The Effect of Acidic Candy on Teeth

S. Maiti

Abstract

The trend in the consumption of candy by children has increased since the 1990s in the USA. Unfortunately, this increased consumption of sweets can lead to negative consequences on oral and overall health. This investigation considered the effect of acidity on an enamel analogue consisting of powdered calcium minerals to simulate the effect of acidic candy on teeth. Four concentrations of 5% acetic acid solution were created (0%, 1%, 10%, 100%) and then allowed to associate with a known height of calcium powder in a clear tube for 24 continuous hours. The height of the calcium powder was measured initially and after 24 hours. The differences in height between the samples were analyzed using an ANOVA test which resulted in an F-statistic of 9.8 and a p-value of 0.089 suggesting a statistically insignificant difference between the difference in the heights of the samples. There were a variety of challenges with the experimental design which decrease the level confidence in the results obtained.

Introduction

The festival of Halloween traces its roots to the ancient Celtic agricultural festival of Samhain (pronounced "sow-in") dating from the 10th century (Rogers, 2002). The festival was historically associated with the end of Summer (Rogers, 2002). The term "Trick-or-Treating" however, which may seem integral to our modern variant, was not recorded until printed by a southern Alberta newspaper in 1927 (Nerman, 2016). "Trick-or-Treating" is the practice of moving from door to door and collecting chocolates and candy from neighbours, usually while dressed up and shouting "Trick-or-Treat!". While fun, and certainly delicious, the activity can lead to increased consumption of candy which can negatively affect the oral and overall health of the consuming individuals (Li, Koltveit, Tronstad, & Olsen, 2000) (Loewen, Marolt, & Ruby, 2008). Overall, the trend of snacking in children has increased in the US since the 1990's, with salty foods and candy being the groups experiencing the most growth (Piernas & Popkin, 2010). For this reason, observing and studying the effects of candy on teeth will be of great importance to dentists and other stakeholders as consumption habits change over time and candy consumption increases. This investigation wanted to find out the effects of the acidic nature of candy on the enamel in teeth specifically.

In order to protect the sensitive parts of the tooth, humans and most other mammals have an outer protective layer of enamel on their teeth (Boyde, 1989). Enamel is composed of highly structured hydroxyapatite crystals, which are a naturally occurring form of the mineral calcium apatite (Hu, Chun, Al Hazzazzi, & Simmer, 2007). Dental enamel is one of the hardest structures in the human body and is usually very resistant to wear (Hu, Chun, Al Hazzazzi, & Simmer, 2007). However, studies have shown that when the pH of its surrounding environment decreases to a critical value of less than pH 5.5, the minerals in the tooth tend towards demineralization

(Tabari, Alaghemand, Qujeg, & Mohammadi, 2017). Demineralization is the process by which the highly structured enamel crystals become free floating ions in solution (Tabari, Alaghemand, Qujeg, & Mohammadi, 2017). Demineralization of the enamel in teeth results in the gradual erosion of teeth surfaces and can cause long-term issues like tooth sensitivity and damage to more sensitive areas of the tooth (Loewen, Marolt, & Ruby, 2008) (Tabari, Alaghemand, Qujeg, & Mohammadi, 2017).

In many cases, candy and chocolates contains sugars and other ingredients like tartaric acid, causing the resulting solution with saliva to be acidic (Jensdottir, Nauntofte, Buchwald, & Bardow, 2005). Normally, saliva is slightly alkaline, having a pH in the range of 6.5 to 7.5 (Jensdottir, Nauntofte, Buchwald, & Bardow, 2005). The chemical composition of saliva allows it to act as a buffer to acidic compounds, (Lilienthal, 1955) however eating an excess amount of acidic foods for an elongated amount of time will eventually decrease mouth pH (Tabari, Alaghemand, Qujeg, & Mohammadi, 2017). The most important component of the buffering system in saliva is the bicarbonate buffer system (Lilienthal, 1955). The chemical equilibrium for this reaction is shown below (Oxtoby & Gillis, 2015):

$$CO2 + H2O \rightleftharpoons H2CO3 \rightleftharpoons HCO3- + H+$$

This means that as the pH of saliva is decreased due to the dissolution of candy, the above chemical equilibrium will be shifted to the left as excess acid is reacted with by the weak base (bicarbonate). The effects of changes in a chemical equilibrium can be predicted by using Le Chatelier's principle (Gall, 2002). As the bicarbonate ion reacts with the acid present in solution, the carbonic acid is converted to bicarbonate ion until the buffer can no longer maintain the pH of the system.

If there is enough acid to exhaust the buffering capability of the system, then eventually the pH will decrease to below the critical value required for demineralization, causing the organized crystal structure of the dental enamel to be converted into free-floating ions in solution, reducing the strength of the enamel. (Jensdottir, Nauntofte, Buchwald, & Bardow, 2005) (Loewen, Marolt, & Ruby, 2008) (Tabari, Alaghemand, Qujeg, & Mohammadi, 2017).

In order to simulate the effect of acid on teeth, varied concentrations of acetic acid were chosen as an analogue for the acidic solution in the oral cavity when eating candy, and 650 mg calcium pills composed of different calcium minerals were chosen to simulate the enamel. After letting the mixtures sit for some time, the amount of calcium was measured to find the difference corresponding to the dissolved amount of calcium.

It was hypothesized that if the concentration of acid in the solutions were increased, then more calcium would be converted from crystalline form to free-floating ionized form because of the increasing inability of the system to maintain a pH above the critical value of 5.5. It is expected that larger concentrations of acetic acid will be able to dissolve larger volumes of calcium, and vice versa.

H: There is a statistical difference in the volume of calcium dissolved by different concentrations of acetic acid, with higher concentrations of acetic acid dissolving more calcium.

H_0: There is no statistical difference in the volume of calcium dissolved by different concentrations of acetic acid.

Materials

- (10) clear plastic tubes of identical size
- (10) 650mg calcium pills
- (1) Ruler
- (~11 tbsp) 5% Acetic acid to make acid solutions
- (~18 tbsp) Tap water to make acid solutions
- Mortar and pestle
- Glassware to hold solutions
- Set of measuring spoons used for baking

Methods

Ideally, a bicarbonate buffer system should be used to properly replicate the environment inside the oral cavity, however this was not possible due to a lack of materials. The oral cavity in this investigation was simulated using an unbuffered solution of tap water and acetic acid. The following procedure was utilized:

We measured out 11 tbsp of 5% acetic acid solution, this corresponded to a sample of 100% strength acetic acid solution. We then measured out 1 tbsp of the 5% acetic acid solution and mixed it with 9 tbsp of tap water. This mixture corresponded to a 10 tbsp sample of a 10% concentration acetic acid solution. Finally, we measured out 1 tbsp of the 10% acetic acid solution and mixed it with 9 tbsp of water. This mixture corresponded to a 10 tbsp sample of 1% acetic acid solution. Since weak acids do not completely ionize in solution a 10x decrease in concentration does not necessarily imply an increase in the pH by 1.

Using a mortar and pestle, we crushed a 650 mg calcium pill and carefully poured it into one of the plastic tubes. We repeated this step until all 10 calcium pills were crushed and put into plastic tubes. We measured and recorded the vertical height of the calcium powder in the tube initially.

We set aside 2 of the tubes filled with calcium powder, these were used as control samples.

We carefully filled the rest of the tubes to the top with the acid solutions we just created, ensuring that the liquid made contact with the side of the tube while pouring as to not disturb the height of the calcium powder; creating 2 samples per concentration of acid. The final 2 tubes were filled with tap water

Finally, the tubes were left for 24h after which the height of the powder was measured and recorded and the difference between the initial height and final height calculated.

An ANOVA test was performed on the height data to determine if there was a statistical difference in the difference of heights between the samples. If there was any statistical significance reported by the results of the ANOVA, a Tukey's test was also performed.

Results

The 100% strength acetic acid solution was slightly yellow in colour and clear initially, while the intermediate concentrations of acid solution were less yellow but still clear. When the 100% strength acid solution was added to the calcium powder, small bubbles were observed floating to the top of the tube. These bubbles were not observed for the samples with tap water, or the solutions with 1% or 10% concentrations of acetic acid.

There was no difference in height observed for the control samples, or samples treated with 10% concentrated acid solution. One of the samples treated with 0% acid solution was observed to have a difference of -0.05 cm seeming to indicate that more calcium powder was present after 24 hours.

Both samples treated with 1% solution observed a difference of 0.1 cm, while the 2 samples treated with the 100% strength 5% acetic acid solution had a difference of 0.2 cm and 0.1 cm.

After 24h had passed, the sample treated with the 100% strength solution of 5% acetic acid had some small precipitate at the top of the tube.

Running an ANOVA test on the data for the difference in heights of the samples treated with 0% acid solution and 100% acid solution resulted in an F-value of 9.8 and a p-value of 0.089.

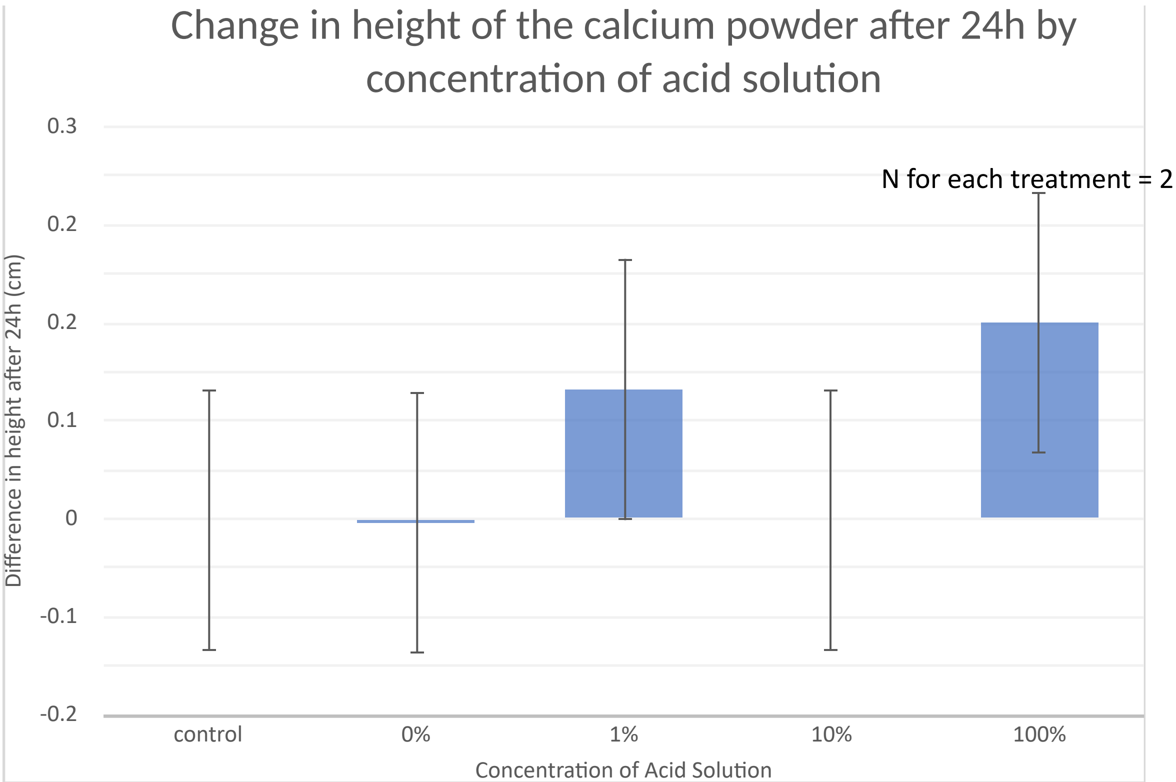

Figure 1. Bar plot of the difference in heights in cm of the calcium powder in the different treatments of acidic solution after 24 h. The error bars represent the smallest marking on the ruler used (±0.1 cm). Each treatment had 2 samples whose observations were averaged for the graph.

Discussion

While the relatively large F-statistic of 9.8 suggests that there is a statistical difference between the difference in the heights of the samples, the p-value being greater than 0.05 indicates that we are not more than 95% confident that these results were not due to circumstance, and therefore have to treat these results as statistically insignificant. Due to the results of our ANOVA test we fail to reject our null hypothesis $\mathbf{H_0}$**.** Support for this conclusion can be drawn from **Figure 1** where the error bars (and therefore uncertainty) associated with the measurements are larger than the differences in the measurements themselves. This information implies that even if there was a significant difference, it's unlikely that it would be possible to observe it given the current level of precision.

While the results seem to match with our initial predictions with the higher concentrations of acidic solution dissolving more calcium powder than the less concentrated solutions, the results of our statistical test make us unconfident in that result.

The biggest source of error in this experiment stems from the lack of precision and accuracy. Only having 2 samples for each treatment could have a huge effect on the accuracy by allowing the results to be much more significantly influenced by random chance. It is also bad practice to perform statistical analysis on small sample sizes. Being able to obtain more precise and accurate readings would increase our confidence in observing a possible difference in the effect of the acid by allowing us to better filter out some of the noise. There were also some issues with the choice of measurement. A better method to see the change in the calcium supplements would be to measure the change in solid mass, however no scale was available which captured the required level of precision to tell the difference between samples. It's very possible that the dissolution of calcium was uneven through the sample, however this is not accounted for by the height which assumes a flat, even layer at the surface. Another change which could have resulted in more significant results is letting the acidic solutions and the calcium powder associate for longer periods of time. While it is likely that a reaction is occurring between the acetic acid solution and the calcium powder due to the presence of bubbles indicating CO_2 being produced in an acid base reaction. It is possible that the reaction proceeds very slowly, and there is not enough of the calcium powder reacted at the end of 24h while sitting at room temperature to make an observable difference. Letting the reaction sit for longer could have produced more significant and observable results.

Furthermore, there are some issues with our assumptions. In animals, the enamel on teeth is in a crystallized structure which is more resistant to erosion than a capsule that is meant to dissolve when ingested (Tabari, Alaghemand, Qujeg, & Mohammadi, 2017). This would suggest that more calcium would dissolve in our experimental conditions than in real life, but our results do not support this. This could be due to one of the errors mentioned above. Finding a closer analogue to enamel would be beneficial in trying to draw conclusions about the effect of acidity on teeth. Performing the investigation using solutions of bicarbonate buffer solution would make it more analogous to the effect of acidity on teeth, and reduce the observations expected as the buffer would initially prevent demineralization by resisting changes in pH. The human body is also closer to 37 °C than room temperature so performing the investigation at a higher temperature not only may have provided more significant results but is also more analogous to the real-life situation.

Conclusion

There was no statistical difference observed in the effects of different concentrations of acidic solution on the enamel analogue and therefore the null hypothesis was not rejected. Due to issues with the experimental design, the authors of this investigation suggest retrying the investigation after implementing the suggestions made above.

Acknowledgements

The authors would like to acknowledge the guidance of Dr. C. Leander in aiding the report writing process by providing helpful guidelines and standards.

The authors would also like to acknowledge Dr. S. Maiti in providing the required materials to perform this investigation.

References

Boyde, A. (1989). Enamel. In B. K. Berkovitz, A. Boyde, R. M. Frank, H. J. Höhling, B. J. Moxham, J. Nalbandian, & C. H. Tonge, *Teeth* (pp. 309-473). Berlin: Springer.

Gall, J. (2002). "The System always kicks back". In J. Gall, *The Systems Bible (3rd ed.).* General Systemantics Press.

Hu, J. C., Chun, Y. H., Al Hazzazzi, T., & Simmer, J. P. (2007). Enamel Formation and Amelogenesis Imperfecta. *Cells Tissues Organs*, 78-85.

Jensdottir, T., Nauntofte, B., Buchwald, C., & Bardow, A. (2005). Effects of Sucking Acidic Candy on Whole-Mouth Saliva Composition. *Caries Research*, 468-474.

Li, X., Koltveit, K. M., Tronstad, L., & Olsen, I. (2000). Systemic Diseases Caused by Oral Infection. *Clinical Microbiology Reviews*, 547-558.

Lilienthal, B. (1955). An Analysis of the Buffer System in Saliva. *Journal of Dental Research*, 516-530.

Loewen, R. R., Marolt, R. J., & Ruby, J. D. (2008). Pucker up: the effects of sour candy on your patients' oral health. A review of the dental erosion literature and pH values for popular candies. *Northwest Dentistry*, 20-29.

Nerman, D. (2016, October 31). *CBC News: Albertans may have been 1st to say 'trick or treat'*. Retrieved November 2020

Oxtoby, D. W., & Gillis, P. (2015). Acid-base Equlibria. In D. W. Oxtoby, & P. Gillis, *Principles of Modern Chemistry (8 ed.)* (pp. 611-753). Boston: Cengage Learning.

Piernas, C., & Popkin, B. M. (2010). Trends In Snacking Among U.S. Children. *Health Affairs*.

Rogers, N. (2002). *Halloween: From Pagan Ritual to Party Night.* Oxford: Oxford University Press.

Tabari, M., Alaghemand, H., Qujeg, D., & Mohammadi, E. (2017). Effect of Popping Chocolate and Candy on Enamel Microhardness of Primary and Permanent Teeth. *Journal of International Society of Preventive & Community Dentistry*, 370-376.