 CAV18-05110

Increasing Cavitation around Dental Ultrasonic Scalers to Improve Biofilm Removal Efficiency: A High Speed Imaging and Image Analysis Study

[1]Nina Vyas, [2]Qianxi Wang, [1]A. Damien Walmsley*;

[1]School of Dentistry, University of Birmingham, UK; [2]School of Mathematics, University of Birmingham, UK

Abstract

Dental ultrasonic scalers are used to remove plaque and mineralised deposits from teeth. Cavitation occurs in the cooling water flowing over the tip and may be used to enhance removal of the biofilm. Our research shows that cavitation occurs around the bend of the scaler tip and at its free end. By increasing the amount of cavitation, the instrument can potentially be used in a novel non-contact mode. The metal tip of the scaler will not touch the tooth surface allowing the cavitation to undertake the removal. This non-touch cleaning will reduce the present damage on both teeth and dental implants, which may be damaged by contact with the metal scaler tip. The aim of this study was to modify an ultrasonic scaler tip and image it with a high speed camera to determine the increase in cavitation. An ultrasonic scaler (P5 XS Satelec, Acteon) operating at 29 kHz at the medium power setting was imaged with tip 10P using a high speed camera (Shimadzu HPV1) at 1,000,000 fps. Imaging was done with the tip immersed in distilled water preventing spray from the scaler. The outer edge of the free end of the tip was ground and polished manually (DAP-7, Struers, Ballerup, Denmark) using P500 and P4000 SiC paper until horizontal. These alterations were made to increase the pressure drag, which would create lower pressures and consequently increase the cavitation. Image segmentation was done using a semi-automatic machine learning approach to calculate the area of the cavitation occurring at the free end of the original and modified tips. The mean area of cavitation around each tip was calculated from 102 images. There was a statistically significant difference between the amount of cavitation occurring around the modified and original ultrasonic scaler tip. The area of cavitation around tip 10P was 0.27 ± 0.05 μm^2 and the area of cavitation around the modified tip was 0.35 ± 0.07 μm^2. High speed imaging also showed that there was cavitation present at the point of the free end in the modified tip but not in the original tip. This will be clinically useful as the point of the tip is the part closest to the tooth surface when in use. These results propose that cavitation from an ultrasonic scaler may be used to remove dental plaque without damaging teeth. This method also has potential to be used to clean dental implants.

Keywords: ultrasonic cleaning, biofilm disruption, cavitation, ultrasonic scalers

Introduction

Dental plaque is a biofilm, consisting of many bacterial species inside a viscous substance known as the extra cellular polymeric substance (EPS), which facilitates the adhesion of the bacteria to all surfaces of the mouth [1]. This biofilm must be removed from teeth and dental implants to prevent disease, although it typically cannot be removed effectively from such surfaces due to their micro- and nano-roughness [2]. The use of ultrasonic cavitation is being investigated as a more effective method of biofilm removal. The shock waves, high velocity micro-jets, and streaming generated by collapsing bubbles are able to disrupt the biofilm structure at the micron scale and to aid in its removal from surfaces [3].

Cavitation occurs around the metal tips of dental ultrasonic scalers, used by clinicians during cleaning of teeth [4]. Ultrasonic scaler tips vibrate at frequencies of approximately 30 kHz, and the vibrating tip is used to dislodge mineralized debris on teeth. Cooling water is passed over the tip to prevent frictional heating, and it has been speculated that cavitation occurs in this cooling water. However cavitation is not currently used as the main method of biofilm removal, and the force of the vibrating metal tip can damage the tooth surface and dental implants. There are currently no suitable methods for effectively removing biofilm from dental implants, therefore the cavitation around ultrasonic scalers is being researched as a more effective and less damaging method of removing biofilm from teeth and dental implants. We have shown using high speed imaging that cavitation occurs around different shaped ultrasonic scaler tips, and that it increases with power and tip vibration amplitude [5]. We also established that that

*Corresponding Author, Professor Damien Walmsley: a.d.walmsley@bham.ac.uk

the cavitation occurred in clusters on the tip, therefore increasing the cavitation area may be beneficial by allowing the instrument to be used in a non-touch mode. The aim of this study was to modify the shape of an ultrasonic scaler tip to increase the amount of cavitation generated around it. We use ultra-high speed imaging and image analysis to calculate the amount of cavitation occurring around the original and modified tips.

Methods

An ultrasonic scaler (P5 Newtron, Satelec, Acteon, France) was imaged with tip 10P at medium power (power setting 10) using a high speed camera operating at 1 million frames per second (fps) (HPV1, Shimadzu Corporation, Japan). The camera was attached to a zoom lens (Monozoom 7, Leica Microsystems UK Ltd) to obtain a resolution of 15.5 µm/pixel. Illumination was provided by two strobe lights which were synchronised with the camera using a flash light controller, delay generator and trigger switch. The scaler was positioned using a translation stage (PT3, Thorlabs, USA). The scaler tip was imaged in a custom-made glass container with a total volume of 10 ml (Figure 1). The container was made by cutting glass microscope slides to 2.7 x 2.7 mm and attaching 5 squares to each other using glass adhesive (Loctite, USA) to create an open cube. The scaler tip was submerged in the container in 10 ml reverse osmosis water at 20.5°C. A modified version of Tip 10P was also imaged using the same conditions. The outer edge of the free end of the tip was ground and polished manually (DAP-7, Struers, Ballerup, Denmark) using P500 and P4000 SiC paper until horizontal (Figure 2). These alterations were made to increase the pressure drag, which would create lower pressures and consequently increase the cavitation.

All image analysis was done using Fiji (distribution of the ImageJ software, US National Institutes of Health, Bethesda, Maryland, USA)[6]. Analysis was done using high speed videos containing 102 images for each tip. The high speed images were first cropped to remove any background artifacts (Figure 3a-d). The cavitation bubbles were then segmented using the Trainable Weka Segmentation plugin (Figure 3e,f)[7]. Some parts were falsely segmented, for example background noise or reflection from the scaler. Larger reflections were removed from the segmentation by manually replacing pixels with pixels of value 0 (Figure 3c,d). Any smaller background noise was removed with the Analyse Particles plugin, where objects smaller than 4 pixels were removed (Figure 3 g,h). The histogram of each image in the stack was calculated to find the area of cavitation. The mean cavitation area and standard deviation were plotted and the Mann-Whitney Rank Sum Test was used for testing for statistical significance. Data graphing and statistical analysis were performed using SigmaPlot 12.5 (Systat Software, USA).

Results

We present a high speed imaging and image analysis study to show how cavitation around dental ultrasonic scalers can be increased by changing the tip shape. We have tracked the position of the cavitation with high spatial and temporal resolution using an ultra-high speed camera and image processing of the data. This allows us to perform quantitative analysis to calculate the amount of cavitation. The high speed images show that cavitation occurred around both tips, at the front and the back of the tip. There was a statistically significant difference between the amount of cavitation occurring around the modified and original ultrasonic scaler tips ($p < 0.001$) where p is the probability value. The area of cavitation around the original tip 10P was 0.27 ± 0.05 µm^2 and the area of cavitation around the modified tip was 0.35 ± 0.07 µm^2 (Figure 4). High speed imaging also showed that there was cavitation present at the point of the free end in the modified tip but not in the original tip.

Figures & Tables:

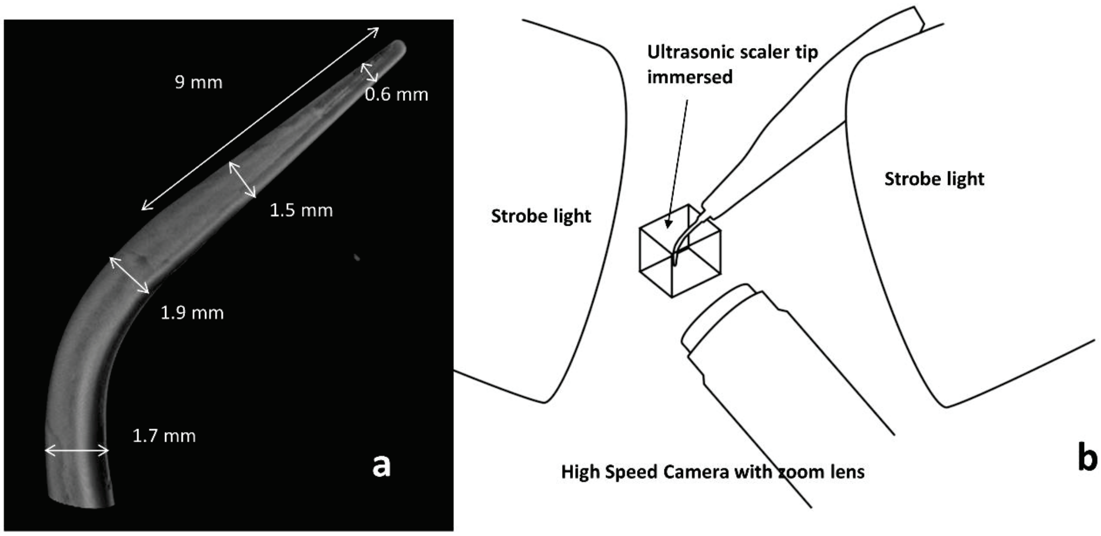

Figure 1: (a) X-ray micro-computed tomography reconstruction of the ultrasonic scaler tip used in this study, showing tip dimensions. (b) Schematic of the experiment setup for high speed imaging.

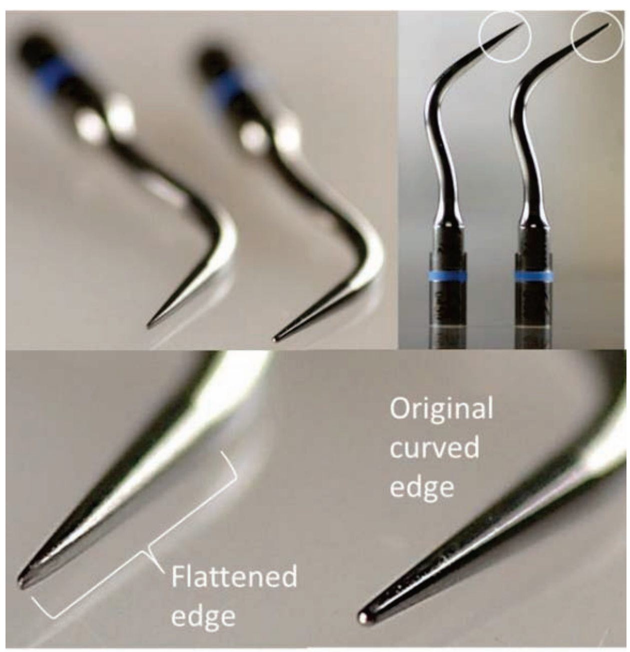

Figure 2: Photographs of the original and modified versions of the ultrasonic scaler tip used in this study.

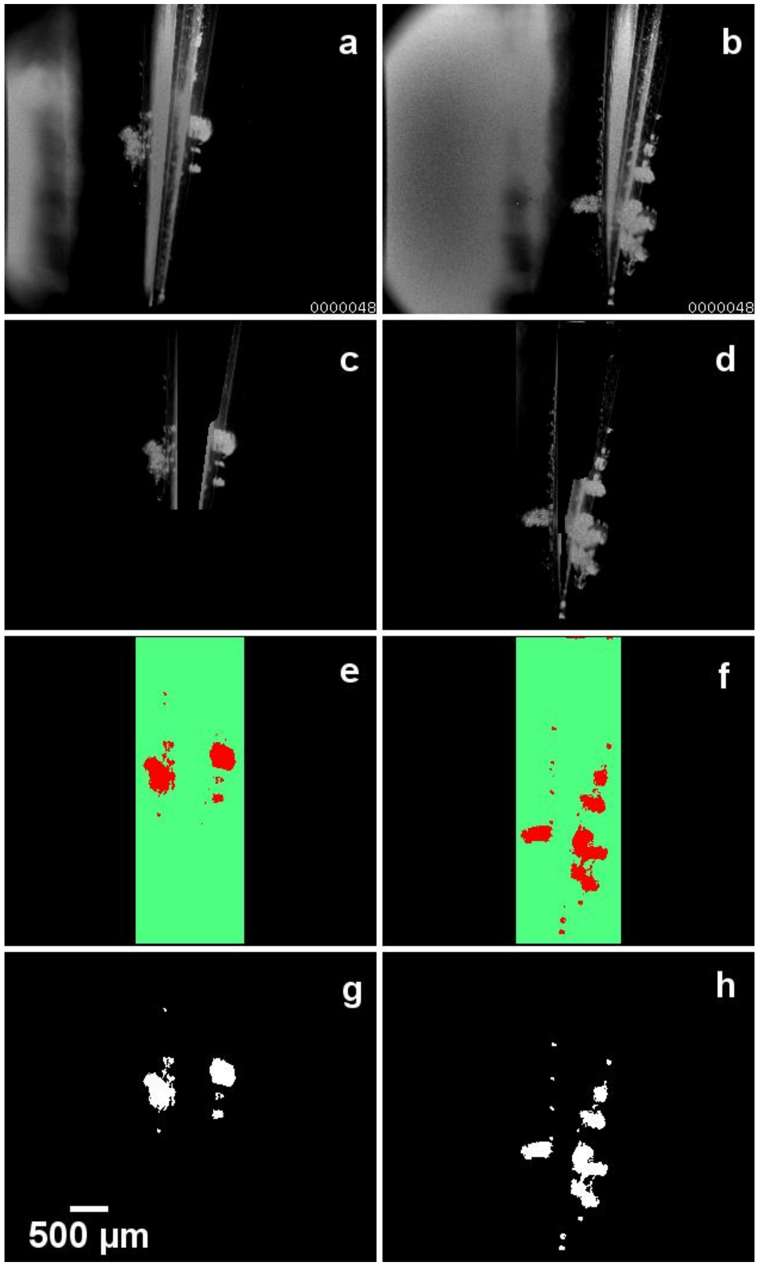

Figure 3: Series of images showing the image analysis process used to calculate the area of cavitation occurring around the tips. (a) High speed image still of tip 10P. (b) High speed image still of modified tip 10P. (c) Image still after pre-processing for segmentation – reflections from the scaler have been manually removed by setting certain pixel values to 0. (d) Corresponding pre-processed image for the modified tip. (e) Segmented image of (c) using the Trainable Weka Segmentation plugin. (f) Segmented image of (d) using the Trainable Weka Segmentation Plugin. (g, h) Segmented images after post-processing, used to calculate the cavitation area.

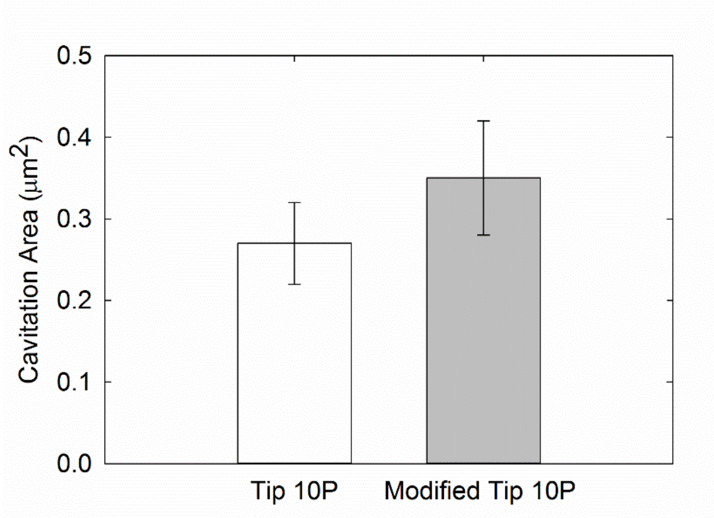

Figure 4: Graph showing the area of cavitation occurring around tip 10P and the modified version of tip 10P, calculated using image analysis from the set of high speed images taken at 1 million frames per second. There was a significant difference in the amount of cavitation between the two tips ($p < 0.001$).

Conclusions

We have used ultra-high speed imaging and quantitative image analysis to demonstrate that a novel tip modification can enhance the amount of cavitation bubbles occurring around dental ultrasonic scaler tips. We speculate that this advancement can increase the amount of biofilm removal as well as reducing the cleaning time. It can therefore help to enable ultrasonic scalers to be used in a non-contact mode, allowing teeth and dental implants to be cleaned more effectively with cavitation without causing damage to their surfaces.

Acknowledgments

The authors acknowledge support from the Engineering and Physical Sciences Research Council (EP/P015743/1).

References

1. Jacob, M., (2006). *Biofilms, a new approach to the microbiology of dental plaque.* Odontology. 94: p. 1–9.
2. Mann, M., et al., (2012). *Effect of plastic-covered ultrasonic scalers on titanium implant surfaces.* Clinical Oral Implants Research. 23(1): p. 76-82.
3. Erriu, M., et al., (2014). *Microbial biofilm modulation by ultrasound: Current concepts and controversies.* Ultrasonics Sonochemistry. 21: p. 15-22.
4. Felver, B., et al., (2009). *Cavitation occurrence around ultrasonic dental scalers.* Ultrasonics Sonochemistry. 16: p. 692-697.
5. Vyas, N., et al., (2016). *High Speed Imaging of Cavitation around Dental Ultrasonic Scaler Tips.* PLoS One. 11(3): p. e0149804.
6. Schindelin, J., et al., (2012). *Fiji: an open-source platform for biological-image analysis.* Nature Methods. 9(7): p. 676-682.
7. Arganda-Carreras, I., et al., (2017). *Trainable Weka Segmentation: a machine learning tool for microscopy pixel classification.* Bioinformatics: p. btx180.