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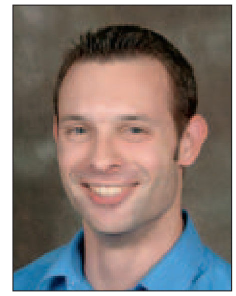
The effect of water flow rate on ultrasonic scaler performance: *in vitro* evaluation



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KEY WORDS *performance, periodontology, ultrasonic scaler, vibration*

Introduction: Applying load to an ultrasonic scaler tip can affect its vibrations. Cooling water flowing over such tips will also act as a load – though this is rarely considered in *in vitro* research investigations. The aim of this study was to determine the effect of water flow rate on ultrasonic scaler vibration.
Study design: The vibration displacement amplitude of three designs of scaler insert, including a Slimline tip, TFI-10 and TFI-3 (Dentsply, USA), were assessed unloaded and under 0.50 N and 1.00 N load and with water flow rates of 20 ml/min and 40 ml/min. Vibration analysis was performed using a scanning laser vibrometer.
Results: Increasing water flow rate from 20 ml/min to 40 ml/min caused a significant decrease ($p < 0.0001$) in all tip vibrations. Increasing water from 20 ml/min to 40 ml/min with the unloaded Slimline tip is equivalent to applying a 1.00 N load, and for the TFI-10 tip is equivalent to applying a 0.50 N load *in vitro*.
Conclusions: Water flow rate has a significant influence on scaler tip vibration characteristics and is particularly important for lighter, thinner tips such as the Slimline design. Future *in vitro* research must consider the loading effect that water flow over ultrasonic scaler tips will have on their performance.

■ Introduction

Since ultrasonic scalers were first introduced in the 1950s, many *in vitro* investigations have been performed to assess their operational characteristics. The effects of contact load, angulation and probe design on tooth and root surfaces following instrumentation, for magnetostrictive and piezoelectric scaler systems, have been investigated in great detail[1–5]. In these studies it was shown that such physical factors can have a significant effect on the resulting tooth surface.

Work has also shown that generator power and the load applied between the scaler tip and the tooth surface affect the scaler probe's performance[6,7]. Alterations in probe length, possibly due to a process

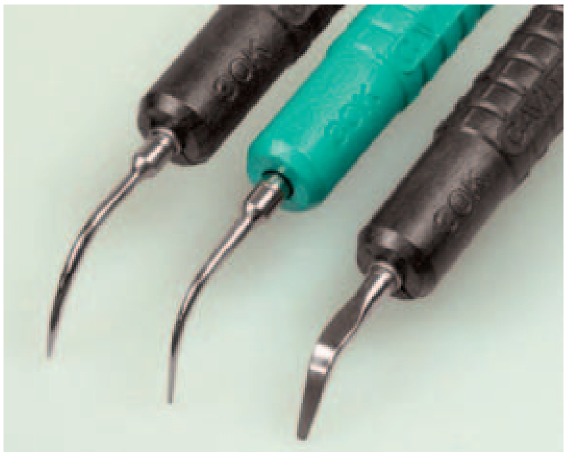

Fig 1 Left to right: TFI-10, FSI-SLI-10S 'Slimline' and TFI-3 tips used throughout the investigation.

of wear through long-term clinical use, has also been shown to affect scaler tip vibrations[8]. Since the primary cleaning mechanism of the majority of ultrasonic scalers is the chipping action as the probe oscillates over the tooth surface, any alteration in their vibration characteristics may potentially alter clinical performance.

These studies have demonstrated that the magnitude of the effect is dependent not only on the magnitude of the applied external factor, but also upon the shape and style of the tip being used and the manner in which it is applied to the tooth surface[1-8].

Physical factors such as ultrasonic scaler tip/tooth contact load, tip angulation, duration of use and generator power setting are recorded with accuracy when assessing the resulting effects on tooth surface morphology. However, a physical factor that is commonly overlooked in ultrasonics research is the effect of the cooling water as it flows over the tip of the instrument.

The aim of the present study was, therefore, to ascertain how water flow rate affects dental ultrasonic scaler vibrations and to determine whether this effect is dependent upon the design of the tip. The null hypothesis is that water flowing over the tip of an ultrasonic scaler does not affect its vibration characteristics.

Study design

Three designs of scaler insert were utilised during this investigation (Fig 1), including a FSI-SLI-10S 'Slimline', a TFI-10 and a TFI-3 (Dentsply, York, PA, USA). All inserts were used in conjunction with a Cavitron SPS generator (Dentsply, York, PA, USA). Vibration displacement amplitude measurements were performed using a scanning laser vibrometer (SLV) (model PSV-300-F/S High Frequency Scanning Vibrometer System, Polytec, Waldbronn, Germany) as described previously[9].

Unloaded scaler evaluation

The first scaler insert was fixed with the front aspect of the tip facing the camera of the SLV and a measurement point superimposed over the video image of the scaler probe, at the unconstrained tip of the instrument.

The ultrasound generator was set to medium power. This was established by monitoring, with a voltmeter, the variation in voltage as the power dial was adjusted. Voltage values ranged, on a linear basis, between 0.1 V (minimum power) and 10.04 V (maximum power). Medium power was therefore determined to be at 5.02 V and the power control knob was adjusted until this value was obtained. Water flow over the tip was measured and adjusted until a flow rate of 20 ml/min was achieved. Ten repeat vibration scans were then performed. The water flow rate was then increased to 40 ml/min and vibration measurements repeated.

Loaded scaler evaluation

The scaler tip was allowed to make contact against a tooth surface *in vitro*. This consisted of extracted molars partially embedded in resin (Orthoresin, Dentsply, Surrey, UK) such that one root aspect was left exposed to allow instrumentation. The resin block was then fixed to a mount on a Model 31 (1,000 g) tension/compression load cell (Sensotec, Columbus, Ohio, USA) connected to an E725 Microprocessor-based Transducer Indicator/Controller. The load cell enables loads to be measured with an accuracy of ± 0.01 N. Vibration displacement amplitude measurements for tip/tooth contact loads of 0.50 N and 1.00 N, in conjunction with water flow rates of 20 ml/min and 40ml/min, were performed (10 repeats per measurement condition). The whole procedure was then repeated for the remaining two tip designs.

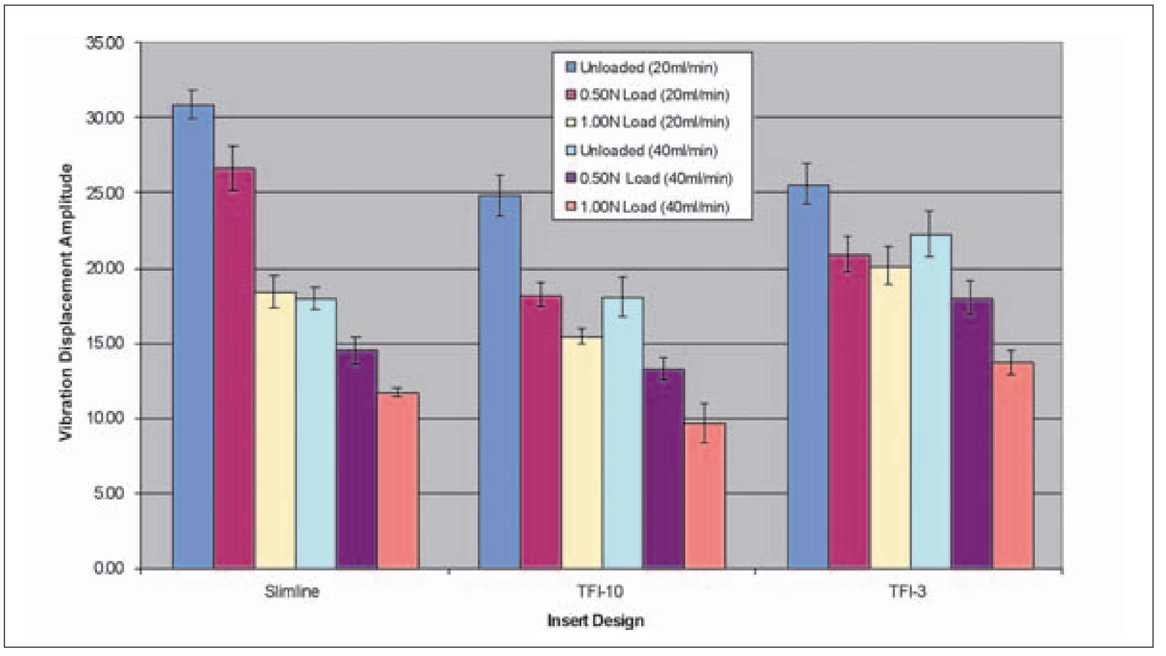

Fig 2 Average maximum vibration displacement amplitude (micrometres) and standard deviation of all scaler insert designs at each load/water flow rate combination.

Statistical analysis

Data were analysed using SPSS v12.0 (SPSS, Chicago, IL, USA). The significance of variation in tip displacement amplitude, for different water flow rates under various load conditions, was tested using univariate analysis of variance (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

The average maximum vibration displacement amplitude and standard deviation of the scaler tips were calculated and recorded (Fig 2).

For all tips, under all load conditions (unloaded, 0.50 N and 1.00N), an increase in water flow rate from 20 ml/min to 40 ml/min significantly reduced the tip vibration displacement amplitude ($p < 0.0001$). The magnitudes of these decreases are provided in Table 1.

For a given water flow rate, an increase in load (from unloaded to 0.50 N, unloaded to 1.00 N and 0.50 N to 1.00 N) was also shown to significantly reduce tip vibration displacement amplitude ($p < 0.0001$) except for the TFI-3 insert where, at 20 ml/min water flow rate, an increase in load from 0.50N to 1.00N caused no significant change in vibration displacement amplitude ($p = 0.768$). The magnitudes of these decreases are provided in Table 2.

Tip design	Unloaded	0.50 N	1.00 N
	20ml to 40ml	20ml to 40ml	20ml to 40ml
Slimline	41.8% *	45.5% *	36.3% *
TFI-10	27.2% *	27.2% *	37.4% *
TFI-3	13.0% *	14.0% *	32.0% *

** Indicates that the difference was significant at the p = 0.05 level (tested using univariate analysis of variance, General Linear Model).*

Table 1 Percentage decrease in tip vibration displacement amplitude due to increasing water flow rate under all load conditions.

Table 2 Percentage decrease in tip vibration displacement amplitude due to increasing load when used at constant water flow rates of 20 ml/min or 40 ml/min.

Tip design	20 ml/min			40 ml/min		
	Unloaded to 0.50 N	Unloaded to 1.00 N	0.50 N to 1.00 N	Unloaded to 0.50 N	Unloaded to 1.00 N	0.50 N to 1.00 N
Slimline	13.6% *	40.4% *	31.0% *	19.0% *	34.7% *	19.3% *
TFI-10	26.7% *	37.7% *	15.1% *	26.7% *	46.5% *	27.0% *
TFI-3	18.4% *	21.3% *	3.5%	19.4% *	38.5% *	23.7% *

** Indicates that the difference was significant at the p = 0.05 level (tested using univariate analysis of variance, General Linear Model)*

■ Discussion

In vitro investigations have assessed, in detail, the effects of instrumentation parameters such as contact load, tip angulation, instrumentation time, ultrasound generation type (magnetostriction and piezoelectricity) and generator power setting on the instrument vibrations and the resulting tooth surface damage[1-8,10]. However, many did not accurately record the amount of water flowing over the instruments. Several papers reported that water cooling was used, but used non-specific terms such as 'profuse water irrigation'[1,2], 'copious water flow'[11], 'constant irrigation'[12] and 'under water-cooling, where the Cavitron device had internal cooling, and the piezoelectric ultrasonic inserts had to be cooled with an external water source from a 3-in-1 spray from a dental unit'[3].

The results of this study have shown that the amount of water flowing over an ultrasonic scaler insert may significantly reduce its vibration displacement amplitude. Therefore the null hypothesis was rejected.

Water loading was observed to preferentially affect the thinner, lighter tips, such as the Slimline design. Thin tips have been shown previously to be affected by external loads more than larger heavier tips[7,13].

The use of 20 ml/min and 40 ml/min water flow rates was not based on previous investigations as no standard flow rate appears to have been agreed. However, literature provided by Dentsply suggests 'Lavage Control knob [should be adjusted] to ensure adequate flow for the selected power setting. Greater flow settings provide cooler irrigant' [14]. Water flow rates of both 20 ml/min and 40 ml/min resulted in a steady stream of water over the tips of the instruments at the generator power setting used and so these were the water flow rates adopted for this study. Flow rates of 20 ml/min and 40 ml/min were also used to represent 'constant irrigation' and 'under water-cooling' (20 ml/min), and 'profuse water irrigation' and 'copious water flow' (40 ml/min) as has previously been described in other investigations[1–3,11,12].

■ Estimation of water's equivalent load damping

The loads of 0.50 N and 1.00 N adopted in the present study were selected to represent the loads utilised in other similar *in vitro* investigations[1,2,7,8]. From the acquired data (Fig 2), the vibration displacement amplitude of an unloaded Slimline tip with a water flow rate of 40 ml/min is not significantly different to the same tip operated with a water flow rate of 20 ml/min in conjunction with a 1.00N load (p = 0.903). This suggests that for an unloaded Slimline tip operated with 20 ml/min water, increasing the water flow rate from 20 ml/min to 40 ml/min is equivalent to the damping observed when applying a load of 1.00 N.

Similarly, the data (Fig 2) show that the vibration displacement amplitude of an unloaded TFI-10 scaler tip with a water flow rate of 40 ml/min is not significantly different (p = 1.000) from the same tip operated with a water flow rate of 20 ml/min in conjunction with a 0.50 N load. This indicates that for an unloaded TFI-10 tip with 20 ml/min water, an increase in water flow rate from 20 ml/min to 40 ml/min produces a damping effect on the displacement amplitude of vibration that is equivalent to applying a load of 0.50 N.

For the TFI-3 tip, an analysis of the data shows that, for a water flow of 20 ml/min, there is no significant difference in the average maximum vibration displacement amplitude with a load of 0.50 N and 1.00 N (p = 0.768). This again shows the lack of dependence on load for the TFI-3 design of tip, which has been shown previously[7]. Furthermore, there is no significant difference in the average maximum vibration displacement amplitude for the TFI-3 tip with 20 ml/min water flow rate and 0.50 N load, and unloaded with 40 ml/min water (p = 0.135).

There are still no published data that indicate whether increased vibration displacement amplitude of ultrasonic scalers leads to increased instrument efficacy. There are many other factors such as tip shape as well as operator-dependent parameters (how fast the tip is moved, in which directions, the pressure applied, duration of scaling, etc.) that may affect such instruments' performance. However, on a theoretical basis, with all other factors remaining constant, it would seem logical that a tip that vibrates with larger displacement amplitude removes calculus more rapidly than a tip with a smaller vibration. On this basis, since an increase in water flow was shown to lead to a reduction in tip displacement amplitude, it is hypothesised that a corresponding reduction in tip efficacy would also result. Whether this reduction would be clinically significant or not is unknown.

What may be suggested by the present study, however, is that when testing ultrasonic instruments to evaluate, for example, their effects on root surfaces, the water flow rate must be measured as this adds a significant load.

■ Conclusions

This study shows that when performing *in vitro* research, it is essential to control and specify measured water flow rates in order to allow meaningful comparisons between different experimental setups and across studies. The magnitude of the effect of water flow is dependent upon the design of tip, with thinner tips (such as the Slimline design) being affected the most.

■ Acknowledgements

The present study was supported by a project grant from the Engineering and Physical Sciences Research Council (GR/T22551/01).

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