Effect of Carbonated Beverages, Coffee, Sports and High Energy Drinks, and Bottled Water on the *in vitro* Erosion Characteristics of Dental Enamel

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Purpose: This study evaluated the effect of carbonated and non-carbonated beverages, bottled and tap water, on the erosive potential of dental enamel with and without fluoride varnish protection. Materials and Methods: Beverages used in this study included: Coca Cola Classic, Diet Coke, Gatorade sports drink, Red Bull high-energy drink, Starbucks Frappuccino coffee drink, Dasani water (bottled), and tap water (control). Enamel surfaces were coated with Cavity Shield 5% sodium fluoride treatment varnish. Twenty-eight previously extracted human posterior teeth free of hypocalcification and caries were used in this study. The coronal portion of each tooth was removed and then sectioned transverse from the buccal to lingual surface using a diamond coated saw blade. The crown sections were embedded in acrylic resin blocks leaving the enamel surfaces exposed. The enamel surfaces were polished using 600 to 2000 grit abrasive paper and diamond paste. Test specimens were randomly distributed to seven beverage groups and comprised 4 specimens per group. Two specimens per beverage group were treated with a fluoride varnish while 2 specimens did not receive fluoride coating. Surface roughness (profilometer) readings were performed at baseline (prior to fluoride treatment and immersion in the beverage) and again, following immersion for 14 days (24 hours/day). The test beverages were changed daily and the enamel specimens were immersed at 37° C. Surface roughness data was evaluated using multiple factor ANOVA at a significance level of $p<0.05$. Results: Results showed that Coca-Cola Classic, Gatorade and Red Bull with/without fluoride revealed the highest post-treatment surface roughness measurements. Coca-Cola Classic, Diet Coke, Gatorade, and Red Bull all showed significantly higher post treatment readings than StarBucks coffee, Dasani water, and tap water. Fluoride varnish was not a significant impact factor; however, beverage (type) and exposure time were significant impact variables.

Conclusion: Both carbonated and non-carbonated beverages displayed a significant erosive effect on dental enamel; however, fluoride varnish treatments did not demonstrate a significant protective influence on enamel surfaces.

Key words: *dental enamel, erosion, profilometer, enamel roughness, carbonated beverages, high energy drink, coffee*

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INTRODUCTION

Soft drink consumption has increased dramatically over the past 50 years, with the average consumption in 2002 approximately 53 gallons per year or over 16 ounces per day, representing about 25% of the recommended daily fluid intake of 67 ounces.[1,2] The largest increase in soft drink consumption has occurred among children and adolescents. Forty percent of preschool children drink more than 250 ml (8.0 ounces) of soft drinks per day while among 12-to-19-year-old males, consumption was 28 ounces per day and among 12-to-19-year-old females, the rate of intake was 21 ounces *per* day.[3,4]

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In recent years, a growing trend towards increased consumption of artificially sweetened soft drinks, sports drinks, high-energy beverages, and coffee products has occurred among adolescents.[1,5] Sports drink consumption has increased dramatically with over $1.5 billion in sales a year.[6]

An association between dental caries and soft drink consumption has been well documented. The induction of refined sugars from these beverages plays a significant role in caries development, although prevalence is affected by the frequency of ingestion, oral levels of cariogenic bacteria, and other modifying factors including diet, water fluoridation, oral hygiene, and variability in oral physiology.[7]

Dental erosion is an irreversible loss of hard tissues due to a chemical process such as dissolution or chelation without the involvement of microorganisms.[8] Factors such as pH, salivary flow and buffering capacity play an important function in the formation of erosion lesions.[9] Studies[1,8-10] reporting the frequency in the ingestion of soft drinks and other low pH beverages have shown and increased potential in the formation of dental erosive lesions.

Carbonated soft drinks, the largest beverage group *per* consumption in this study, along with other non-carbonated beverages have a low pH, contain refined carbohydrates (sugar) and other additives that may subject dental enamel to acid dissolution, caries formation, and erosion.[11-13] Also, soft drinks and other beverages can remain on the enamel surfaces to be removed by saliva, for an increased cariogenicity potential.[14] The total acid content, and type of acid (phosphoric, citric, etc.) are primary factors regarding enamel destruction.[14,15] These acidulants or polybasic acids exhibit buffering capacities, maintaining the local pH at the tooth surface, below the threshold for enamel dissolution.[16]

Dental erosion and caries formation cause significant damage to dental enamel, particularly in adolescents who ingest high amounts of soft drink or other low pH high sugar containing beverages.[17-19] Altering or reducing the intake of these beverages can decrease the degree of enamel destruction in children and young adults.[7] Although much information has been published studying the effects of carbonated soft drinks on dental enamel, limited data, concerning an association with enamel erosion/cariogenicity and the intake of other beverages (sports and high-energy drinks, coffee beverages, bottled water and processed fruit-based beverages), has been made available.

Fluoride varnishes (5% sodium fluoride) have been used for treating the primary and adult dentitions in the prevention of dental caries. Advantages associated with fluoride varnishes include: sustained release for up to 6 months, can be easily applied to the teeth, less fluoride ingested as with fluoride tray delivery systems, and are applied as semi-liquids in a resin base for increased adherence to enamel.[20,21] One study has investigated the interaction and preventive influence of fluoride treatments associated with intake of citric acid based beverages.[22]

The purpose of this *in vitro* study was to evaluate the effects of six different beverages and a control on enamel surface morphology using profilometer (surface roughness) analysis.

MATERIALS AND METHODS

Seven test beverages were selected for the study based upon current drinking trends of male and female adolescents in the United States. These beverages included: Coca Cola (Classic), Diet Coke, Gatorade sports drink, Red Bull High-Energy drink, Starbucks Frappuccino coffee drink, Dasani bottled water, and tap water as the control (Table 1).

Experimental Design

Previously extracted human anterior teeth free of hypocalcification and caries were carefully cleaned of calculus and other debris and stored in a 1% chloramine-T solution (Fisher Chemical, Fair Lawn, NJ) consisting of 12% active chlorine diluted in distilled water, for infection control purposes, prior to usage in the study. The study protocol, involving human research specimens (teeth), was approved by the University of Tennessee, Memphis, Institutional Review Board (IRB). The teeth were then randomly divided into seven equal groups (beverage) for further subdivision into two subgroups (fluoride varnish/no fluoride varnish). Surface characteristics were evaluated, quantitatively through surface roughness (profilometer) analysis.

Enamel Surface Roughness

Twenty-eight posterior test teeth (4 teeth/beverage group) were used for enamel surface roughness measurement. Enamel specimen blocks were prepared by sectioning the crowns from the root surfaces using a diamond bur in a high-speed handpiece with an air-water spray. The crowns were then sectioned transverse from the buccal to lingual surface through the center of the crown using a high-speed saw (Buehler Int., Evanston, IL) cooled with water. The enamel sections were then embedded in acrylic resin in molds with the outer enamel surface exposed. The enamel surfaces were ground using 600 to 2000 grit abrasive paper and polished with diamond paste. Half of the exposed enamel surface was painted with acrylic

Table 1. Beverage Characteristics

Group	Beverage	Manufacturer	Composition	pH (0-14)	TA (ml of 0.1 M NaOH)
1	Coca-Cola Classic 20 0z.	The Coca-Cola Co. Atlanta, GA	Carbonated water, High fructose corn syrup, Caramel color, Phosphoric acid, Natural flavors, Caffeine	2.49	18.3
2	Diet Coke 20 oz.	The Coca-Cola Co. Atlanta, GA	Carbonated water, Caramel color, Aspartame, Phosphoric acid, Potassium benzoate, Natural flavors, Citric acid, Caffeine	3.12	20.1
3	Gatorade	The Gatorade Co. Chicago, IL	Water, Sucrose syrup, Glucose-fructose syrup, Citric acid Natural lemon/lime Flavors, Natural flavors, Salt, Sodium Citrate, Monopotassium phosphate, Ester gum, Yellow dye #5	2.93	14.8
4	Red Bull	Red Bull N.A., Inc. Santa Monica, CA	Water, Sucrose, Glucose, Sodium citrate, Taurine Glucuronolactone, Caffeine, Inositol, Niacinamide, Calcium-Pantothenate, Pyridoxine HCL, Vitamin B12, Artificial flavors, Colors	3.24	51.9
5	StarBucks Frappuccino Coffee	StarBucks Co. Seattle, WA	Brewed StarBucks Coffee (Water, Coffee), Reduced fat milk, Sugar, Maltodextrin, Pectin, Ascorbic acid	6.59	4.73
6	Dasani Purified	The Coca-Cola Co.	Water, Magnesium sulfate, Potassium chloride, Salt	5.48	N/A
7	Tap Water	N/A	Water, various minerals	7.33	N/A

nail varnish while the remaining surface was left exposed to the testing media (Figures 1a-b). This established a baseline evaluation prior to immersion in the beverage media.

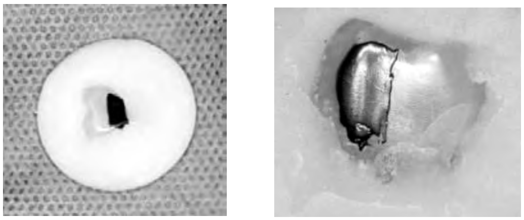

Figure 1a-b: Representative photographs of enamel specimen (one-half coated with nail varnish) embedded in acrylic resin.

The average surface roughness (Ra) is the arithmetic average height of roughness component irregularities from the mean line measured within the sampling length and is expressed in microns (um). Smaller Ra values indicate smoother surfaces. Six traverses of the stylus was made across each side of the specimen (rotated clockwise at 90º angles) so the entire surface of the specimen was evaluated. Sampling lengths of 0.25 mm were used, giving a total evaluation of length of 1.5 mm. The profilometer was calibrated prior to each measuring session (Figures 2a-b).

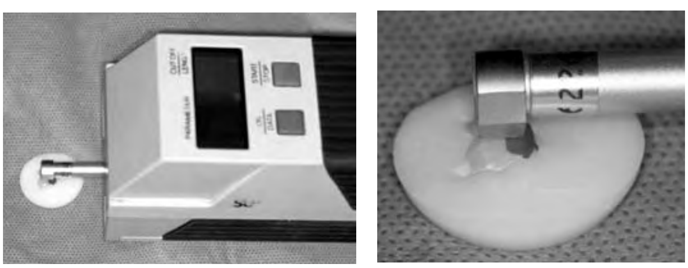

Figure 2a-b: Profilometer analysis of enamel specimen.

Four specimens were assigned to the beverage groups with 2 specimens per beverage receiving fluoride varnish and 2 specimens without fluoride varnish. The enamel specimens were stored in opaque plastic containers (beverages) at 37° C for a total of 14 days. The beverages were changed daily for 14 days. The testing period or beverage immersion period adopted protocol followed by a study by von Fraunhofer and Rogers[7] for dissolution of enamel in beverage solutions. This protocol was based upon an average daily consumption of 25 ounces of soft drink and a residence time in the mouth of 20 seconds (before salivary clearance), making an annual exposure of enamel to soft drinks approximately 90,000 seconds (25 hours) *per* year. The test period of 350 hours used in the study is comparable to 14 years of normal beverage consumption, a reasonable time period for evaluating the erosion of enamel in adolescents and young adults.

The surface roughness (profilometer) of each enamel specimen was again assessed at the end of the 14 day test period. The pH and total acidity (titratable acidity) of each beverage was also measured (Table 1). Three trials were performed for the pH and titratable acidity with an average obtained from each. Figure 3 reveals the titratable acidity of each beverage, plotted at different pH values.

Statistical Analyses

Enamel surface roughness data was subjected to three-factor Analysis of Variance (ANOVA) and post hoc Fisher's tests at a $p<0.05$ level of significance. The statistical calculations were completed using Statview 5.0 (SAS Institute, Cary, NC, USA).

RESULTS

Distribution of mean scores regarding independent variables of beverage, fluoride status (with, without application), and evaluation (exposure) period (baseline, post-treatment), are revealed in Table 2.

Table 2. Distribution of Mean Surface Roughness Scores Three-Factor (Beverage + Fluoride + Evaluation Period)

Independent Variable	Mean	Std. Dev.
C/F/Baseline	.332	.141
C/F/Post	.938	.074
C/NF/Baseline	.388	.090
C/NF/Post	.848	.200
DC/F/Baseline	.358	.114
DC/F/Post	.877	.227
DC/NF/Baseline	.388	.115
DC/NF/Post	.526	.178
G/F/Baseline	.353	.081
G/F/Post	.557	.225
G/NF/Baseline	.221	.066
G/NF/Post	.925	.279
RB/F/Baseline	.322	.109
RB/F/Post	.810	.347
RB/NF/Baseline	.273	.080
RB/NF/Post	.902	.244
SB/F/Baseline	.212	.051
SB/F/Post	.252	.095
SB/NF/Baseline	.217	.090
SB/NF/Post	.252	.095
DH20/F/Baseline	.255	.067
DH20/F/Post	.313	.116
DH20/NF/Baseline	.343	.117
DH20/NF/Post	.336	.077
TH20/F/Baseline	.287	.101
TH20/F/Post	.300	.067
TH20/NF/Baseline	.271	.104
TH20/NF/Post	.253	.152

Significant interaction was exhibited between these factors using three-way ANOVA with Fisher's post hoc testing showing significant differences between paired groups (Table 3). Mean surface roughness scores showed significant differences considering beverage and evaluation period; however no significance difference was observed regarding the fluoride status. Individually, Coca-Cola Classic exhibited significantly greater scores compared to the other beverages, except Red Bull. Diet Coke showed significantly greater roughness scores than both water groups and StarBucks coffee. No significant differences were observed between Diet Coke, Gatorade, and Red Bull, while no significant difference was noted comparing Dasani and tap waters.

Figures 4 and 5 show representative surface erosion by test beverages.

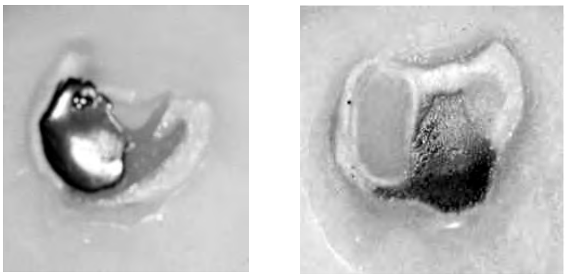

Figure 4-5: Representative post-treatment photographs (40x magnification) of enamel specimens following immersion in Gatorade, Red Bull, and tap water. Note, almost complete dissolution of enamel from non-carbonated beverages.

DISCUSSION

An increased frequency of carbonated and non-carbonated beverages (sports, high-energy, coffee) and bottled water (usually without added fluoride) consumption among adolescents and young adults has precipitated an increase in the caries rate and erosive type lesions.[23] Carbonated and non-carbonated beverages have a low pH, are sweetened by highly refined carbohydrates (sugar and/or sugar substitute components) that are metabolized by plaque microorganisms forming organic acids, and also contain additional additives, all of which can contribute to the demineralization effect and erosive potential of dental hard tissues (enamel).[23]

Two ways to quantify the acid content of a foodstuff or beverage include pH and total or titratable acidity. The pH or actual acidity is the negative logarithm of the hydrogen ion concentration (actual hydrogen ion concentration) and is measured on a scale of 0 to 14 with a reading below 7 indicating an acid content or environment. In general, beverages with lower pH values have greater erosive effect; however, additional factors can also contribute to enamel dissolution in the oral cavity. The titratable acidity (TA) level may be a more realistic and accurate method for measuring the potential acidity in a given beverage. Titratable acidity is the total number of acid molecules, both protonated and non-protonated and determines the actual hydrogen ion availability for interaction with the tooth surface.[24] Other factors involved with the erosion process include the type/concentration/amount of acid, calcium chelating properties, exposure time and temperature, and the buffering capacity of saliva or flow rate and/or saliva content.[7, 9,15]

The acidogenicity is described as the production of oral acids from sugars or refined carbohydrates found in soft drinks. Consequently, the ability of a soft drink to foster caries is referred to as cariogenicity.[23] Developments in beverage technology have focused on means of reducing the harmful effects of soft drinks by modification (addition or deletion) of beverage components. Methods have included the reduction of the total amount of sugar in soft drinks (total sugar concentration in most fruit drinks is between 7 and 10%, although lower concentrations around 0.1 – 1% have shown acidogenic responses in plaque) while other ways include the addition of calcium and/or phosphate supplements that can potentially buffer the effects of low pH values. Citric acid or citrate has also been studied as a soft drink modifying agent for the reduction of plaque pH and in turn, inhibition of the erosive potential; however, current research has revealed inconsequential results regarding the effects on dental erosion.[23,25,26] Soft drinks (carbonated and non-carbonated) contain modifying agents such as phosphoric and/or citric acids (citrates) and have the ability to 1) chelate calcium at higher pHs, increasing the erosive effect in enamel and 2) maintain the pH of the beverage below the threshold level (pH of 5.5) for dental erosion and caries formation, even if diluted.[23,27]

In the present study, quantitative (profilometer) analysis was performed verifying the erosive potential of the carbonated beverages, sports drink, high energy and coffee drinks, bottled water. Profilometer or surface roughness measurements indicated several significant findings comparing independent variables of beverage, fluoride status (with/without), and exposure duration (baseline/post-treatment). Three-way ANOVA showed a significant interaction between the three independent variables. Significant differences were exhibited between different beverages and exposure duration, with no significant differences (overall) exhibited by the fluoride pre-treatments, revealing that the significant impact factors were beverage type and exposure duration and not fluoride specimen pre-treatment. Coca-Cola Classic exhibited significantly greater surface roughness readings than all other beverages, except Red Bull. The StarBucks coffee drink and both waters (bottled and tap) displayed lower readings than the four soft drinks. No significant difference was exhibited between the bottled and tap waters.

The data reported in this study indicates that carbonated and non-carbonated beverages cause significant long term enamel erosion. These findings are in agreement with research conducted by von Fraunhofer and Rogers[7] and Wongkhantee *et al*.[28] in which high levels of enamel dissolution from carbonated beverages were reported. Further research by von Fraunhofer *et al*.[29] has indicated that beverages containing higher concentrations of citric acid are more aggressive towards enamel, which also confirms some of the findings in the present study, in that both the Gatorade and Red Bull drinks contain citric acid or citrates.

In this study, the results indicate that pH, titratable acidity, beverage composition (refined carbohydrate type/concentration and additives), temperature, and time were indeed predisposing factors necessary for the erosion of enamel. Although the pH or "initial pH" is an important factor regarding enamel solubility, the pH alone does not necessarily indicate the potential pH or buffering capacity (titratable acidity), and therein the true erosion potential of a particular beverage. Carbonated beverages contain carbonic acid formed by carbon dioxide in solution, i.e. "carbonated". These beverages also contain inorganic acids such as phosphoric acid to stimulate taste and counteract sweetness. Carbonated and non-carbonated beverages such as fruit-flavored or high sugar concentration drinks consist of organic acids such as citric (orange), tartaric (grape), maleic (apple) and ascorbic (vitamin C) all of which can contribute to the beverage acidity, but can be used as modifying or "buffering" and flavoring agents.[23] Carbonated beverages start with a low pH, but have been found not to require as much titration using sodium hydroxide (NaOH) as do non-carbonated or fruit-based drinks containing multiple refined carbohydrates (sugars).[28] Generally, the more titration required, the higher the buffering capacity, with a corresponding increase of erosion potential of dental enamel. Research by Edwards *et al*.[24] and Wongkhantee *et al*.[28] that tested the titratable acidity of different beverages verified the results of the present study. The titratable acidity or buffering capacity of Red Bull was signifi-

Table 3. Analysis of Variance Statistical Distributions

			Three-Factor Analysis				
Variable	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Beverage (1)	6	7.318	1.220	48.647	<.0001	291.882	1.000
Fluoride Status (2)	1	1.458	1.458	.001	.9808	.001	.050
Evaluation Period (3)	1	6.455	6.455	257.435	<.0001	257.435	1.000
1 * 2	6	.535	.089	3.554	.0020	21.326	.958
1 * 3	6	4.487	.748	29.828	<.0001	178.971	1.000
2 * 3	1	3.646	3.646	.015	.9041	.015	.052
1 * 2 * 3	6	1.326	.221	8.813	<.0001	52.878	1.000
Residual	308	7.722	.025				

cantly higher than the carbonated beverages, Gatorade, or coffee drinks indicating an increased potential for erosion of enamel to occur. Beverages with a strong buffering capacity can also interfere with natural salivary buffering effects, or competition with saliva, on these beverages.[19] Red Bull and Gatorade drinks which revealed significant surface roughness values contain sucrose and glucose compounds that have been shown to cause a substantial reduction in plaque pH, production of acids, and in turn surface erosion of enamel (hydroxyapatite).[23]

Research[23,27,28] has reported that beverages containing citric acid have shown an increased potential for the dissolution of hydroxyapatite due to the formation of calcium citrate and the chelating (calcium binding) action of citric acid that withdraws Ca ions from the beverage, resulting in an increased dissolution tendency due to loss of common ion effect. Red Bull high-energy drink contains sodium citrate (sodium salt of citric acid), a buffering agent which is thought to aid in maintaining the pH levels in soft drinks; however, is also sequestering agent that binds to calcium.[25,26] Red Bull contains calcium-pantothenate and several other additives (glucuronolactone, inositol, pyridoxine HCL). The addition of calcium is presumably to account for earlier depletion during attraction to the citrate compound. The remaining additives are B-complex vitamins, all of which could negatively impact the erosion potential of enamel, although evidence supporting this conclusion could not be verified by the current literature. It is the authors' supposition that the high degree of enamel dissolution noted in the present study associated with sports and high-energy drinks is primarily caused by the addition of high concentrations of refined carbohydrates (sucrose, glucose) that promotes acid production. Citric acids and/or citrates are added as buffering and flavoring agents, although these additions can concurrently bind to calcium, promoting increased titratable acidity levels. In turn, calcium and phosphates are added to compensate for this loss of calcium.

Although the coffee drink contained ascorbic acid, sugar, and maltodextrin - a refined carbohydrate derived from maize starch, no statistically significant differences in surface roughness were exhibited, compared to the control. Ascorbic acid (Vitamin C, L-enantiomer of ascorbic acid) or ascorbate (sodium salt of ascorbic acid) are commonly used as antioxidant food additives or preservatives and may contribute to beverage acidity.[23] Antioxidants are chemicals that reduce oxidative damage to cells and biomolecules.[30] Since the coffee drink contained sugar, maltodextrin, and to a lesser extent, ascorbic acid, greater surface readings compared to the control would have been expected, but were not evident.

Dasani bottled water does not contain added fluoride; however, reverse osmosis involved in the purification process does not remove all of the fluoride from each municipal water source. Although no significant differences in surface roughness values were recorded quantitatively between the Dasani and tap waters, the mean pH of the Dasani water was substantially lower (5.48) than the tap water. This value (all pH readings were performed in triplicate) was also unexpectedly low. These results indicate that perhaps pH alone, is not the traditionally assumed negative variable, impacting enamel surface morphology. The tap water tested was from the Memphis, Tennessee municipal water supply and contains approximately 1.05 ppm fluoride content. The fluoride content in both the bottled and tap waters tested would not have caused a synergistic effect with the fluoride varnish added to the enamel specimens.

Increased temperature and exposure periods have also been reported to increase the erosion and/or dissolution of enamel surface structure.[15,31] An increased solubility and diffusion coefficient rate of ions (calcium and phosphate) in aqueous solution through the enamel at higher temperatures, especially with citric acids, has been reported.[31] These conclusions confirmed the results of the present study, whereby beverages containing citric acid (citrate) and/or fruit-based sugar ingredients showed greater titratable acidity or buffering capacity and in turn, greater enamel dissolution (although not necessarily greater surface roughness measurements). Also, the enamel specimens were immersed in the respective beverages in an incubator at 37° C, simulating an oral environment, and therefore considerably warmer than room temperature. This higher temperature could have expedited the erosion process, although in this experimental model, different temperature variables were not considered. Additional research[32] has investigated the degree of saturation (DS) of a particular beverage and the effect on enamel dissolution. A small increase in DS can cause a reduction in the dissolution rate.

Increases in beverage pH and the addition of calcium and/or phosphates have been methods to increase the DS, consequently lowering the dissolution or erosion potential of enamel. Results from one study[32] did reveal that addition of low concentrations of calcium and phosphate to a citric acid solution comparable to a soft drink did indeed reduce the erosive potential. As previously stated, the Red Bull high-energy drink contained calcium as an ingredient while Gatorade included phosphate. Product modification using additional calcium and phosphate compounds permits alteration of beverage quality without coping with regulatory provisions.

The study protocol (evaluation period) the specimens were immersed, attempted to realistically simulate an adolescent-to-young adulthood experience of beverage consumption. This clinical model probably provided a worst-case scenario, but does logically extrapolate to possible clinical findings of a direct relationship of time (several years) and enamel destruction from beverage exposure. In addition, this study only considered chemical erosion, possibly understating possible tooth wear from other etiologic sources such as abrasion and attrition.

Also, fluoride varnish application was not a statistically significant factor according to quantitative analysis, possibly due to the small group sizes. These results were in agreement with conclusions drawn by Hughes *et al*.[22], whereby the addition of fluoride varnish to tooth structure prior to treatment from various beverages, showed limited protection for enamel.

A possible limitation of this study would include a small sample size. The group size was determined to be small enough to facilitate the logistics of the experimental design, yet large enough to demonstrate statistically significant differences. This study attempted to identify which drinks were the most aggressive towards enamel using quantitative analysis and explore and/or confirm the possible reasons for the erosive effect of these beverages. A secondary experimental concern was the fluoride interaction or preventive effect of these caries inhibiting coverings as erosive protectants.

Beverages containing high percentages of refined carbohydrates and low pH values have been increasingly marketed to a younger age group. An increased consumption of these beverages will concurrently increase enamel surface roughness and/or demineralization, revealing greater plaque adherence and elevated caries risk. The public may perceive that sports and high-energy drinks are healthy without the destructive effect to tooth structure; however, evidence from this study was to the contrary, confirmed by previous research.[6-8,16,28,29,31] General dentists and especially pediatric dentists need to be aware of the potentially damaging effects and consequences of these beverages on dental hard tissues, and diagnostic criteria, so necessary for definitive treatment.

CONCLUSIONS

Within the limitations of this *in vitro* study the following conclusions were drawn:

1) Coca-Cola Classic, Diet Coke, Gatorade, and Red Bull all showed significant surface roughness changes to enamel; while StarBucks Frappucino coffee drink and Dasani bottled water did not show significant surface changes.

2) Significant factors that impacted the change of surface roughness on enamel included the beverage type and the duration of exposure.

3) Although significant differences were exhibited between paired beverage/fluoride groupings, overall, fluoride pre-treatment was not a significant impact factor regarding surface roughness

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