Commercial soft drinks: pH and *in vitro* dissolution of enamel

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Abstract

Background

Most soft drinks are acidic in nature and exposure to these drinks may result in enamel erosion. The purpose of this study was to measure the pH of twenty commercial brands of soft drinks, the dissolution of enamel through immersion in these drinks and the influence of pH on enamel loss. Comparison of the erosive potential of cola versus non-cola drinks as well as regular sugared and diet versions of the same brands was undertaken.

Methods

The pH of 20 brands of soft drinks was measured immediately after opening the soft drink can. Enamel slices obtained from freshly extracted teeth were immersed in the soft drinks and weighed at baseline and after 6, 24 and 48 hours of immersion.

Analysis of variance (ANOVA) was used to determine significant differences in pH. The mean percent (%) of weight loss was calculated for each drink at 6, 24 and 48 hours. ANOVA and Tukey's post-hoc test ($\alpha = 0.10$) were used to test for significant differences in weight loss.

Results

In performing the analyses, several groupings of the drinks were considered. Considered individually, there was no statistically significant difference in pH values; however, RC Cola had the lowest pH at 2.39 and Mug Root beer had the highest at 4.04. Tap water, our control, had a pH of 7.67. Categorized into four groups – cola, non-cola, iced tea, and root beer - there was a statistically significant difference in pH values ($p = 0.003$) with root beer having a significantly higher pH value than the other categories. Comparing only cola and non-cola drinks, non-cola drinks had significantly higher pH values ($p=0.011$). Considering only the five cola and non-

cola drinks which had sugared and diet versions, the sugared versions had significantly lower ($p=0.008$) pH values.

As expected, the % weight loss of the enamel slices increased as the immersion time got longer. The percent weight loss at 48 hours was used for all analyses.

Considered individually, there was no significant difference in mean percent weight loss among the brands. Mug Root beer produced the lowest percent weight loss at 1.58% while Surge produced the highest at 7.85%. When the drinks were categorized into the four groups, there was a statistically significant difference ($p= 0.001$). Non-cola drinks produced significantly higher mean % weight loss than the other categories. Considering only cola and non-cola beverages, there was a significant difference ($p=0.007$) in the mean % weight loss, which was 5.13% for non-cola drinks and 3.65% for cola drinks. When the sugared versions of the five cola and non-cola drinks were compared to their diet counterparts, significant differences were found. Regular Coke and Pepsi had higher mean % weight loss than Diet Coke and Diet Pepsi ($p=0.004$ and $p=0.03$ respectively).

Conclusions

Non-cola drinks had significantly higher pH values than cola drinks but showed higher mean % weight loss. On the other hand, sugared versions of the cola and non-cola drinks had significantly lower pH values and higher mean % weight loss compared to their diet counterparts. pH value of the soft drink did not significantly influence the mean % weight loss ($r = -0.28$).

Clinical implications

Prolonged exposure to soft drinks can lead to significant enamel loss. Non-cola drinks are significantly more erosive than cola drinks. In addition, sugared versions of cola and non-cola drinks are more erosive than their diet counterparts. The erosive potential of the soft drinks was not related to their pH value.

Introduction

Soft drinks continue to replace milk and other nutrient-dense foods and beverages in American diets. In 2003, Americans consumed 46.4 gallons of soft drinks and 21.6 gallons of milk as opposed to 20.3 gallons of soft drinks and 33.0 gallons of milk in 1966.[1] Soft drinks contain no nutrients other than sugar, whereas milk contains minerals, proteins, vitamins and most importantly, calcium. In spite of calcium fortification of some fruit juices, fluid milk consumption exhibits the strongest association with calcium intake.[2] However, soft drinks are considered harmless by the layman. The only concern is regarding their sugar content and that is alleviated by consumption of 'diet' drinks. The fact that even diet drinks have pH values lower than 3.5 and most contain phosphoric acid and/or citric acid is not well understood by most.

Dental erosion is one of the chief concerns with prolonged exposure of teeth to acidic beverages. The most important parameters of beverages affecting dental erosion are their pH, titrable acidity, phosphate and calcium concentration and fluoride content.[3] The effects of soft drinks on enamel, salivary and plaque pH values have been studied in some detail. Various detection techniques have been utilized to study the erosive effects of soft drinks on enamel.[4-7]

Exposure of enamel to soft drinks, even of very short durations, has been shown to reduce enamel microhardness.[8] It has been reported that the erosive potential of cola drinks is ten times higher compared to fruit juices, in the first 3 minutes of exposure to teeth. However,

salivary proteins have been shown to reduce the erosive potential of cola drinks by up to 50%.[9]

A recent study has shown that orange juice and sports drinks significantly reduce the surface hardness of enamel and a cola soft drink significantly reduces the surface hardness of enamel, dentin, microfilled composite resin and resin-modified glass ionomer.[10]

Jensdottir et al. (2005) studied the erosive potential of sixteen soft drinks (including 3 modified drinks) and reported 0-10% weight loss from tooth slices after 72 hours of immersion in these drinks. They found the pH of carbonated and sport drinks to be lower than that of fruit juices whereas titrable acidity and buffer capacity of fruit juices was considerably higher. Addition of calcium and phosphate to the experimental drinks considerably decreased their erosive potential.[11]

A comparison of the erosive potential of regular sugared and diet versions of soft drinks has been conducted by several researchers. Fraunhofer and Rogers (2004) reported that regular and diet versions of soft drinks by the same manufacturer resulted in similar amounts of enamel dissolution.[12] Grobler et al. have reported that diet colas are less erosive than their sugared counterparts and other acidic juices.[13]

In a comparison of cola versus non-cola drinks, non-cola drinks (Mountain Dew, Sprite and Ginger ale) have been found to be more aggressive in enamel dissolution than the cola products (Coca-Cola, Pepsi-Cola and Dr. Pepper).[12] In demineralization experiments on hydroxyapatite, pure citrus juices have been shown to be more erosive than carbonated beverages.[14]

Fraunhofer and Rogers (2005) studied enamel dissolution in several beverages and reported that non-cola beverages, commercial lemonades and energy/sports drinks showed the most aggressive dissolution of enamel. They found no correlation between enamel dissolution

and beverage pH.[15] On the other hand, Larsen and Nyvad (1999) have previously reported that dissolution of enamel increases logarithmically inversely with the pH of the drink.[16]

Purpose of study

The purpose of our study was to measure the pH of twenty commercial brands of soft drinks on the market, the dissolution of enamel in these soft drinks by measuring the amount of enamel lost (by percent weight loss) through immersion in these drinks and the influence of pH on enamel loss. Erosive potential of the soft drinks was analyzed using different groupings: individually, categorized into four groups (cola, non-cola, iced tea, root beer), and cola versus non-cola. For those drinks that had both regular sugared and diet versions, the erosive potential of the two versions was compared.

Methods

Beverages tested

Twenty soft drink brands, including nine cola, eight non-cola, two iced tea and one root beer, most popularly sold at a local gas station were tested in this study. For five cola and non-cola drinks, both the sugared as well as diet formulations were evaluated. Table 1 lists all products included in the study. All products tested were in cans and tap water was used as the control.

Measurement of pH

A digital pH meter (Fisher-Scientific Accumet 925 pH/ion meter) was used to measure the pH of all products. The potentiometer was calibrated at pH 4 and 7 by the use of standard buffer solutions. pH was measured immediately after opening the beverage can. pH of tap water was measured immediately after collection.

Measurement of weight loss

Two hundred fifty two enamel slices (~1 mm x 3 mm x 3 mm) were obtained from buccal and lingual surfaces of freshly extracted teeth using a diamond saw. The teeth were stored in normal saline containing 0.2 % sodium azide until used. The enamel slices were stored in distilled water. These were divided into 21 groups (n=12). Each group was immersed in a different beverage. One group was kept as control and immersed in tap water.

Each enamel slice was weighed using a digital weighing balance (Mettler H2O weighing balance) and then immersed in 5 ml of beverage in a capped plastic vial. At 6 hours, 4 discs from each group were removed from the vials for weighing. Each enamel slice was blotted dry before it was weighed. At 24 hours, another 4 discs from each group were weighed. This protocol was repeated at 48 hours.

Data analysis

pH values

In performing the analyses, several groupings of the drinks were considered. The drinks were considered individually, categorized into four groups (cola, non-cola, iced tea, and root beer), and categorized as cola versus non-cola. For the five drinks which came in both regular sugared and diet versions, a comparison was made between the two formulations. Analysis of variance (ANOVA) was used to determine the existence of significant differences. Paired t-tests were used in the comparison of the regular sugared and diet versions.

Weight loss of enamel

Since the enamel slices were not identical in size, the response variable considered was the percent of weight loss. The drinks were considered individually as well as categorized into four groups- cola, non-cola, iced tea and root beer. Then, cola and non-cola drinks were

analyzed separately. Finally, the sugared and diet versions of five cola and non-cola drinks were compared. ANOVA is the main tool that was used and post-hoc multiple comparisons were carried out using Tukey's test with a family error rate of $\alpha = 0.10$. Regression analysis was performed to examine if a linear relationship exists between pH values and percent weight loss.

Results

pH values

Taken individually, there was no statistically significant difference in pH between the drinks. Table 1 shows the pH values upon opening. RC Cola had the lowest pH at 2.39 and Mug Root beer had the highest at 4.04. Tap water, our control, had a pH of 7.67. When the drinks were classified into the four groups, there was a significant difference in the mean % weight loss ($p = 0.003$) with root beer having a significantly higher pH value than the rest. Comparing only cola and non-cola drinks, non-cola drinks had significantly higher pH values ($p=0.011$). When the sugared versions of the five cola and non-cola drinks were compared to their diet counterparts, the sugared versions had significantly lower ($p=0.008$) pH values.

Weight loss

As expected, immersion in soft drinks resulted in weight loss of the enamel slices and % weight loss increased as immersion time increased. Figure 1 shows mean percent weight loss over time for the four groups and tap water.

The ensuing analyses focus only on the % weight loss after 48 hours of immersion since the greatest weight loss occurred at this time. Table 1 shows the mean percent weight loss for the different beverages tested. Note that Surge produced the highest mean % weight loss at 7.85%, while Mug Root Beer produced the lowest mean % weight loss at 1.58%. However, there were no statistically significant differences in mean % weight loss between the different

soft drinks. Taking all the different soft drinks tested into account, the mean % weight loss was 4.09%.

If we categorize the tested beverages into the four groups mentioned earlier, there is a statistically significant difference in mean % weight loss ($p=0.001$). Non-cola drinks had significantly higher mean % weight loss compared to the other groups.

Considering only cola and non-cola beverages, there is a statistically significant difference ($p=0.007$) in the mean % weight loss. The mean % weight loss for non-cola drinks was 5.13% while for cola drinks, it was 3.65%.

For the five soft drinks that have both sugared and diet formulations, the diet version had consistently lower mean % weight loss than its sugared counterpart, as shown in Figure 2. It is interesting to note that the only significant differences were found between Coke and Diet Coke ($p= 0.004$) and Pepsi and Diet Pepsi ($p= 0.03$).

How does the pH of a beverage affect the % weight loss of enamel slices? Taking all 20 drinks and tap water into account, the correlation between pH upon opening and % weight loss after 48 hours of immersion was found to be -0.241. This shows that as the pH values decrease, % weight loss increases but the linear relationship is weak. When cola and non-cola drinks were compared, non-cola drinks had significantly higher pH values but also significantly higher mean % weight loss. However, when sugared versions of five cola and non-cola drinks were compared to their diet counterparts, the sugared versions had significantly lower pH values and higher mean % weight loss.

Discussion

Limitations of this study include the small sample size of the discs immersed in each kind of beverage and the immersion time. There are inherent differences in solubility of enamel slices

from different teeth. One of the factors influencing the solubility of enamel is the fluoride content of enamel, in the form of fluorapatite. A large sample size ensures even distribution of solubility characteristics in the different groups. We used 4 discs for each beverage for each time period.

It is very difficult to calculate the actual amount of time that the enamel in human mouths is exposed to these acidic beverages. The total exposure time would depend on the actual amount of beverage consumed, the frequency of consumption, i.e., whether small sips are taken at frequent intervals of time or the whole can/bottle is drunk quickly, whether a straw is used to drink these beverages, which would reduce exposure of enamel to them, etc.

An important finding of this study is that the diet versions of the popular soft drinks tested have significantly higher pH values ($p=0.008$) and result in lower enamel dissolution values than the regular sugared versions. The difference in mean % weight loss was statistically significant between Coke and Diet Coke ($p =0.004$) as well as between Pepsi and Diet Pepsi ($p =0.030$). On the other hand, Fraunhofer and Rogers (2004) found no significant difference in enamel weight loss between regular and diet versions of the soft drinks they tested.[12] This may be because of differences in sample size, length of immersion time and the way weight loss was measured (i.e., mean % weight loss versus weight loss per unit area). It is already known that the sugar-free and low-calorie nature of diet drinks lowers their cariogenic potential and their contribution to the obesity epidemic.

When we compared cola and non-cola drinks, the non-cola drinks had significantly higher pH values ($p=0.011$) but also produced significantly higher mean % weight loss than cola drinks ($p=0.007$). This finding suggests that pH is not the major determinant of the erosive potential of a soft drink. In fact, we found a very weak relationship between pH and % weight

loss (r=-0.24). Regression analysis showed that pH accounted for only 5.8% of the variability in % weight loss. Therefore, the type of acid, total acid level and calcium chelating properties may be the more important factors.[17,18] The predominant acid in non-cola drinks is citric acid. Citric acid has been found to be especially erosive because of its ability to chelate calcium at higher pH levels.[19]

Although we tested only one root beer product (Mug root beer), we found it had the highest pH and the lowest % weight loss. This might be attributed to the fact that root beer products are non-carbonated and do not contain phosphoric or citric acids.

It is to be noted that we found a slightly higher mean % enamel weight loss with tap water than with root beer. This difference was not statistically significant and could be attributed to the calcium and phosphorus content of root beer.

Enamel dissolution (% enamel weight loss) increased as the time of immersion got longer indicating that greater length of exposure to these acidic beverages would result in greater loss of enamel. On this basis, limiting intake of these soft drinks to a minimum is recommended. It is further recommended that consumption of non-cola drinks be kept low as these produced significantly higher enamel loss.

Conclusions

Results of this study suggest that:

1. There was a statistically significant difference in the pH of the different categories of soft drinks with root beer having a significantly higher pH value than the rest.
2. Sugared versions had significantly lower pH values than the diet versions of the same soft drink (p=0.008).
3. Enamel dissolution increased with time of immersion.

4. When cola and non-cola drinks are compared, non-cola drinks produced significantly greater mean % weight loss than cola drinks ($p=0.007$).

5. Diet Coke and Diet Pepsi produced significantly lower mean % weight loss than Coke ($p=0.004$) and Pepsi ($p=0.03$) .

6. pH value of the soft drink did not significantly influence the mean % weight loss. There was a weak negative relationship between pH and % weight loss ($r = -0.24$).

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Figure and Table captions

Table 1. List of products included in the study, pH values upon opening, and mean percent weight loss after 48 hours of immersion

Figure 1. Mean % weight loss over time for the four categories of drinks

Figure 2. Mean % weight loss after 48 hours for the five drinks with regular sugared and diet versions

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Table 1

Drink	pH	Mean % Weight Loss at 48 hours
Cola		
Coke	2.525	5.925
Diet Coke	3.289	1.607
Pepsi	2.530	5.619
Diet Pepsi	3.031	2.917
Dr. Pepper	2.899	2.894
Diet Dr. Pepper	3.169	2.220
Cherry Coke	2.522	3.886
RC Cola	2.387	5.452
Mr. Pibb	2.902	2.352
Non Cola		
Mountain Dew	3.229	4.199
Diet Mountain Dew	3.365	3.037
Squirt	2.898	5.692
Surge	3.004	7.85
Slice Orange	3.059	4.95
Sprite	3.298	4.098
7 Up	3.202	6.17
Diet 7 Up	3.706	5.04
Iced Tea		
Lemon Brisk	2.868	2.839
Lemon Nestea	2.969	3.426
Root Beer		
Mug Root Beer	4.038	1.579
Control		
Tap water	7.67	2.45

Figure 1

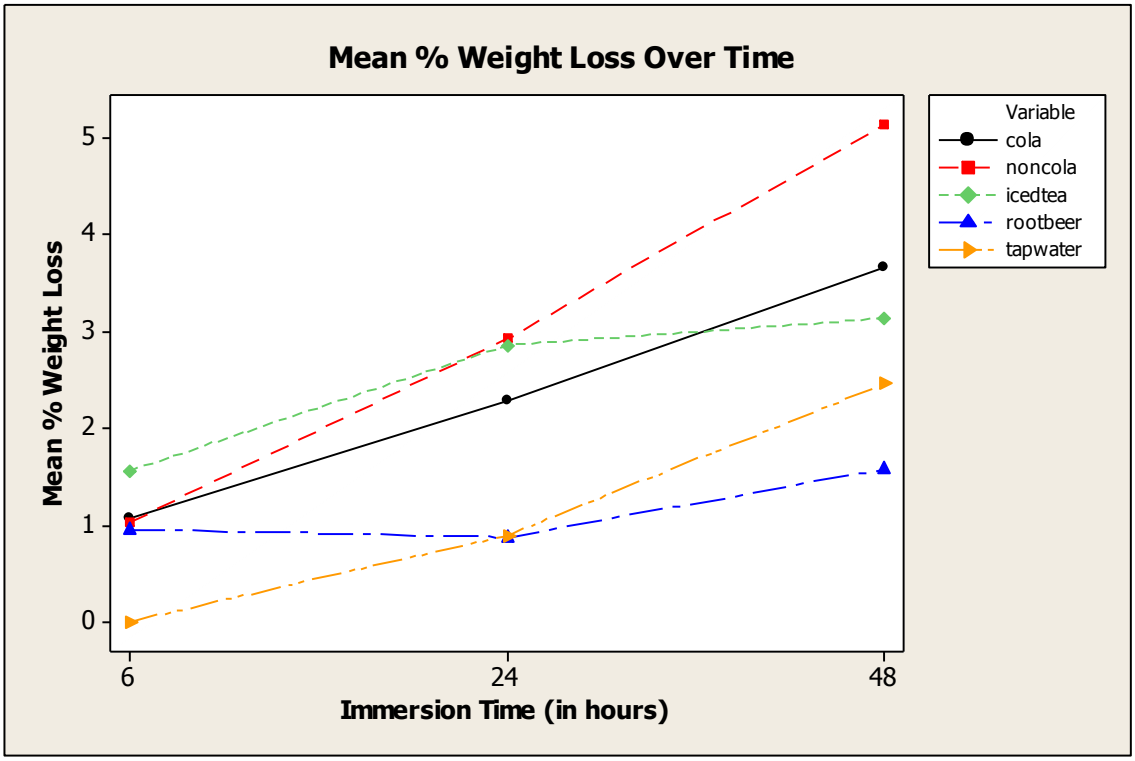
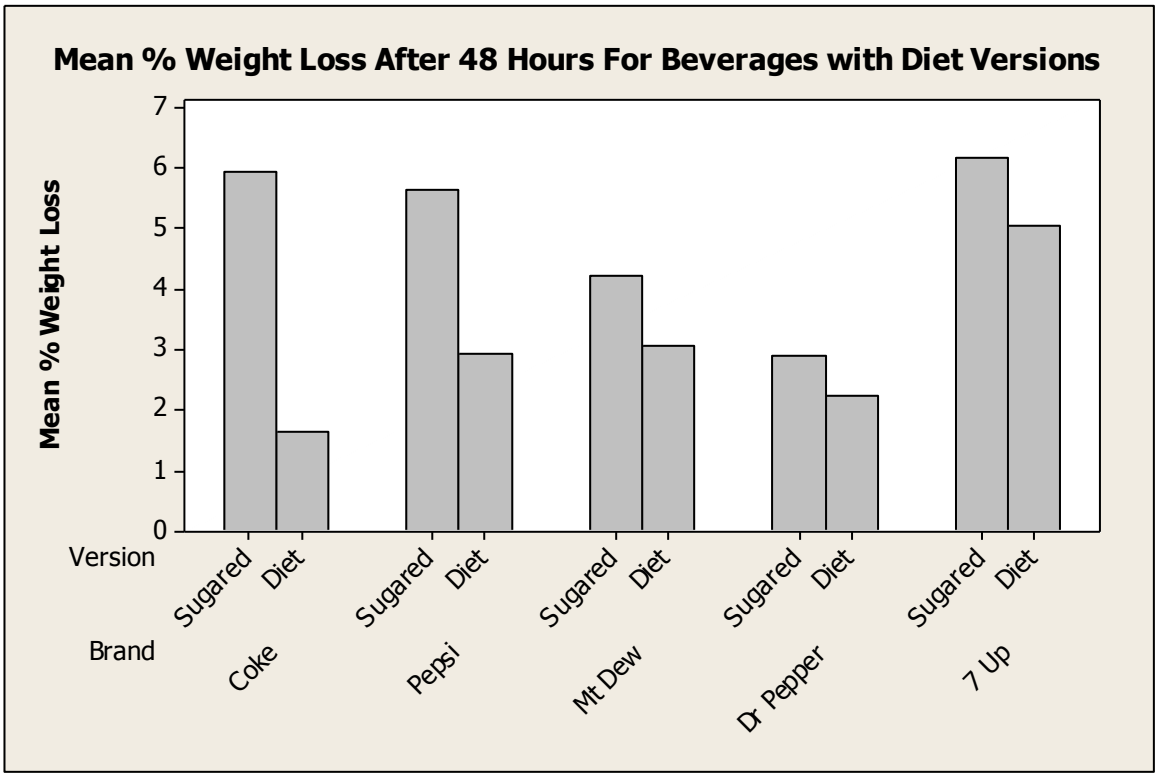

Mean % Weight Loss Over Time
Mean % Weight Loss
0
1
2
3
4
5
6
24
48
Immersion Time (in hours)
Variable
cola
noncola
icedtea
rootbeer
tapwater

Figure 2


Mean % Weight Loss After 48 Hours For Beverages with Diet Versions
Mean % Weight Loss
0
1
2
3
4
5
6
7
Version
Sugared
Diet
Brand
Coke
Pepsi
Mt Dew
Dr Pepper
7 Up