low and high power settings, were plotted including (a) Slimline and (b) P probes. Each *X*-axis increment represents a probe, its power setting and the load applied. Increments 1, 2 and 3 are probes 1, 2 and 3 at low power (100 g) and increments 4, 5 and 6 are tips 1, 2 and 3 (respectively) at high power (100 g). Increments 7, 8 and 9 are probes 1, 2 and 3 at low power (200 g) and increments 10, 11 and 12 are tips 1, 2 and 3 (respectively) at high power (200 g).

($p < 0.001$). Load did not, for a given generator power setting, significantly affect any of the other tips' vibration displacement amplitudes ($p > 0.211$).

Discussion

All unloaded ultrasonic scaler probes were found to oscillate in an elliptical manner, but different designs showed variation in the magnitude of the lateral component. The vibration data demonstrate that the pattern of motion at the free end (or tip) of an ultrasonic scaler probe is not dependent upon whether the instrument is magnetostrictive or piezoelectric (Fig. 1). Rather, the pattern of motion depends upon the generator power driving the vibration and the shape or physical dimensions of the probe.

At low generator power, the shorter and broader TFI-3 (magnetostrictive) and A (piezoelectric) probes both produced near-linear (but still elliptical) oscillations. The longer, slimmer probes (particularly the Slimline) demonstrated a greater degree of elliptical motion. At full generator power, the increase in the elliptical motion was greatest for the longer, thinner Slimline and P probes (Fig. 1) that are less rigid and more susceptible to lateral motion.

The elliptical nature of the vibrations was observed along the length of the Slimline and P probes (Fig. 3a–d). Under loaded conditions, the Slimline and P probes still oscillated with elliptical patterns at their free ends, though this was flattened compared with the unloaded condition, that is there was a reduction in the magnitude of the minor axis (Fig. 2). This reduction was seen along the entire length of the probes (Fig. 3a–d). Along the length of the unloaded probes, the major axes of the ellipses vary in orientation (Fig. 3a and c). This is demonstrated at the tip of the probe where the major axis is oriented differently to further up the probe. Applying load to the probe tip realigned the major axes of oscillation along the length of the probe towards the same direction as the probe tip. Applying a scaler probe to a root surface alters the ''bodily'' motion of the probe and may increase the stability of its vibration by reducing the lateral motion (Figs 2 and 3). Application of load at the tip of a probe, therefore, not only affects the vibrations at that point but also modifies the vibrations along the length of the whole probe (Fig. 3a–d).

This work also highlighted the variability in the vibration characteristics of scaler probes that are nominally of the same design. This has been observed previously (Lea et al. 2003a, b) although reasons for such variability have not been proposed. Although it could be argued that some degree of variability arises through the process of loading the probes, differences in vibration are observed when they are operated in an unloaded environment. There may be voltage fluctuations that lead to corresponding increases/decreases in the vibrations of the tips but this was never observed during the testing. Other relevant factors may be the tolerances in the insert/probe production processes. For instance, the amounts of solder used on the internal stack structure of magnetostrictive inserts can vary considerably both in the volume of material used and how it spreads along the stack. Variability in the behaviour of piezoelectric probes may arise through how tight they are screwed into position in the handpiece. All these factors may result in the differences observed in the use of the instrument. Such potential problems (and their clinical significance, if any) should be included in future in vitro and in vivo studies to enable greater inter-study comparisons (Walmsley et al. 2008).

The mechanism of driving scaler probe oscillations (magnetostriction or piezoelectricity) is not the determining factor regarding how a probe will oscillate. The primary factors are the generator power setting and the shape of the scaler probe, with high generator powers and longer, slimmer probe designs more likely to produce increased elliptical vibrations than shorter, broader probes operated at low generator power.

Slimline and P probes both showed elliptical behaviour, even under load. This is contrary to some of the current thinking, where it is suggested that a probe driven by a piezoelectric mechanism is more likely to produce non-elliptical oscillations (Flemmig et al. 1998, Drisko et al. 2000, Oda et al. 2000, Sato et al. 2004, Arabaci et al. 2006). Differences in observed tooth surface defects following instrumentation have been attributed to one type of instrument oscillating in a different manner to another (Flemmig et al. 1998, Rühling & Kocher 2005, Kawashima et al. 2007). It is suggested that magnetostrictive instruments produce a more elliptical motion which is therefore more likely to damage tooth surfaces than a piezoelectric instrument.

Previous evaluation of the 3D motion of ultrasonic scaler tips has been limited and the data produced in this study is in contrast to the result of previous studies (Jacobson et al. 1994). The magnitude of the vibrations observed by Jacobson et al. (1994) was significantly greater, with longitudinal oscillation amplitudes between 75 and 119 μm at medium generator power settings. In this study we rarely measured vibrations exceeding 50μm, even at high generator power settings. We also observed elliptical motion for all tip designs whereas Jacobson et al. detected no lateral motion for the piezoelectric probes. It should be noted that, as there is no evidence to suggest otherwise, Jacobson et al. appear to base their linear *versus* elliptical claims upon one measurement performed once for one of each type of tip (there is no mention of repeat readings and there are no standard deviation data provided).

For clinicians, this work demonstrates that the type of generator mechanism (magnetostrictive or piezoelectric) does not affect the pattern of oscillation of the ultrasonic probe. What will have more of a potential influence on the clinical result is the shape and design of the probe, which has been shown previously to affect root surfaces (Jepsen et al. 2004). Future studies should consider this aspect of the ultrasonic scaler as a factor affecting tooth surface defects.

The slimmer designs of instrument (P and Slimline) are commonly used clinically for subgingival debridement as well as for supragingival. Probe constraint in a periodontal pocket may also modify probe oscillation characteristics and this merits further investigation.

Conclusions

All designs and types of ultrasonic scaler probes tested oscillate with an elliptical motion, however, some have a more pronounced elliptical pattern than others. Loading a scaler probe against a tooth surface still resulted in elliptical probe motion for both the magnetostrictive Slimline instrument and the piezoelectric P tip.

The results of this study confirm that probe oscillation pattern depends primarily upon the shape/design of the probe and the generator power setting is operated at. Oscillation pattern is not dependent upon whether the system used is magnetostrictive or piezoelectric.

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Clinical Relevance

Scientific rationale for the study: Investigations to evaluate the effects of ultrasonic instruments on tooth surfaces often consider whether the scaler is magnetostrictive or piezoelectric and relate this to the resulting tooth surface.
Principal findings: The motion of the working scaler probe is more dependent upon generator power setting and the shape of the probe body. Longer, slimmer probes are more prone to elliptical motion, especially at higher powers.
Practical implications: All scaler probes oscillate with an elliptical motion which may affect calculus removal and resulting tooth surface morphology.