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 five, increased demineralisation of the enamel surface in turn accelerates the development of cavities.

Fluoride has been used as a preventive measure against dental caries. Whether as an additive to drinking water or its incorporation into fluididated dentifrices and rinses, three main mechanisms have been proposed to explain the anticaries effect of fluoride. Firstly, fluoride enhances the resistance of enamel to acid attack by reducing enamel solubility. Secondly, fluoride inhibits the formation of lactic acid in the plaque. As a result, it is conceivable that reaction/remineralisation by retemic fluoride delivery results in the dentition can still result in demineralisation in tooth enamel, postively impacting the ongoing process of remineralisation/demineralisation in tooth enamel. 2 If exposure to acid is short, saliva will raise the pH naturally, so that the enamel loss can be repaired through remineralisation. However, continued exposure to acid (eg, through continuous sucking on sugar-containing candy) can create a situation whereby the remineralisation rate may be insufficient to repair the loss from demineralisation, increasing the likelihood of caries development. 3 Hence, the right balance in the rates of demineralisation and remineralisation influences the success of caries reduction.

Repeated exposure of plaque to fluoridated drinking water or dentifrice enables fluoride to bind to cells' sticky polysaccharide slimes in the biofilm. 4 Even when the fluoride source is no longer present, bound fluoride in the plaque biofilm is slowly released over time, which prolongs its anti-caries impact. 5 This instance, the biofilm actually acts as a storage reservoir for fluoride (and other ions, such as calcium and phosphate) and enhances fluoride retention and exchange between these ions and the tooth. Indeed, there is evidence that the removal of the biofilm can actually increase enamel fluoride concentration (enamel dissolution) and enhance remineralisation (enamel deposition) in tooth enamel, positively impacting the ongoing process of remineralisation/demineralisation in tooth enamel. 6 If exposure to acid is short, saliva will raise the pH naturally, so that the enamel loss can be repaired through remineralisation. However, continued exposure to acid (eg, through continuous sucking on sugar-containing candy) can create a situation whereby the remineralisation rate may be insufficient to repair the loss from demineralisation, increasing the likelihood of caries development. Hence, the right balance in the rates of demineralisation and remineralisation influences the success of caries reduction.

The objective of the in vitro study was to evaluate the efficacy of sonic brushing in delivering fluoride into a model S. mutans biofilm by measuring the rate in which sodium fluoride (representing fluoride ions) passed through this biofilm (Fig. 1). 7,8 To accomplish this, a fluid container with two chambers separated by a permeable membrane colonised with S. mutans biofilm, representing dental plaque, was used to simulate in vivo biofilm in interproximal plaque and to measure how quickly sodium fluoride passed through the colonised membrane from one chamber into the other during sonic brushing. Such interproximal sites represent areas that are difficult to access through mechanical brushing alone, so enhanced fluoride delivery to these sites would repre- sent an added clinical benefit should insufficient interproximal plaque be removed mechanically. A diagrammatic illustra-
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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 1,150 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 tool for comparative assessments of power brushing. S. mutans biofilms on esterase membranes are similar in structure to naturally grown human dental plaque biofilms. As this study 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.13 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 dynamics, 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.