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.

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 fluoridated dentifrices and rinses, three main mechanisms have been proposed to explain the anti-caries effect of fluoride. Firstly, fluoride enhances the resistance of enamel to acid attack by reducing enamel solubility.

Plaque bacteria or the inhibition of their metabolic pathways that result in lactic acid production. A reduced pH environment also favours growth of beneficial bacteria such as the oral streptococci (over the acidogenic cariogenic S. mutans or S. sobrinus) that are harmed by the presence of high acid levels, and whose presence in the biofilm is indicative of sound oral health. It has also been suggested that fluoride may temper the localised anaerobic and acidic micro-environments found near the surface of the biofilm and highly conducive to the acid-loving anaerobes that increase the risk of cariogenic biofilm formation. Thirdly, fluo-

ricide can inhibit demineralisation (enamel dissolution) and enhance remineralisation (enamel deposition) in tooth enamel, positively impacting the ongoing process of remineralisation/demineralisation in tooth enamel. 

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 (through continuous sucking on sugar-containing candy, for example) creates a situation whereby the remineralisation rate may be insufficient to repair the loss from demineralisation, increasing the likelihood of cavity development. Hence, the right balance in the rates of demineralisation and remineralisation influences the success of cavity reduction.

Repeated exposure of plaque to fluoridated drinking water or dentifrice enables fluoride to bind to cells’ sticky polysaccharide slime in the biofilm. Even when the fluoride source is no longer present, bound fluoride in the plaque biofilm is slowly released over time, which prolongs the anti-caries action. In this instance, the biofilm actually acts as a storage reservoir for fluoride (and other ions, such as calcium and phosphate) during enhanced fluoride retention and exchange between these ions and tooth enamel. 

However, there is still insufficient knowledge on the exact mechanisms by which biofilms actively control fluoride passage through their complex layers, other than passive diffusion of fluoride through inert areas of the biofilm where there is virtually no fluid flow. Transport of small molecules or ions, such as fluoride, by diffusion is relatively last 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 aggre-

gates impede fluid flow (and hence fluoride mobility) through the cell clusters and to the tooth enamel surface itself. Although power brushing is designed to re-

move as much plaque as possible mechanically, fluoride is attained with difficulty in inaccessible areas of the oral cavity. Such areas include fissures, interproximal, and even subgingival areas, as well as less accessible locations of the dentition, such as posterior teeth. Increased penetration of fluoride into the biofilm through hydrodynamic forces could enhance the period of fluoride re-

tention and prolonging its efficacy. Since topical rather than sys-

temic fluoride delivery results in caries protection, the efficacy of topically delivered fluoride on problematic sites is as important as the con-

centration of salivary fluoride and fluoride exposure. 

Dental plaque biofilms formed in stagnant areas within the dentition can still result in allergic reactions, as there is virtually nothing to fluoride delivered through the enamel.

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ics, which contributes to fluoride passage into biofilm sites, leading to enhanced bioavailability of the fluoride in the plaque biofilm. As a result, it is conceivable that in vivo process is shown in Figure 1. 

Sonic brushing with two power toothbrushes was compared: the Sonicare FlexCare, which operates on sonic brushing, and the Oral-B Triumph 9000, which employs rotary brushing. A sonic brush-

ing treatment was used as the control.

S. mutans biofilms were grown on cellulose ester mem-

branes for four or five days, to ensure development of mature biofilms similar to the com-

plex biofilms formed in dental plaque, with water channels that reached to the membrane filter surface (Fig. 5). The colonised membrane filter was then in-

serted into a support that was posi-

tioned between the two cham-

bers of the dual chamber system (Fig. 1). A primary chamber served as the brushing chamber, while a secondary measurement chamber served as the fluoride detection chamber, to measure accumulating fluoride. A Flo-

ride electrode in the measure-

ment chamber measured how much fluoride passed through the biofilm membrane,

S. mutans biofilm by measuring the rate in which sodium fluoride (repre-

senting fluoride ions) passed through this biofilm (Fig. 1). To accomplish this, a fluid con-

tainer with two chambers sepa-

rated 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 much sodium fluoride passed through the biofilm.

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ment chamber measured how much fluoride passed through the biofilm membrane,
following sonic brushing in the right hand chamber (Fig. 5). The brushing chamber was filled with 1,000 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 esterese 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. 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.