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Technical note

The performance characteristics of a piezoelectric ultrasonic dental scaler

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ABSTRACT

The objective of this work was to investigate the performance characteristics of a piezoelectric ultrasonic dental scaler using scanning laser vibrometry. The vibration characteristics of three standard piezoelectric tips were assessed with scanning laser vibrometry under various conditions: unconstrained, under a stream of flowing water, in a water tank, as well as subjected to loads to simulate clinical conditions. Subsequently, the tips were used to disrupt an in-vitro biofilm model of dental plaque, developed using a non-pathogenic Gram-negative species of *Serratia* (NCIMB40259).

The laser vibrometry data showed that the oscillation pattern of the ultrasonic tip depends primarily on its shape and design, as well as on the generator power. Thin tips and high power settings induce the highest vibrations. Water irrigation of the tip and loads influence the tip performance by diminishing its vibration, while water volume increases it.

Serratia biofilm was disrupted by the cavitation bubbles occurring around the scaler tip. The most effective biofilm removal occurred with the thinner tip.

Understanding how the ultrasonic tip oscillates when in use and how it removes dental plaque is essential for gaining more knowledge regarding the cleaning mechanisms of the ultrasonic system. Cavitation may be used to remove plaque and calculus without a mechanical contact between the dental tip and the teeth. Better knowledge would enable dental specialists to understand and improve their techniques during routine cleaning of teeth. It will also lead to improving tip design and to the production of more effective instruments for clinical use.

1. Introduction

When using ultrasonic scalers, the debridement of plaque and calculus is primarily achieved by the mechanical chipping action of the scaler tip [1–3]. A stream of water flows over the tip to prevent frictional heating and to wash debris from the treatment site. It was found that cavitation bubbles are generated in the water around the oscillating ultrasonic scaler tip [4,5]. One effect that cavitation causes is the breakdown of water molecules and hence the production of reactive species inside the cavitation bubbles [6,7]. In addition, microstreaming occurs and it impacts on a surface thus aiding the surface cleaning [8,9]. Recently it has been proposed that ultrasonic scaler debridement involves the use of the cavitation bubbles as another mechanism to remove plaque and calculus from teeth surface, periodontal pockets and dental implants and may lead to advances in enhancing the cleaning process [9–11].

An appreciation of the movement of ultrasonic scalers would enable dental specialists to understand and improve their techniques during routine teeth cleaning. The oscillations of ultrasonic tips have been successfully assessed using a novel technique, namely scanning laser vibrometry (SLV), providing a more detailed understanding of the way in which factors such as constraint, load and wear affect scaler vibrations and hence its performance [12,13]. These papers proved a useful insight into the oscillation of the tips, however newer piezoelectric generators have entered the market which have different shapes to those previously evaluated.

This paper aims to assess the vibration motion of a piezoelectric ultrasonic scaler with different shaped tips ranging from broad based shape to those which resembled a thin probe shape for better accessing periodontal pockets. These were assessed under simulated clinical conditions to determine which factors lead to the greatest influence on the movement. In addition, the disruption of a bacterial biofilm representing the dental plaque was studied to explore the action of assumed cavitation bubbles around the ultrasonic tip.

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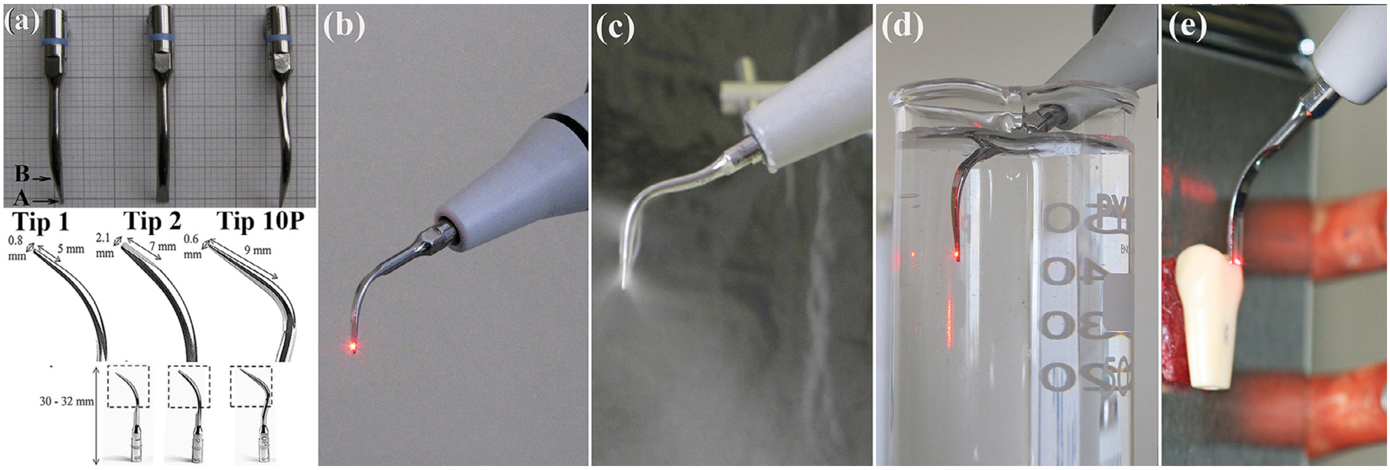

Fig. 1. (a) Design of Satelec tips 1, 2 and 10P; the free end of the tip (position A) is placed side-on to the tooth during treatment. Tip vibrations are measured in air (b), under water flow (c), in water tank (d) and loaded (e).

2. Materials and methods

2.1. Tip design and measurement settings

A piezoelectric dental scaler (Satelec P5XS Newtron, Acteon, France, 30 kHz) was selected for this study with three tips of different designs (Fig. 1a) used by dental specialists to access subgingival pockets [10]. Tips 1 and 2 had rectangular cross-section and tip 2 was broader than tip 1. Tip 10P had circular cross-section and it was the thinnest, and the longest tip. Tips were handmade of stainless steel and before the analysis and experiments they were cleaned with ethanol. The analysis of tip vibrations was performed under unconstrained and unloaded conditions in air (Fig. 1b). Subsequently, the oscillating tips were put under constrained conditions by adding water either as a flow from a small outlet on the back of the tip, running over its body at a constant rate of 30 ml/min (Fig. 1c), or in a water tank containing 50 ml of distilled water (Fig. 1d). Finally, tips were tested against a plastic tooth attached to a digital balance (Timetop, capacity 1000 g, precision 0.1 g) and loads from 10 g to 150 g were applied towards the front side of the tip during its vibration (Fig. 1e); the contact was made at the free end of the oscillating tip (final 1 mm).

2.2. Scanning laser vibrometry analyses

The vibration analyses of the scaler tips were performed using a SLV high frequency scanning vibrometer system (PSV 300-F/S, Polytech GmbH, Waldbronn, Germany), which works with an eye-safe He–Ne laser (λ=632.8 nm, class 2). The principle of SLV measurement has been discussed previously [14,15]. A frequency measurement range of 0–100 kHz was selected to allow detection of the fundamental frequency of the scaler, as well as higher order harmonics. The SLV was set to perform fast Fourier transformation using 800 data points, giving a frequency resolution of 125 Hz thus enabling both the longitudinal and lateral oscillation pattern of the tip to be accurately determined. The laser beam was focused at the tip free end as shown in Fig. 1b and a number of equally-spaced scan points were chosen along the tip length, from the free end to as close to the handpiece as could be measured. The handpiece was clamped so that the tip was vertical and clearly visible to the SLV camera. Full characterisation of the unconstrained tip vibrations was performed with the laser beam focused on the front, back and side of the tip. The maximum tip displacement at each scan point was measured and an average of 5 measurements was recorded for each tip, at each power setting (1-lowest to 20-highest). Each scan lasted approximately 10 s with an interval of 20 s between scans.

2.3. Bacterial biofilm formation and its disruption

An in-vitro biofilm model system using a non-pathogenic Gram-negative species of *Serratia* (NCIMB40259) has been developed in a bioreactor [16]. *Serratia* is capable of forming biofilm on various surfaces and also mineralising it to calcium deficient hydroxyapatite that chemically resembles calculus and has a similar tenacity on surfaces [16]. The bacterial biofilm with thickness of about 2 μm was grown on microscope glass slides (20 $\times$ 10$\times$1 mm) and titanium disks (Ti; diameter 15 mm). The irrigated dental tip was placed parallel to the biofilm-coated materials with their front side and tip end facing down. Then the ultrasonic scaler has been operated for 30 s at a fixed power setting, giving a tip displacement of 15 μm. Direct mechanical contact of the tip with the materials was avoided by placing them at a distance of 40 μm. To extract the effect of water impingement on the biofilm disruption, a stream of water from a 50 ml syringe placed at 1 or 5 mm distance to the Ti and glass surfaces was directed to the biofilm.

2.4. Statistical analysis

SLV data from the scan point located at the unconstrained end of the tips were analysed using IBM SPSS v.21 for Windows (SPSS Inc., Chicago, IL, USA). The significance of variation in the maximum tip displacement amplitude at different generator power settings, as well as under various constrains and load conditions was tested using univariate analysis of variance (ANOVA, general linear model) and multiple post hoc comparisons (Tukey test). For similar studies the significance level is set as $p < 0.05$ with the dependent variable being the displacement amplitude.

3. Results

The SLV data is presented as the maximum displacement amplitudes along the length of the unconstrained tip and the scans revealed one node at about 3.5 mm (tips 1 and 2) or 4.5 mm (tip 10P) measured from the tip free end (Fig. 2a). Two antinodes could be identified: at the very end of the tips (first scan point; position A in Fig. 1a) and at about 6.5 mm, 5.0 mm or 8.5 mm for tips 1, 2 and 10P, respectively (position B in Fig. 1a). Displacement clearly increased with increasing power from the lowest (1) to the maximum generator power (20). There was an over-range signal when recording the tip end at the highest power settings. Tip 2 exhibited the lowest displacements whilst tip 1 gave higher amplitudes of oscillation. Tip 10P had the highest vibrations at all power settings.