Evidence for biofilm acid neutralization by baking soda

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ABSTRACT

Background. The generating of acids from the microbial metabolism of dietary sugars and the subsequent decrease in biofilm pH below the pH at which tooth mineral begins to demineralize (critical pH) are the key elements of the dental caries process. Caries preventive strategies that rapidly neutralize biofilm acids can prevent demineralization and favor remineralization and may help prevent the development of sugar-induced dysbiosis that shifts the biofilm toward increased cariogenic potential. Although the neutralizing ability of sodium bicarbonate (baking soda) has been known for many years, its anticaries potential as an additive to fluoride dentifrice has received only limited investigation.

Types of Studies Reviewed. There is evidence that baking soda rapidly can reverse the biofilm pH decrease after a sugar challenge; however, the timing of when it is used in relation to a dietary sugar exposure is critical in that the sooner its used the greater the benefit in preventing a sustained biofilm pH decrease and subsequent demineralization. Furthermore, the effectiveness of baking soda in elevating biofilm pH appears to depend on concentration. Thus, the concentration of baking soda in marketed dentifrice products, which ranges from 10% to 65%, may affect their biofilm pH neutralizing performance. People with hyposalivation particularly may benefit from using fluoride dentifrice containing baking soda because of their diminished ability to clear dietary sugars and buffer biofilm acids.

Conclusions. Although promising, there is the need for more evidence that strategies that modify the oral ecology, such as baking soda, can alter the cariogenic (acidogenic and aciduric) properties of biofilm microorganisms.

Practical Implications. The acid neutralization of dental biofilm by using fluoride dentifrice that contains baking soda has potential for helping counteract modern high-sugar diets by rapidly neutralizing biofilm-generated acid, especially in people with hyposalivation.

Key Words. Baking soda; sodium bicarbonate; adaptation; psychological, biofilms; caries prevention products; dentifrices; bacteria; diet; fluoride; xerostomia.

JADA 2017:148(11 suppl):10S-14S

http://dx.doi.org/10.1016/j.adaj.2017.09.005

ROLE OF DENTAL BIOFILM ACID PRODUCTION IN THE CARIES PROCESS

Dental caries is a complex disease in which there are interactions among the tooth structure, oral microbial biofilm formed on the tooth surface, dietary sugars, and, to a lesser extent, starches and salivary and genetic influences.[1] Biofilm bacteria metabolize sugars and produce acids, which over time demineralize tooth enamel and can lead to progressive destruction of the tooth's hard tissues—and if left untreated, pain, abscess, and possible tooth loss. The central role of the interaction between dietary sugars and dental biofilm is well established.[2] However, views on the role of specific organisms, such as *Streptococcus mutans*, in caries causation have changed over time. Several other biofilm microorganism species from the genera *Veillonella*, *Lactobacillus*, *Bifidobacterium*, and *Propionibacterium*; low-pH non–*S mutans* streptococci; *Actinomyces* species; and *Atopobium* species with acid-producing and acid-tolerating properties also have been associated with caries.[3] The emphasis is now on the biofilm as a community of endogenous microorganisms and how ecological conditions, mainly determined by frequent consumption of dietary sugars and low salivary flow (hyposalivation), can shift the biofilm from a healthy state to a caries conducive condition.[4-6] This ecological pressure from biofilm acidification leads to adaptation of the endogenous microorganisms to an acid environment that favors more acid tolerant (aciduric) bacteria and increased acid producing potential.[4]

Dental caries is a dynamic process involving cycles of mineral loss (demineralization) and mineral gain (remineralization).[1,7] The tooth surface is in a healthy state of dynamic equilibrium with the local oral environment (mainly created by saliva and the fluid phase of the biofilm) when demineralization and remineralization

Publication of this article was sponsored by Church & Dwight Co., Inc. The articles in this issue have an accompanying online continuing education activity available at http://www.ADA.org/bakingsoda.

are in balance. The caries process occurs in oral conditions that favor more net demineralization than remineralization, resulting in sustained net mineral loss. The demineralization phase starts with the formation of organic acids, mainly lactic acid, as an end product from sugar metabolism.[6] As acid builds up in the biofilm, the pH decreases to the point at which conditions become undersaturated with respect to tooth mineral (critical pH is approximately 5.5); the lower the pH, the greater the degree of undersaturation and the greater the rate of demineralization.[8] In conditions in which sugar metabolism is not taking place or acids have been neutralized, the biofilm pH tends to be in the neutral or basic range, and the fluid phase of the biofilm is saturated sufficiently with calcium and phosphate ions so that redeposition of mineral (remineralization) is favored. The presence of low levels of fluoride reduces the net mineral loss during acid challenge and greatly enhances the reprecipitation process, which is considered the main mechanism of action for fluoride.[9]

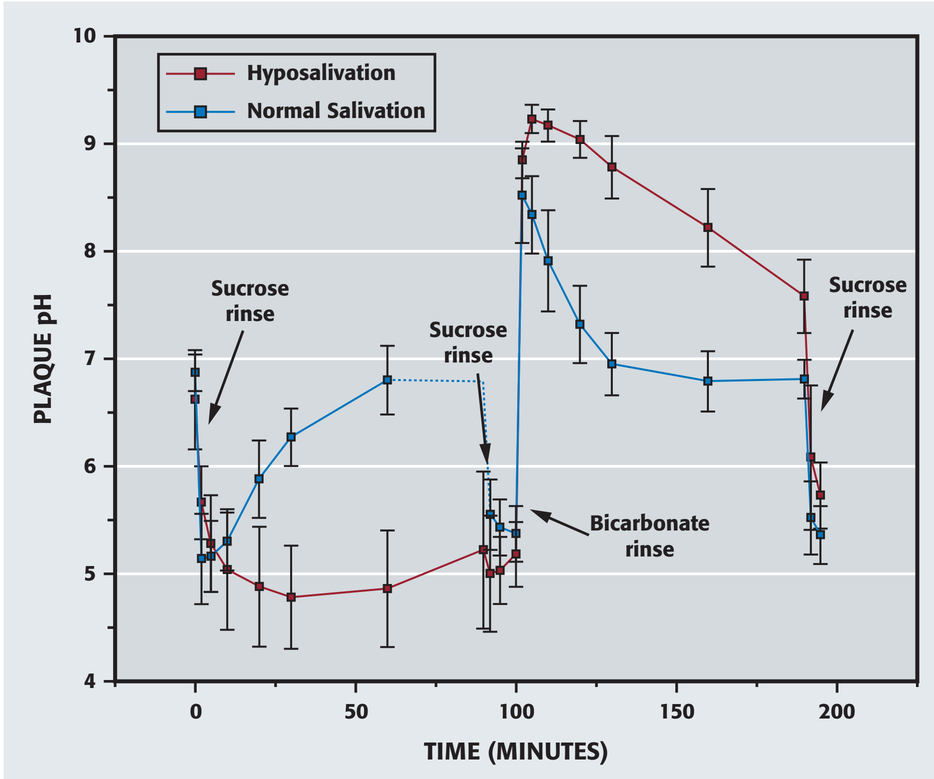

Figure. Mean plaque pH changes in participants with hyposalivation (n = 5) and with normal salivary flow (n = 5) after a one min 10% sucrose rinse, a second one min 10% sucrose rinse, a one minute rinse with 0.1 mol/L $NaHCO^3$ solution, and a third one minute 10% sucrose rinse. Error bars represent standard deviations.

The pH of the biofilm is influenced by many factors, including the concentration of the dietary sugars; the composition, thickness, and diffusion properties of the biofilm; the bicarbonate concentration in the saliva; and the velocity of the film of saliva as it passes over the surface of the biofilm.[1,10] The decrease in pH and subsequent return to neutrality that occurs when the biofilm is exposed to dietary sugars commonly is referred to as the *Stephan curve*.[10] Saliva plays an important role in modifying biofilm pH.[11] Salivary flow rate is the main factor affecting the clearance pattern of cariogenic foods and beverages. Saliva also plays an important role in modifying biofilm pH. In the absence of normal salivary flow, the pH stays at a low level for an extended period after exposure to dietary sugars (Figure). Therefore, saliva is responsible for the recovery of biofilm pH back toward neutrality. Stimulated saliva, because of its higher flow rate (increased volume) and enhanced buffering capacity (bicarbonate buffering system), dilutes and neutralizes biofilm acids.

The greater the acid concentration in the dental biofilm, the greater the driving force for acid to diffuse into the tooth. The 2 important factors that influence the amount of enamel demineralization are the extent of the pH decrease below the critical pH and the extent of time the pH remains below the critical pH. Measures that decrease acid production or elevate the pH through acid neutralization will prevent demineralization and favor remineralization and caries prevention.

DIRECT EFFECTS OF SODIUM BICARBONATE (BAKING SODA) ON BIOFILM pH

The potential of caries intervention strategies directed at the main driver of the caries process—acidification of the dental biofilm below the critical pH—long have been a subject of interest. The rapid alkalization of the biofilm by baking soda is 1 such approach. The author of an earlier review has supported the use of baking soda in dentifrice formulations because of its safety, low abrasiveness, and compatibility with fluoride.[12] The high solubility of baking soda makes it ideally suited to

penetrate the dental biofilm rapidly and neutralize acids; however, this quality also limits its ability to have a protracted effect in the oral cavity.[12]

There is limited direct evidence that baking soda in dentifrice can neutralize biofilm acidity when used in association with a dietary sugar challenge. Blake-Haskins and colleagues[13] reported on a series of experiments in which they used 3 models to study the effectiveness of dentifrices containing bicarbonate as buffering agents to neutralize biofilm acids. The first model involved touch electrode measurements at mesiobuccal sites of maxillary premolars and molars of participants after 3 days of biofilm growth and 2 hours of fasting. For the first control test, baseline pH measurements were followed by a 10% sucrose rinse for 3 minutes, and then the investigators monitored the pH for 60 minutes. For the second test, the participants rinsed with 10% sucrose for 3 minutes and after a 2-minute interval rinsed with a 45% weight by weight slurry of fluoride dentifrice with baking soda for 3 minutes. The investigators then monitored the pH for another 60 minutes. The fluoride dentifrice with baking soda slurry treatment resulted in a higher mean (standard deviation [SD]) minimum pH after sucrose challenge than did the control: 5.60 (0.55) and 4.34 (0.45) pH units, respectively, ($n = 5$). This study provides some evidence of the ability of dentifrice with baking soda to help neutralize biofilm acids; however, people typically do not brush their teeth 2 minutes after a sugar challenge.

The second model involved pH telemetry with a partial denture, and the results showed a dose-dependent transient increase in biofilm pH to sodium bicarbonate concentration. The third model involved the extraoral testing of biofilm samples that before collection received no treatment, rinsing with fluoride dentifrice with baking soda slurry, or rinsing with fluoride dentifrice slurry. After baseline pH measurement, the investigators challenged the biofilm samples in vitro with a glucose solution and recorded the pH for 10 minutes. Results of this somewhat contrived experiment showed that the fluoride dentifrice with baking soda inhibited the pH decrease for a glucose challenge more than did the fluoride control dentifrice.

Dawes[10] used a well-controlled in vitro test plaque model to study the effects of different dilutions of fluoride with baking soda (65%) dentifrice and another marketed fluoride dentifrice on the recovery phase of the Stephan curve. The author applied the treatments as a dentifrice and saliva slurry for 1 minute, 20 minutes after a 1-minute challenge with 10% sucrose when the pH had decreased to approximately 4.5. The author found that at the higher baking soda concentrations tested (0.5 and 1 mole per liter), there was a rapid return toward neutrality, which remained elevated for a further 2 hours. For the control fluoride dentifrice, the pH increased slightly, but after 2 hours it had not reached pH 5.5.

Meyerowitz and Zero[14] reported further evidence of the ability of sodium bicarbonate to neutralize biofilm acid rapidly in participants with marked hyposalivation. People with salivary dysfunction have a diminished ability to clear dietary sugars and buffer biofilm acids. For the study, the investigators recruited 5 participants with radiation-induced hyposalivation or Sjögren disease (mean [SD] stimulated saliva 0.06 [0.08] milliliters per minute). The investigators measured biofilm pH by using the touch electrode method at baseline and then at 2, 5, 10, 20, 30, 60, and 90 minutes after a 1-minute 10% sucrose rinse. After an additional 10% sucrose rinse, the participants rinsed with a 0.1 mol/L sodium bicarbonate solution for 1 minute, and the investigators measured plaque pH again at intervals up to 90 minutes. The investigators followed a similar protocol for 5 control participants whose mean (SD) stimulated salivary flow rate was 1.42 (0.55) mL/min. After the 0.1 mol/L sodium bicarbonate rinse, the mean (SD) pH in the participants with hyposalivation increased from 5.0 (0.5) to 9.2 (0.1) at 5 minutes and remained alkaline for 90 minutes. In the control participants, the mean (SD) pH increased from 5.4 (0.3) to 8.5 (0.4) at 2 minutes and rapidly returned toward neutrality. After a third sucrose challenge, the biofilm pH rapidly decreased again.

These results indicate that the participants with marked hyposalivation had protracted decreases of plaque pH after an acidogenic challenge compared with those observed in participants with normal salivary flow. However, a bicarbonate rinse can readily reverse and maintain pH in the alkaline range for extended periods in individuals with hyposalivation. Although not tested in this study, it is likely that people with hyposalivation can use baking soda toothpaste as a measure to reverse the biofilm pH decrease rapidly after sugar consumption; however, it appears that it may be less effective in preventing an acidogenic response when used as a pretreatment before a dietary sugar challenge.

Investigators in other studies have evaluated a fluoride dentifrice with baking soda for its effect on in vitro and in situ demineralization and remineralization, which can be related more directly to the caries process. Kashket and colleagues[15] used a short-term intraoral demineralization model with *S mutans*–coated blocks of bovine enamel. They found that a fluoride dentifrice containing baking soda and peroxide reduced surface enamel demineralization from a 10% sucrose rinse in a manner comparable with that seen with a control fluoride dentifrice. In a subsequent study with this model, Kashket and Yaskell[16] reported that a high-concentration baking soda dentifrice reduced sucrose-induced demineralization and that the buffering effect of baking soda was predominant over the effect of fluoride in this model. However, the sucrose challenge was delayed for 30 minutes after the 20% dentifrice slurry treatment in the former study and 30 or 60 minutes in the latter study to minimize the effect of fluoride in the model. These findings could be applicable for people who brushed

before a cariogenic meal or snack, although the nature of the model and study design limit clinical inference.

Cury and colleagues[17] evaluated the effect of fluoride dentifrice with baking soda in a longer-term (28-day) in situ biofilm demineralization-remineralization model that involved 2 sound enamel specimens (demineralization model) and 2 enamel specimens with artificial carious lesions (remineralization model) held in acrylic palatal appliances of 10 participants. The enamel specimens were recessed from the surface of the appliance by 1 millimeter and covered with a plastic mesh to encourage biofilm formation. During mealtimes, participants removed the appliances and exposed the specimens to a 10% sucrose solution 3 times per day. Ten minutes after the sugar challenge, participants applied a slurry of either a placebo, fluoride or fluoride, and baking soda (20%) dentifrice to the specimens before reinserting their appliances.

Both fluoride dentifrice treatments enhanced remineralization compared with results with the placebo as determined by means of changes in cross-sectional microhardness; however, for the fluoride with baking soda dentifrice, the remineralization response was only slightly higher than that of the fluoride-positive control dentifrice and did not reach statistical significance. Only the fluoride with baking soda dentifrice showed significantly less demineralization than did the placebo, and although the difference between the 2 fluoride dentifrices was not statistically significant, it was directionally in favor of the dentifrice with baking soda. It is not clear whether this study was powered adequately to show differences between the treatments because the investigators included no power calculations.

In summary, there is evidence that sodium bicarbonate can elevate an acidic biofilm pH rapidly to alkaline levels. There is the potential that daily use after exposure to dietary sugars may be of some benefit in preventing dental caries; however, the timing is critical, and it appears that the effectiveness of baking soda in dentifrice depends on concentration.

EFFECT OF BAKING SODA ON ENAMEL REMINERALIZATION

The carbonate content of human enamel apatite is well established as being associated with lower crystallinity and higher acid solubility.[18] Investigators in several studies have evaluated whether sodium bicarbonate interferes with the remineralization of enamel subsurface carious lesions and their subsequent acid resistance.[19,20] Tanaka and Iijima[19] showed that the combination of fluoride and bicarbonate increased acid resistance more than each of them did alone. Kuramochi and colleagues[20] found that in the presence of bicarbonate, carbonate ions were incorporated into enamel lesions during remineralization; however, the extent of remineralization or acid resistance was not affected.

EFFECTS OF BAKING SODA ON BIOFILM COMPOSITION AND METABOLIC ACTIVITY

Dentifrices with baking soda may influence the cariogenic properties of the dental biofilm by changing its composition and metabolic activity. On the basis of the ecological plaque hypothesis, interventions that shift the oral ecology toward a more neutral pH should favor tooth health.[5] Dentifrice with baking soda could help shift the biofilm toward a health-conducive state by interfering with the acid adaptive response of biofilm microorganisms to the low pH environment created by ingestion of dietary sugars and the subsequent selection of cariogenic microorganisms that can tolerate and adapt to the low pH conditions, thereby creating a dysbiosis. This may be particularly beneficial for people with hyposalivation because of the lack of natural buffering capacity from saliva.

There is some evidence that the use of baking soda dentifrices can alter the composition of the biofilm. Legier-Vargas and colleagues[21] investigated the clinical effects of baking soda (65%) dentifrices with and without fluoride against a placebo dentifrice without baking soda or fluoride. They randomly assigned 10 participants to 1 of the 3 dentifrice treatments by using a crossover design over a 4-week period. There were statistically significant reductions in the numbers of mutans streptococci in saliva after use of the baking soda dentifrices compared with results with the placebo treatment. Although not statistically significant, the numbers of lactobacilli were reduced similarly. However, this promising finding has not been followed up with larger-scale clinical studies, despite the now wide acceptance of the ecological plaque hypothesis.[6,22] Furthermore, studies on the effect of baking soda on the acidogenic and aciduric properties of the biofilm microorganisms are warranted, especially in people with hyposalivation.

OTHER STRATEGIES TO CONTROL BIOFILM pH

In addition to baking soda dentifrices, other approaches to maintain biofilm pH in a healthy range, above the critical pH, also should be considered. Chewing gum–containing baking soda is another promising strategy in which the addition of bicarbonate to the increased bicarbonate levels in saliva because of gustatory and mechanical stimulation may be beneficial. Anderson and Orchardson[23] showed that in healthy participants with normal salivary flow, sugar-free gum with baking soda (4%) resulted in a significantly greater salivary pH than did the sugar-free control gum over a 30-minute test period but that the salivary flow rates with the 2 gums were not different. Investigators also have shown that baking soda (2%) in sugar-free chewing gum significantly increased the extent and rate of increase in interproximal plaque pH compared with results with a control gum when chewed 20 minutes after a sugar challenge (toffee).[24] In addition, the elevated pH benefit persisted for the gum with baking soda for at least 20 minutes after the 10-minute chewing period ended. Chewing the gum

with baking soda before the toffee exposure had only a slight effect on minimum pH compared with results with the control gum (4.6 versus 4.4).

Another strategy involves the use of prebiotics such as arginine to improve the pH homeostasis by inducing alkali production by the bacterial arginine deiminase system, thus altering the biofilm ecology toward a healthier state.[25,26] There is some evidence that arginine when added to fluoride dentifrice may contribute to caries prevention.[27]

CLINICAL IMPLICATIONS OF ACID NEUTRALIZATION IN CONTROLLING DENTAL CARIES

Although there are many approaches to treating the consequences of the dental caries disease process, the emphasis is shifting toward measures that preserve teeth.[28] There is the recognition that maintaining the dental biofilm in a healthy state by preventing sugar- and hyposalivation-induced biofilm dysbiosis is an underused strategy.[22] The acid neutralization of dental biofilm by using fluoride dentifrice that contains baking soda has potential for helping to counteract modern high-sugar diets by rapidly neutralizing biofilm-generated acid.

On the basis of the limited available evidence, it appears that the benefits of baking soda depend on concentration, and the wide range of baking soda concentrations (10%-65%) in marketed products likely will affect their ability to neutralize biofilm acids. The timing of using a baking soda dentifrice in relationship to a dietary sugar exposure is also important—the sooner the better—to prevent a sustained biofilm pH decrease and demineralization. It is highly likely that people with decreased salivary flow may benefit the most; however, this benefit depends on the timing of product use in relationship to the sugar exposure. It appears from clinical study results that baking soda, because of its high solubility, has limited substantiveness and does not have a marked effect on limiting the biofilm pH decrease when used before a dietary sugar challenge. Because most people brush only once or twice per day and do not brush their teeth after every sugary meal and snack, other measures are needed to maintain pH homeostasis throughout the day. Besides limiting exposures to dietary sugars, these could include the use of sugar-free chewing gum and mints that contain baking soda, as well as products that contain arginine. ■

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Disclosure. Dr. Zero received an honorarium from the American Dental Association.

The author wishes to thank Dr. Frank Lippert for his help in preparing the Figure.

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