Commercial soft drinks: pH and in vitro dissolution of enamel
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Most soft drinks are acidic in nature and exposure to these drinks may result in enamel erosion. This study sought to measure the pH of 20 commercial brands of soft drinks, the dissolution of enamel resulting from 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. The pH 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.

Non-cola drinks had significantly higher pH values than cola drinks but showed higher mean percent weight loss. By contrast, sugared versions of the cola and non-cola drinks showed significantly lower pH values and higher mean percent weight loss than their diet counterparts. The pH value of the soft drink did not have a significant influence on the mean percent weight loss \( r = -0.28 \).

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

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Soft drinks continue to replace milk and other nutrient-dense foods and beverages in American diets. In 1966, Americans consumed, on average, 20.3 gallons of soft drinks and 33.0 gallons of milk; by comparison, Americans consumed an average of 46.4 gallons of soft drinks and 21.6 gallons of milk in 2003.1 Soft drinks contain no nutrients other than sugar, whereas milk contains minerals, proteins, vitamins, and, most importantly, calcium. Although some fruit juices now are fortified with calcium, fluid milk consumption exhibits the strongest association with calcium intake.2 However, in the experience of one of the authors, patients consider soft drinks to be harmless. 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.3

Dental erosion is one of the chief concerns about prolonged exposure of teeth to acidic beverages. The pH, titrable acidity, phosphate and calcium concentration, and fluoride content are the most important parameters of beverages in terms of their ability to affect dental erosion.4 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.5-8
According to Van Eygen et al, exposing enamel to soft drinks even for a very short duration reduces enamel microhardness.9 It has been reported that in the first three minutes of exposure to teeth, the erosive potential of cola drinks is ten times than that of fruit juices; however, salivary proteins have been shown to reduce the erosive potential of cola drinks by up to 50%.10 A 2006 study reported that orange juice and sports drinks significantly reduce the surface hardness of enamel, while a cola soft drink significantly reduces the surface hardness of enamel, dentin, microfilled composite resin, and resin-modified glass ionomer.11

In 2005, Jensdottir et al studied the erosive potential of 16 soft drinks (including three drinks that were experimentally modified by the addition of calcium and phosphorus) and reported 0–10% weight loss from tooth slices after 72 hours of immersion in these drinks.12 The pH of carbonated and sport drinks was lower than that found in fruit juices, whereas fruit juices demonstrated higher titrable acidity and buffer capacity. Adding calcium and phosphate to the experimental drinks decreased their erosive potential considerably. Dissolving 8.00 g of calcium triphosphate in 1.0 L of pure orange juice reduced the juice’s erosive potential six-fold.

Various studies have compared the erosive potential of regular sugared and diet versions of soft drinks. von Fraunhofer and Rogers reported that regular and diet versions of soft drinks from the same manufacturer resulted in similar amounts of enamel dissolution.13 A decade earlier, Grobler et al reported diet colas to be less erosive than their sugared counterparts and other acidic juices.14

According to the literature, non-cola drinks (such as Mountain Dew, Sprite, and ginger ale) are more aggressive in enamel dissolution than cola products (such as Coca-Cola, Pepsi-Cola, and Dr. Pepper).13 Demineralization experiments involving hydroxyapatite reported that pure citrus juices were more erosive than carbonated beverages.15

von Fraunhofer and Rogers studied enamel dissolution in 2005 and reported that non-cola beverages, commercial lemonades, and energy/sports drinks showed the most aggressive dissolution of enamel, although they found no correlation between enamel dissolution and beverage pH.16 By contrast, Larsen and Nyvad reported that dissolution of enamel increases inversely with the pH of the drink.17

**Purpose of study**

The present study sought to measure the pH of 20 commercial brands of soft drinks and the extent to which pH affects enamel loss. Additionally, this study sought to measure the amount of enamel that was lost (measured as percent weight loss) as a result of immersion in these drinks. Different groupings were used to analyze the erosive potential of the soft drinks: individually, categorized into four groups (cola, non-cola, iced tea, root beer), and cola versus non-cola. For those drinks available in both sugared and diet versions, the erosive potential of the two versions was compared.

**Materials and methods**

**Beverages tested**

This study tested 20 commercially available soft drink brands, including nine cola beverages, eight non-cola beverages, two iced teas, and one root beer. Five cola and non-cola drinks were available in both sugared and unsugared diet formulations. All products tested were in cans and tap water was used as the control.

**Measurement of pH**

A digital pH meter (Accumet 925 pH/ion meter, Fisher Scientific, Pittsburgh, PA; 800.640.0640) was used to measure the pH of all products. Standard buffer solutions were used to calibrate the potentiometer at pH 4.0 and 7.0. pH was measured immediately after the canned beverage was opened. The pH of tap water was measured immediately after it was collected.

**Measurement of weight loss**

Using a diamond saw, 252 enamel slices (~1.0 mm x 3.0 mm x 3.0 mm) were obtained from the buccal and lingual surfaces of freshly extracted teeth. The teeth were stored in normal saline (containing 0.2% sodium azide) until they were sliced. The enamel slices were stored in distilled water until they were
divided into 21 groups (n = 12). Each group was immersed in a different beverage; one group was kept as a control and immersed in tap water.

Each enamel slice was weighed using a digital weighing balance (Mettler AT261 DeltaRange, Mettler-Toledo, Inc., Columbus, OH; 800.638.8537) and immersed in 5.0 mL of beverage in a capped plastic vial. Four discs from each group were removed from the vials for weighing at six hours. Each enamel slice was blotted dry before it was weighed. At 24 hours, another four 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 beverages 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 that were available in both sugared and diet versions, a comparison was made between the two formulations. ANOVA was used to determine the existence of significant differences. Paired t-tests were used to compare the regular sugared and diet versions.

**Weight loss of enamel**

Since the enamel slices were not identical in size, percent of weight loss was the response variable considered. The drinks were considered individually and categorized into four groups: cola, non-cola, iced tea, and root beer. Cola and non-cola drinks were analyzed separately. Finally, the sugared and diet versions of five cola and non-cola drinks were compared. ANOVA was the primary measurement utilized 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 existed between pH values and percent weight loss.

**Results**

**pH values**

Taken individually, there was no statistically significant difference in pH among the drinks. The table shows the pH values of each beverage upon opening the soft drink can. RC Cola had the lowest pH at 2.39 and Mug Root Beer had the highest at 4.04; tap water, the control for this study, had a pH of 7.67. When the drinks were classified in the four groups, there was a significant difference in the mean percent weight loss ($p = 0.003$); root beer had a significantly higher pH value than the rest. When cola and non-cola drinks were compared, non-cola drinks demonstrated 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 pH values ($p = 0.008$).
Weight loss

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

<table>
<thead>
<tr>
<th>Beverage</th>
<th>pH</th>
<th>Mean percent weight loss at 48 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cola</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coke</td>
<td>2.525</td>
<td>5.925</td>
</tr>
<tr>
<td>Diet Coke</td>
<td>3.289</td>
<td>1.607</td>
</tr>
<tr>
<td>Pepsi</td>
<td>2.530</td>
<td>5.619</td>
</tr>
<tr>
<td>Diet Pepsi</td>
<td>3.031</td>
<td>2.917</td>
</tr>
<tr>
<td>Dr. Pepper</td>
<td>2.899</td>
<td>2.894</td>
</tr>
<tr>
<td>Diet Dr. Pepper</td>
<td>3.169</td>
<td>2.220</td>
</tr>
<tr>
<td>Cherry Coke</td>
<td>2.522</td>
<td>3.886</td>
</tr>
<tr>
<td>RC Cola</td>
<td>2.387</td>
<td>5.452</td>
</tr>
<tr>
<td>Mr. Pibb</td>
<td>2.902</td>
<td>2.352</td>
</tr>
<tr>
<td><em>Non-cola</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mountain Dew</td>
<td>3.229</td>
<td>4.199</td>
</tr>
<tr>
<td>Diet Mountain Dew</td>
<td>3.365</td>
<td>3.037</td>
</tr>
<tr>
<td>Squirt</td>
<td>2.898</td>
<td>5.692</td>
</tr>
<tr>
<td>Surge</td>
<td>3.004</td>
<td>7.85</td>
</tr>
<tr>
<td>Slice Orange</td>
<td>3.059</td>
<td>4.95</td>
</tr>
<tr>
<td>Sprite</td>
<td>3.298</td>
<td>4.098</td>
</tr>
<tr>
<td>7 Up</td>
<td>3.202</td>
<td>6.17</td>
</tr>
<tr>
<td>Diet 7 Up</td>
<td>3.706</td>
<td>5.04</td>
</tr>
<tr>
<td><em>Iced tea</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lemon Brisk</td>
<td>2.868</td>
<td>2.839</td>
</tr>
<tr>
<td>Lemon Nestea</td>
<td>2.969</td>
<td>3.426</td>
</tr>
<tr>
<td><em>Root beer</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mug root beer</td>
<td>4.038</td>
<td>1.579</td>
</tr>
<tr>
<td><em>Control</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tap water</td>
<td>7.67</td>
<td>2.45</td>
</tr>
</tbody>
</table>
The ensuing analyses focus only on the percent weight loss after 48 hours of immersion, since the greatest weight loss occurred at this time. The mean percent weight loss for the different beverages tested appears in the table. Surge produced the highest mean percent weight loss at 7.85%, while Mug Root Beer produced the lowest mean percent weight loss at 1.58%; however, there were no statistically significant differences in mean percent weight loss among the different soft drinks. The mean percent weight loss for all of the different soft drinks tested was 4.09%.

When the tested beverages were categorized into the four groups mentioned earlier, there was a
statistically significant difference in mean percent weight loss ($p = 0.001$). Non-cola drinks had a significantly higher mean percent weight loss compared with the other groups.

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

For the five soft drinks available in both sugared and diet formulations, the diet version had consistently lower mean percent weight loss than its sugared counterpart (Fig. 2). 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 percent weight loss of enamel slices? The correlation between pH upon opening the beverage can and percent weight loss after 48 hours of immersion (regression analysis between pH and percent weight loss) was found to be -0.241 for all 20 drinks and tap water. This shows that percent weight loss increases as the pH values decrease, although the linear relationship is weak. Non-cola drinks had significantly higher pH values than cola drinks but also demonstrated a significantly higher mean percent weight loss; however, sugared cola and non-cola drinks had significantly lower pH values and a higher mean percent weight loss than their diet counterparts.

**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 the solubility of enamel slices from different teeth. The fluoride content of enamel (in the form of fluorapatite) is one factor that influences the solubility of enamel. A large sample size ensures even distribution of solubility characteristics in the different groups. The present study utilized four discs for each beverage for each time period.

It is very difficult to calculate the specific period during which the enamel in the human mouth is exposed to these acidic beverages. The total exposure time would depend on the actual amount of beverage consumed, the frequency of consumption (that is, if small sips are taken at frequent intervals or the entire can/bottle is consumed quickly), if the consumer uses a straw to drink these beverages (reducing the enamel's exposure as a result), and so forth.

It is important to note that the diet versions of the popular soft drinks tested showed significantly higher pH values ($p = 0.008$) and lower enamel dissolution values than the regular sugared counterparts. The difference in mean percent weight loss between Coke and Diet Coke was statistically significant ($p = 0.004$), as was the difference between Pepsi and Diet Pepsi ($p = 0.030$). By comparison, von Fraunhofer and Rogers tested regular and diet versions of the same soft drinks and found no significant difference in terms of enamel weight loss.13 The different results regarding enamel weight loss from immersion in regular and diet drinks may have resulted from differences in sample size, length of immersion time, and the method used to measure weight loss (that is, mean percent weight loss versus weight loss per unit area). Because diet drinks are sugar-free and low-calorie, their cariogenic potential is reduced.

When cola and non-cola drinks were compared, the non-cola drinks showed significantly higher pH values ($p = 0.011$) but also produced a significantly higher mean percent weight loss than cola drinks ($p = 0.007$). This finding suggests that pH is not the major determinant of a soft drink’s erosive potential; in fact, there was a very weak relationship between pH and percent weight loss ($r = -0.24$). Regression analysis showed that pH accounted for only 5.8% of the variability in percent weight loss. The type of acid, total acid level, and calcium chelating properties of the beverages may be more important factors.18,19 Citric acid is the predominant acid in non-cola drinks; its ability to chelate calcium at higher pH levels makes it especially erosive.19

Although only one root beer product was tested, it had the highest pH and the lowest percent weight loss. These findings could result from the fact that root beer products are non-carbonated and do not contain phosphoric or citric acids. Samples stored in tap water displayed a slightly higher mean percent enamel weight loss than those stored in root beer. This difference was not statistically significant and could be attributed to the calcium and phosphorus content of root beer.

Enamel dissolution (that is, percent enamel weight loss) increased as the time of immersion increased, indicating that longer exposure to these acidic beverages would result in greater loss of enamel. On this basis, the authors recommend limiting intake of these soft drinks to a minimum; in addition, the
Conclusion

Results of this study suggest a statistically significant difference in pH between the different categories of soft drinks, with root beer demonstrating a significantly higher pH value than the others. Sugared soft drinks had significantly lower pH values than their diet counterparts ($p = 0.008$).

Enamel dissolution increased with time of immersion. Non-cola drinks produced a significantly greater mean percent weight loss than cola drinks ($p = 0.007$). The pH value of the soft drink did not influence the mean percent weight loss significantly. There was a weak negative relationship ($r = -0.24$) between pH and percent weight loss.

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References