Sonic brushing and the delivery of fluoride through Streptococcus mutans biofilms

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The accumulation of dental plaque biofilms plays a role in the development of caries, gingivitis, and periodontitis. Bacteria in dental plaque biofilms constitute a viable community of microorganisms with complex ecological relationships. As the biofilm grows, it forms an irregular heterogeneous sponge-like structure containing clusters of cells surrounded by channels through which liquid, such as saliva, can flow. Micro-organisms in plaque derive nutrients from saliva and the food we eat for their energy and metabolic needs. One such micro-organism is Streptococcus mutans, which produces lactic acid from the fermentation of sucrose, resulting in caries.1 This is due to an increase in the dissolution rate of hydroxyapatite, a mineral that constitutes more than 95 per cent of tooth enamel. As acidity increases such that the pH drops below 5, it is no longer possible to repair the enamel by mechanical brushing alone, so enhanced fluoride delivery to problematic proximal sites represent areas that are difficult to access through mechanical brushing alone, so enhanced fluoride delivery to these sites would represent an added clinical benefit should insufficient interproximal plaque be removed mechanically. A diagrammatic illustration of the in vitro fluoride delivery model and the analogous in vivo process is shown in Figure 2. To evaluate comparative efficacy of two power toothbrushes were compared: the Sonicare FlexCare, which operates on sonic brushing, and the Oral-B Triumph, which employs rotary brushing. A brushing treatment was used as the control.

Fluoride has been used as a preventive measure against dental caries. Whether as an additive to drinking water or as a toothpaste component, fluoride is one of the most effective strategies for the prevention of dental caries. Fluoride has been shown to inhibit the development of dental caries, reduce the severity of existing caries, and enhance the remineralization of enamel surfaces. It is effective in reducing the risk of developing new cavities and in arresting existing ones. Fluoride also has a systemic effect, as it can reduce the rate of carious lesion development in high-risk individuals.

The transport of small molecules or ions, such as fluoride, by diffusion is relatively fast across minute distances, but the time to attain a certain concentration at the base of the biofilm increases with the square of the thickness of the biofilm. Biofilm cell agglomerates impede fluid flow (and hence fluoride mobility) through the cell clusters and to the tooth enamel surface itself. Although power brushing is designed to reduce the thickness of biofilm, this is not always effective in reducing the thickness to the level required for complete biofilm removal. In this study, we evaluated the efficacy of sonic brushing in delivering fluoride to the tooth enamel surface.

The motion from a sonic toothbrush has been demonstrated to increase the rate of fluoride delivery to the tooth enamel surface, which is significantly greater than the two-minute exposure time from regular brushing had demonstrated. The sonic toothbrush increases fluoride delivery by about 30 per cent, while power brushing increases fluoride delivery by about 80 per cent. Sonic brushing, therefore, offers an added clinical benefit.

The objective of this study was to evaluate the ability of sonic brushing in delivering fluoride to the tooth enamel surface. To evaluate this, we used a simulated in vitro model of the oral cavity, which was colonized with Streptococcus mutans biofilms. The fluoride concentration in the plaque biofilms was measured using a specialized electrode. The results of this study showed that sonic brushing significantly increased the fluoride concentration in the plaque biofilms, with the highest increase observed with the Oral-B Triumph, which was used for two minutes. This study suggests that sonic brushing is an effective method for increasing the fluoride concentration in the plaque biofilms, which may contribute to the prevention of dental caries.


following sonic brushing in the right hand chamber (Fig. 5). The brushing chamber was filled with 1,100 ppm fluoride solution, and over a four-minute monitoring period, the concentration in the measurement chamber never fell to less than 1,050 ppm, suggesting that the concentration gradient driving the fluoride flux would remain more or less constant. Immediately prior to brushing, brush heads were positioned 1 cm from the biofilm-colonised membrane, to minimise biofilm removal during treatment, as the intent was to evaluate efficacy of fluoride delivery through the membrane rather than mechanical dislodgement of the biofilm. As fluoride diffused through the biofilm and membrane into the measurement chamber, fluoride accumulation measurements were recorded over a four-minute period, with 15 replicate measurements for the no-brushing control, and 17 replicates for the two power toothbrushes.

Results
Even with no brushing, fluoride concentration increased from 0.4 ppm to 0.5 ppm after four minutes, due to the difference in fluoride concentration between the two chambers (passive diffusion). With active brushing, the delivery of fluoride through the biofilm membrane increased considerably over the four-minute brushing period for both power toothbrushes. The fluoride concentration measured in the measurement chamber was 0.8 ppm after FlexCare brushing, while the concentration after Triumph brushing was 0.65 ppm (Fig. 4). Fluoride delivery rate through the colonised membrane was measured as the mass transfer rate coefficient, which was significantly greater with power brushing (P < 0.05) than with passive diffusion alone. FlexCare caused an increase of 129 per cent over no brushing compared to 79 per cent over no brushing for Triumph, while the mass transfer coefficient generated by FlexCare was significantly greater (P < 0.05), by 29 per cent than that generated by Triumph (Fig. 5).

Discussion and relevance
The application of an in vitro two-chamber method, to assess and compare rate of fluoride delivery through a viable microbial biofilm, is a useful one for comparative assessments of power brushing. S. mutans biofilms on esterase membranes are similar in structure to naturally grown human dental plaque biofilms. As such, the data demonstrated that fluid dynamics from powered brushing with both sonic and rotary brushes increased the transport of fluoride through the S. mutans biofilm compared with diffusion alone, the use of fluid dynamic activity generated by powered tooth brushing to enhance delivery of fluoride deep into the biofilm was significant. The potential for enhanced delivery becomes even more useful where plaque biofilms are located in hard-to-access areas that are typically beyond the impact of mechanical bristle activity, such that these biofilms could benefit from enhanced fluoride interventions. Clinically, a four-day trial revealed that sonic brushing increased the concentration of retained fluoride in plaque biofilm by more than 40 per cent compared to rotary brushing, manual brushing, and manual brushing and flossing. The combination of data from this clinical study and the in vitro data on enhanced fluoride delivery rates through S. mutans-colonised membrane biofilms indicates compelling evidence of the role of sonic brushing in driving fluoride into biofilms. Further research into the relationship between sonic brushing, fluid dynamic activity, and the role of oral biofilms in retention and delivery of other anti-cariogenic or anti-microbial agents should be explored. Many of the more pathogenic, anaerobic bacteria reside deeper in the plaque biofilm, where the availability of oxygen is low and they are protected from chemotherapeutic agents. However, this environment also represents a target area, where the potential is highest for improvement by increasing oxygen availability and by delivering anti-microbial agents directly to these anaerobes through sonic brushing. Should the enhanced delivery of fluoride be conclusively shown to result from the dynamics of sonic brushing-induced fluid motion, then the opportunity for delivering other broad-based, anti-cariogenic or anti-microbial agents as part of a regular oral brushing regimen will be significantly augmented.