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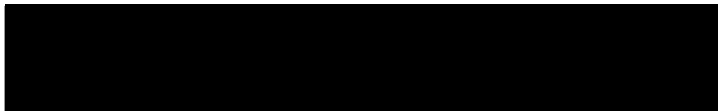


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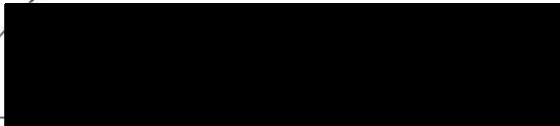


The Erosive Potential of Sugar-Free Waters on Cervical Dentin
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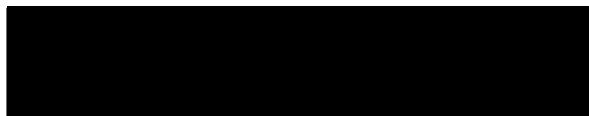


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The Erosive Potential of Sugar-free Waters on Cervical Dentin

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Abstract

Purpose: It has been well documented that highly acidic beverages containing sugar are capable of dental erosion. As dentin has a lower critical pH it is more susceptible than enamel to erosion. The aim of this study was to examine the effect of sugar-free water beverages on the erosion of cervical dentin.

Materials and Methods: Eight beverages were selected including a positive control and a negative control. For each beverage the pH (n=5) and total acidity (n=3) was determined with a digital pH meter. Freshly extracted human premolars were sectioned to create cervical dentin specimens (n=48). The specimens were embedded in acrylic and dentin specimens were polished to create uniformly smooth specimens across groups. Specimens were imaged using a laser profilometry before and after the specimens were challenged with beverages for 24 hours. The three-dimensional before and after scans were analysis to determine the change in surface volume and surface roughness. The data was analyzed with a Kruskal-Wallis with Dunn's post hoc test ($\alpha=0.05$).

Results: The pH of all samples were less than 5.5, except the negative control. Non-carbonated waters required significantly less base in order to neutralize the acid than the carbonated beverages (See table 1).

Conclusion: Within the limitations of this study carbonated beverages have greater potential to cause dentinal erosion. The low total acidity of the non-carbonated waters makes them more likely to be buffered in the oral environment than beverages with carbonation and/or a higher total acidity.

Introduction

Erosion is a prevalent problem for the human dentition with the increasingly acidic foods and beverages that are regularly consumed. The National Health & Nutrition Examination Survey (2003-2004) reported an estimated prevalence of 45.9% among children and 80% among adults (ADA, 2019). Contact time, pH, and total acidity have been shown to be key elements with these acidic foodstuffs in their ability to cause erosion (Lussi, et al., 2004). According to Jarvinen et al. dental erosion is currently described “as loss of dental hard tissue by a chemical process that does not involve bacteria” (1991, p. 942). The American Society for Testing and Materials Committee on Standards defines erosion as “the progressive loss of a material from a solid surface due to mechanical interaction between that surface and a fluid, a multi component fluid, impinging liquid or solid particles” (ASTM, 2002). As such, dental erosion would more properly be termed corrosion, but due to the overwhelming use of the term erosion in literature this nomenclature will be maintained (Grippio et al., 1995). Soft drinks have been the main target of dental erosion research and have been shown to lead to significant amounts of erosion in vitro (Von Fraunhofer & Rogers, 2004). More recently other ‘popular’ beverages like energy drinks have been studied to similar effect due to their total acid content and category of acid contained in the drink (Kitchens et al., 2007).

In recent years there has been a heightened awareness of “making healthy choices”. To address these changing consumer demands many new products have come on the market (Falguera et al., 2012). Bottled and flavored water have been two such developments that are seen as a positive health choice (Ward et al., 2009, Wilk, 2006). In fact, bottled water sales set a new record with over 13 billion gallons being consumed in the United States in 2017 (Smith, 2018). With this milestone bottled water is now the top consumed beverage in the US (Smith, 2018). Unfortunately, these products often have a pH well below a neutral 7.0 and their potential effect on the erosion of

the tooth surface is not known (Rees et al., 2007). It is well-recognized that the critical pH of enamel is 5.5 and the critical pH of dentin is 6.5 (Sulieman, 2004). These values are significant as they represent the pH at which saliva is no longer saturated with calcium and phosphate and the tooth substrate can be dissolved.

Another key issue with changing attitudes and behaviors towards beverages is that the frequency of exposure is critical. It is common for many people to operate under the assumption that the frequent sipping and recapping of an acidic beverage over the course of the day is acceptable. Unfortunately it is not. The salivary pH will drop for a certain period of time after consuming any acidic beverage even if the beverage doesn't contain fermentable carbohydrates. If the acidic fluid continues to be consumed the salivary pH doesn't return to its resting pH until the sipping is discontinued (Humphrey, 2001). Keeping the oral cavity in an erosive pH (below the critical pH of 5.5) has been shown to cause enamel dissolution through the loss of hydroxyapatite from the enamel surface (Millward et al., 1997).

With much research being targeted towards the erosion of enamel, an equally important analysis is needed on the presence and level of erosion that can occur on the dentin substrate. Dentin is more prone to dissolution with its significantly higher critical pH and is exposed on worn dentition and with gingival recession (Sulieman, et al, 2004). Through investigation Moawia et al. found that "more than 50 percent of the population has one or more sites with gingival recession of 1 mm or more" (2003, p. 220). This is significant in that half of patients have an exposed dentinal substrate that is susceptible to erosion.

The purpose of this study is to determine if "Healthy Choice," sugar-free, beverages such as bottled water have the potential to cause dentinal erosion. The null hypothesis for this study is

no differences between beverages when evaluating: 1) pH 2) total acidity 3) erosion of dentin 4) change in dentin roughness.

Materials & Methods

Eight total beverages were selected to be included in this study. All included drinks are commonly sold in the United States of America and do not contain sugar (except Coca Cola as a corrosive beverage reference). These selections were made to be broad sample of drinks that are available to the American consumer. Of each beverage that was chosen, at least three separate containers were purchased to ensure all samples were not from the same container.

All selected beverages were randomly assigned an alternate name to ensure that the testing was blinded.

pH is a measure of the concentration

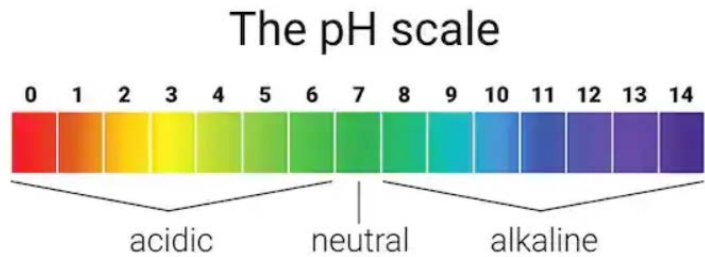


Figure 1: pH scale

of free H⁺ ions in a solution, and uses a 0-14 logarithmic scale (Figure 1). pH analysis was completed with a pH meter (FiveEasy, +/-0.01 pH, Mettler Toledo, Columbus, OH). Prior to analyzing beverages, the pH meter was calibrated using 3 calibration solutions to enhance accuracy. After calibration, 50ml of a freshly opened beverage was poured into a glass beaker and an average of 5 pH readings were immediately recorded for each sample. After each beverage the pH meter was re-calibrated. Five samples of each beverage were analyzed for pH (n=5).

Next, the total acidity was determined. This assessment was selected as it measures both the free and bound H⁺ ions within a solution as opposed to pH, which is a more static finding. Two solutions with a similar pH can have markedly different levels of total acidity based upon the

contained acid or acids. The higher total acidity, the more buffering solution that would be needed to neutralize the acid.

Each beaker of beverage (50ml) was placed on a magnetic stirrer plate (C-MAG HS 7, IKA, Wilmington, NC). The pH of each beverage was constantly monitored as a solution of 0.1M sodium hydroxide was slowly added with a motorized pipette (Pipet-aid, Drummond, Broomall, PA) until a pH of 8.20 was reached. As the 0.1 M NaOH solution was added the mixture was automatically stirred with cylindrical magnetic stirring bars (Radleys, Saffron Walden, UK) at a speed of 4. Three samples of each beverage were analyzed for pH (n=3).

For uniformity, this study focused on evaluating the corrosive effects to cervical dentin of premolars utilizing recently extracted human premolars. To create specimens, teeth was sectioned to create small hexahedral blocks of cervical dentin that were roughly 1.5mm x 1.5mm x 1.5mm in size and then stored in 0.1M PBS prior to mounting. The dentinal block was embedded and oriented into a cylinder of acrylic resin (Diamond D Self Cure Acrylic, Keystone Industries, Gibbstown, NJ) with the superficial dentinal surface exposed (Figure 2). To standardize the variability of each mounted specimen, all specimens were polished with a series of polishing plates



Figure 2: Mounted dentin specimens in 0.1M PBS

in an automatic sample preparation system (Buehler Vanguard 2000, Buehler, Lake Bluff, IL) to create a homogenize surface roughness and to eliminate superficial fluoride-rich layer if present. The smear layer from polishing was removed with a 25% Polyacrylic acid (Ketac Conditioner, 3M, Maplewood,



Figure 3: Specimen after smear layer removal

MN) by a microbrush for 10 seconds (Figure 3). Afterwards, the specimens were rinsed for 30 seconds with deionized water and sonicated (Blazer Ultrasonic Cleaner, Blazer Products, Farmingdale, NY) for 180 seconds in 0.1M PBS and lightly air dried for 10 seconds. The

surface morphology was imaged with the Laser Microscope/Profilometer (Keyence, VK x1000; 10x Nikon lens, Laser).

After scanning, individual specimens were challenged with a freshly-opened cold beverage (8°C) by placing the sample in a container and gently pouring 40ml of a beverage on the exposed dentinal surface. The samples were kept sealed for 24 hours (Figure 4). The tested specimens were then removed from the test solutions, rinsed for 30 seconds with deionized water,

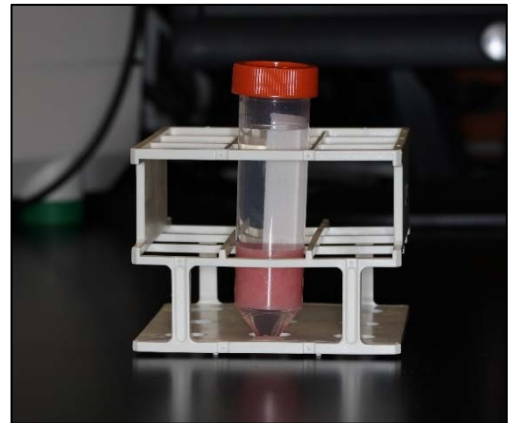


Figure 4: Specimen during testing

sonicated in 0.1M PBS for 180 seconds, lightly air dried for 10 seconds, and post beverage laser profilometer imaging was accomplished. The pre and post profilometer images were aligned and data was analyzed by a blinded examiner. Analysis was performed to determine the change in surface volume and surface roughness of a 1mm x 1mm area. The data did not meet the assumptions of parametric testing. Thus, the data was analyzed with a Kruskal-Wallis with Dunn's post hoc testing ($\alpha = 0.05$).

Results

Table 1: Characteristics of Tested Beverages

The pH of all beverages were less than 5.5, except the negative control, Alkaline 88 (Table

1). Unsurprisingly, the most acidic beverage was Coca-Cola (pH = 2.25) which was selected as

Groups	pH	Total Acidity (ml NaOH)	Volume Loss (μm^3)	ΔR_s (μm)
Alkaline	8.90 (0.05) a		-382,008 (171029) a	0.03 (0.06) a
Coke	2.25 (0.01) g	26.37 (0.32) f	33,698,058 (4244016) f	1.20 (0.39) c
Dasani	5.03 (0.02) c	0.05 (0.01) a	1,180,491 (804772) c	0.09 (0.11) a
La Croix	3.84 (0.04) d	23.30 (0.26) d	12,492,874 (1857486) e	1.08 (0.16) c
Perrier	5.22 (0.03) b	19.90 (0.3) b	4,102,816 (1346609) d	0.70 (0.22) b
Polar	3.71 (0.02) e	22.50 (0.26) c	14,459,465 (2386689) e	1.17 (0.35) c
SmartWater	5.19 (0.03) b	0.06 (0.01) a	456,662 (201318) b	0.07 (0.05) a
Zevia	2.68 (0.01) f	24.73 (0.21) e	37,558,711 (2331692) f	1.57 (0.54) c

Standard Deviation in (); Kruskal-Wallis with step-wise comparison test ($\alpha=0.05$); Lowercase letters indicates statistical subsets by column

the negative control. The other carbonated beverages Zevia Cherry Cola (pH = 2.68), Polar Seltzer Lemon (pH = 3.71), LaCroix Cran-Raspberry (pH = 3.84), and Perrier (pH = 5.22) all had pHs below the critical pH of enamel and dentin. It is of note that the least acidic carbonated beverage, Perrier, was the only one that was unflavored. Zevia Cherry Cola was nearly the most acidic beverage and contained additional acids (tartaric acid and citric acid) unlike the other carbonate beverages. The non-carbonated beverages had pHs that were less acidic in comparison. SmartWater (pH = 5.19) and Dasani (pH = 5.03) were approximately as acidic as Perrier, but contained no carbonation. The non-carbonated beverages also had a pH beneath the critical pH of enamel and dentin. The positive control, Alkaline 88, had a pH much higher than all of the other

tested drinks. The pH was assessed at 8.9, which approximated the advertised pH of 8.8, which far above the critical pHs of enamel and dentin.

When NaOH was added to these beverages, there was a bimodal difference in their behavior between the carbonated and non-carbonated beverages; Alkaline 88 was not tested as its resting pH was above the titratable endpoint. From highest to lowest order with ml of NaOH added was Coca Cola, Zevia Cherry Cola, LaCroix Cran-Raspberry, Polar Seltzer Lemon, Perrier, SmartWater, and Dasani. This quantity amounted to 23.36ml or 47% of the volume of the initial beverage. The non-carbonated waters (Dasani and SmartWater) however, required significantly less base in order to neutralize the acid than the carbonated beverages. Only 0.06ml or 0.12% of the volume of the tested beverage was required to reach the titratable endpoint.

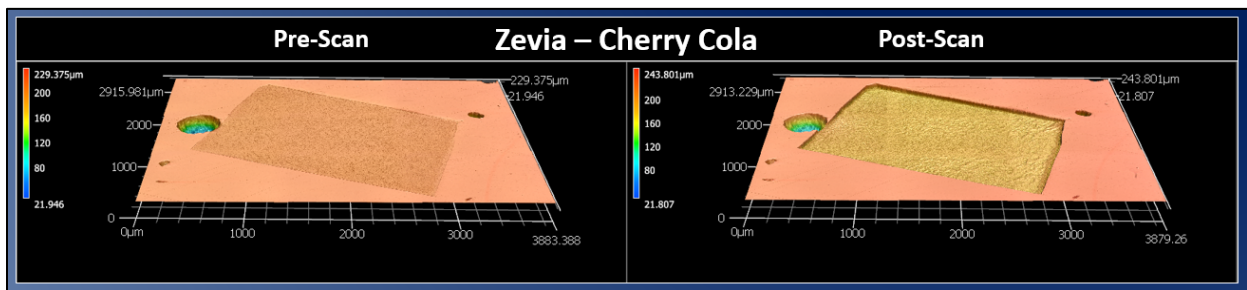


Figure 5: Profilometry scans for Zevia Cherry Cola sample

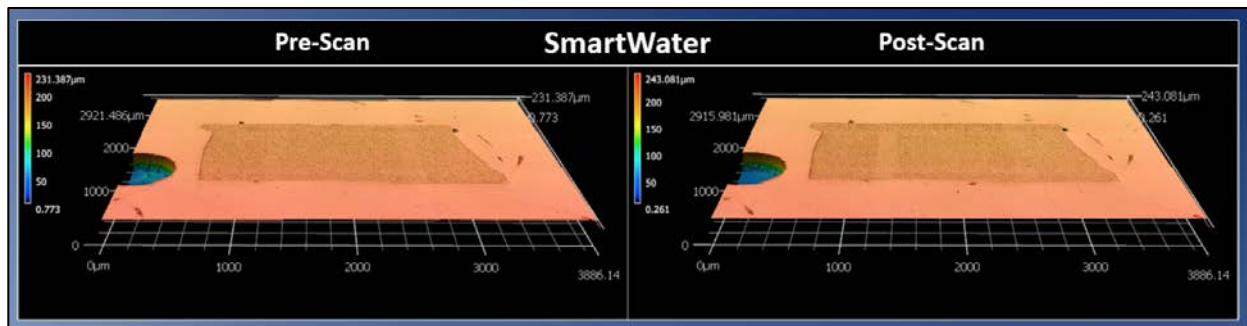


Figure 6: Profilometry scans for SmartWater sample

Upon analyzing the surface roughness from the acidic challenges the bimodal distribution observed with base titration was again observed. Change in surface roughness (S_a) showed the five carbonated beverages to be significantly higher than the non-carbonated water and Alkaline

88 (Figure 5,6). However, the Perrier samples presented as a statically significant third group between the Coca Cola, Zevia Cherry Cola, LaCroix Cran-Raspberry, and Polar Seltzer Lemon samples and the Dasani, SmartWater, and Alkaline 88 samples.

All beverages were shown to be statistically different from each other for the amount of volume loss; Coca Cola and Zevia Cherry Cola were not statistically different from each other and both had the greatest amount of volume loss record. The order of volume loss was nearly identical to the rank order witnessed with the base titration.

Discussion

This investigation exposed caries-free cervical dentin specimens to sugar-free acidic beverages for a time period of 24 hours. After the erosive challenge five beverages produced significant erosion of cervical dentin. Many previous studies utilized enamel specimens that were tested against significantly acidic beverages such as fruit juices and sodas. This study aimed to test waters and beverages that were considered “healthier”.

The pHs revealed that all of the tested beverages, except the negative control Alkaline 88, had a pH beneath the critical pH of dentin (5.5). In order to replicate an acidic challenge in the oral cavity the dentin specimens were immersed in a selected beverage. Erosion can be a product of contact time between the acidic challenge and the dental substrate. 24 hours of contact time between beverage and dentinal substrate was chosen. This time interval corresponds to an actual year of beverage consumption. This math is based on an average beverage intake of 25 ounces per day with a clearance time of 20 seconds (Von Fraunhofer & Rogers, 2004). This would lead to 1,500 minutes (25 hours) on beverage contact time. This period of exposure led to a statistically significant amount of volume loss in all beverages and a change in surface roughness in all but

Alkaline 88, SmartWater, and Dasani. Therefore, dentinal erosion is plausible with sugar-free beverages in vitro.

SmartWater and Dasani as representatives of non-carbonated, non-flavored bottled waters produced the smallest changes upon the dentinal substrates. This was largely due to their lack of total acidity. The beverages' pH were acidic (5.03 for Dasani; 5.19 for SmartWater) but a very small amount of base was more than enough to titrate the acids past the neutral pH point. In healthy individuals, saliva serves this role and buffers the acidic challenges that occur on a daily basis. Therefore, dentinal erosion from non-carbonated, non-flavored bottled waters is not likely in individuals who are capable of producing natural amounts of saliva.

The flavored and carbonated beverages produced significantly more erosion on the dentin samples. The addition of carbonated water to these drinks greatly increased the amount of base that was added to reach a basic pH. In fact, nearly 400x the amount of 0.1 M NaOH was required to hit the titration end-point compared to the non-carbonated waters. The carbonation enabled these waters to incur significantly more volume loss and surface roughness than the non-carbonated waters.

Coca Cola and Zevia Cherry Cola demonstrated the greatest change in surface roughness and loss in surface volume. Both have a low pH due to their added acids (phosphoric acid for Coca Cola; tartaric acid and citric acid for Zevia Cherry Cola) along with the carbonated water they contain. However, the main difference between the two is the presence of traditional sugar versus a sugar substitute, Stevia. The presence of either doesn't seem to make a difference as both are the most likely to cause dentinal erosion in vivo.

Conclusion

Within the limitations of this study carbonated beverages have the potential to cause dental erosion. The low total acidity of the non-carbonated waters makes them more likely to be buffered in the oral environment than beverages with carbonation and/or a higher total acidity.

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