Published in final edited form as:

J Am Dent Assoc. 2009 July ; 140(7): 906–913.

In vitro enamel erosion associated with commercially available original and sour candies

Stephanie N. Wagoner, BS^{*}, Teresa A. Marshall, PhD, RD/LD^{*}, Fang Qian, PhD[†], and James S. Wefel, PhD[†]

^{*} Department of Preventive and Community Dentistry, College of Dentistry, University of Iowa

[†] Department of Dows Research, College of Dentistry, University of Iowa

Abstract

Background—Exposure to acidic foods and beverages is thought to increase risk of dental erosion. We hypothesized that the erosion potential of sour candies was greater than the erosion potentials of original candies.

Methods—The pH and titratable acidity of candies dissolved in artificial saliva or water were measured. Lesion depths of enamel surfaces exposed to candy slurries for 25 hours were measured. Statistics included two sample t-tests and Wilcoxon rank-sum tests to identify differences between original and sour candies and correlations to identify relationships between lesion depths, pH and titratable acidity.

Results—Lesion depths were generally higher following exposure to sour candies compared to original candies, and for candies dissolved in water compared to artificial saliva. Lesion depths were negatively associated with initial slurry pH and positively associated with titratable acidity.

Conclusions—Both original and sour candies are potentially erosive, with sour candies being of greater concern. Although saliva might protect against the erosive effects of original candies, saliva is much less likely to protect against the erosive effects of sour candies.

Clinical Implications—Individuals at risk for candy-associated erosion, particularly those with high intakes, pocketing behaviors or decreased salivary flow, should be provided preventive guidance regarding candy habits.

Keywords

enamel erosion; candy

Corresponding Author: Teresa A. Marshall, PhD, RD/LD, N-335 Dental Science Building, University of Iowa, Iowa City, IA 52242-1010, teresa-marshall@uiowa.edu, phone: 319-335-7190, fax: 319-335-7187.

Author contributions: Study design: SNW, TAM

Data collection: SNW, JSW

Statistical analyses: FQ

Data interpretation: SNW, TAM, JSW

Manuscript preparation: SNW, TAM

Disclaimers: none

Poster Presentation: Portions of this study were presented and published in abstract form at the General Sessions of the American Association for Dental Research in Dallas, TX (2008).

BACKGROUND

Dental erosion is defined as the chemical removal of the enamel surface, and can increase risk of tooth wear associated with mechanical forces.^{1,2} Erosion is categorized as either intrinsic or extrinsic in nature. Intrinsic erosion is associated with exposure to gastrointestinal fluids and reported in individuals with gastroesophageal reflux disorders or eating disorders.^{3,4} Extrinsic erosion is associated with environmental exposures, including acidic foods and beverages.^{1,2,5}

Erosion is more commonly observed in European, Middle Eastern and South American countries than in the United States.^{6–12} In European countries, in vivo erosion is most often associated with acidic beverage consumption,^{13–17} although Milosevic has reported associations between erosion and dietary intakes of vinegar-containing and spicy foods in 14 year olds.¹⁸ The in vitro erosion potentials of beverages consumed in Europe and the United States have been reported, and are thought to be associated with the beverage's pH, titratable acidity and mineral composition.^{13–17,19} Observed in vivo erosion is also thought to be influenced by quantity of beverage consumed, length of consumption episode and oral habits such as holding or swishing the beverage in the mouth.^{18,20,21}

The in vitro erosion potentials of acidic foods have received much less attention than the erosion potentials of beverages. Consumption of most acidic foods such as fruits or pickled vegetables would be expected to occur at meals or snacks; however, consumption of sour or tangy candies would be expected to occur between meals and at snacks. In addition, such candies are typically held in the mouth during the dissolution period which would be expected to increase the exposure period. Jensdottir et al evaluated the erosion potential of saliva produced in vivo during sucking on acidic candies, and reported that, although the salivary buffering capacities increased, the salivary pH fell below the critical pH.²² Their group subsequently compared erosion potentials of hard candies both with and without calcium fortification in Denmark.²³ In their model hard candies were dissolved intra-orally with saliva collected before, during and after candy dissolution. Both fortified and unfortified candies stimulated saliva secretion, and fortified candies released more calcium into the saliva. Calcium fortification significantly lowered the candy's ability to dissolve ground hydroxyapatite, effectively minimizing the candy's erosion potential.²³

Davies et al quantified the erosion potential of sour sweets commonly available in the United Kingdom.²⁴ The sweets were dissolved in deionized water and generally produced greater lesion depths in deciduous than in permanent enamel. The investigators also compared erosion produced by the dissolved sour sweets to erosion produced by orange juice; 2 of the products tested were significantly more erosive than orange juice tested under identical circumstances. Although water is an appropriate solvent to identify the actual erosion potential of the sour sweet and to enable comparison to beverages produced with water, water is not representative of the usual in vivo solvent saliva.²⁴

The epidemiology of erosion associated with exposure to acidic candies has not been described in the scientific literature; however, anecdotal reports of erosion in patients consuming sour candies have gained the attention of the dental profession. In fact, the potential for erosion associated with sour candies has been identified as a “new and emerging concern” by the Minnesota Dental Association.²⁵ In the United States several candy manufacturers have introduced “sour” or “tangy” versions of their original candies. Neither the erosion potentials of the original nor the sour candies have been investigated.

We hypothesized that the erosion potentials of sour candies are greater than the erosion potentials of the original candies. The objective of this study was to compare the pHs and titratable acidities of both the original and sour counterparts dissolved in either artificial saliva

or water, and compared erosion potentials on enamel surfaces following exposure to dissolved candies.

MATERIALS AND METHODS

Experimental design

An in vitro design was used to identify the erosion potential of original and sour candy slurries exposed to extracted human teeth. Following dissolution in either artificial saliva or water, the pH and titratable acidity of original candies were compared to those of sour candies. Lesion depths in enamel surfaces following incubation were compared between original and sour candies dissolved in either artificial saliva or water. Finally, lesion depths were compared between artificial saliva and water solvents.

Candy selection

Four sour candies having original counterparts were selected for study and purchased from local grocery stores. Individual candies included: Jolly Ranchers®, Sour Jolly Ranchers®, Life Savers®, Sour Life Savers®, Mike & Ike®, Sour Mike & Ike®, Twizzlers® and Sour Twizzlers®. The manufacturer of and acidic ingredients within each candy are provided in Table 1.

Slurry preparation

Candies were crushed using a meat cleaver and cutting board or snipped using scissors. Forty grams of crushed/snipped candy were added to 250 ml of inorganic artificial saliva or reverse osmosis water, and stirred with a magnetic stir-bar until all candy was dissolved. This concentration is roughly equivalent to 1 Jolly Rancher® per oz or 1 Twizzlers® per 2.5 oz. The composition of the inorganic, artificial saliva was 20mM NaHCO₃, 3mM NaH₂PO₄ · H₂O and 1mM CaCl₂·2H₂O²⁶.

Physiochemical properties

The pH and titratable acidity of candy slurries were measured in triplicate using an automatic titrator (Metrohm E512 analog pH meter, Brinkmann Instruments, Inc, Westbury, NY 1982). The titratable acidity was measured by adding 1M KOH to 50 ml slurry until a pH 7.0 was reached.

Tooth preparation

Eighty extracted, uncavitated premolars and molars were selected from a pooled supply, disinfected with Streck tissue fixative (Streck Laboratories, Omaha, NE) and cleaned of soft tissue and debris.¹⁹ Soft tissue debris was removed using a razor blade, tweezers, sonicator (Branson 1510, Branson Ultrasonics Company, Danbury, CT) and tooth brush. A small hole drilled in the root was laced with dental floss for suspension. The teeth were painted with fingernail polish to expose one 1×4 mm window of enamel on a flat, smooth surface per tooth. Each tooth served as an independent experimental unit. The University of Iowa Institutional Review Board has ruled that approval is not needed for use of de-identified and pooled extracted teeth for research purposes.

Candy slurry exposure

Teeth (n = 5 teeth per slurry, each tooth having one window) were randomly assigned to candy slurries. Teeth were suspended in 250 ml of candy slurry at room temperature with windows submerged for a total of 25 hours.¹⁹ Every 5 hours teeth were rinsed with distilled water, and incubated in a fresh slurry. Slurries were stirred using a magnetic stir bar during exposures. At the end of the 25 hour exposure period, the teeth were removed from the slurry and rinsed.

Measurements

Exposed teeth were mounted in a mandrel with sticky wax leaving the window exposed and protruding from the mandrel.¹⁹ Teeth were sectioned through the window using a microtome (Series 1000 Hard Tissue Microtome, SciFab, Lafayette, CO, 1996). Six 100–150 micron thick sections were removed from each tooth and stored in water prior to viewing.

A polarized light microscope (Olympus BX-50, Olympus America Inc, Center Valley, PA, 1996) on 4x magnification was used to identify changes in the exposed surface. Four representative sections containing lesions were photographed for each tooth (Spot RT Color Video Camera, software v3.1, Diagnostic Instruments, Sterling Heights, MI, 2000).

The Image Pro Plus system (v5.1, Media Cybernetics, Inc, Silver Spring, MD, 2004) was used to measure lesion depths.¹⁹ Lesion depth was defined as the average distance between a straight line representing the original tooth structure and a line drawn at the base of demineralization. Three lesion depths per tooth were averaged to create a tooth value.

Statistical Analysis

Statistical analyses were conducted using SAS for Windows (v.9.1 SAS Institute Inc, Cary, NC, USA). Physiochemical properties and lesion depths were reported as means and standard deviations. Two sample t-tests and Wilcoxon rank-sum tests were used to identify differences in pH, titratable acidity and lesion depths between original and sour candies and between artificial saliva and water solvents. Pearson correlation and Spearman rank correlations were used to identify relationships between lesion depths and either pH or titratable acidity. The level of significance chosen was $p < 0.05$.

RESULTS

Physiochemical properties of original candies and their sour counterparts dissolved in either artificial saliva or water are presented in Tables 2. With artificial saliva as a solvent, sour candies had lower pHs and higher titratable acidities than the original candies. With water as a solvent, only sour Twizzlers® had a lower pH than the original candy; all sour candies had higher titratable acidities than the original candies.

Original candies dissolved in water had lower pHs and higher titratable acidities than original candies dissolved in artificial saliva ($p < 0.05$). The pH of sour Twizzlers® was lower when dissolved in water than when dissolved in artificial saliva ($p < 0.05$). Neither the pHs nor titratable acidities of other sour candies differed when dissolved in artificial saliva and water.

Mean lesion depths in enamel following 25 hours of exposure to either original or sour candies dissolved in artificial saliva or water are presented in Table 3. With an artificial saliva solvent, enamel lesion depths were greater following exposure to sour candies than to original candies for Jolly Ranchers®, LifeSavers®, and Mike & Ike®, but not for Twizzlers®. Lesion depths of original candies were negatively associated with initial slurry pH ($r = -0.99$; $p < 0.001$), and positively associated with titratable acidity ($r = 0.99$; $p = 0.012$). Lesion depths of sour candies were negatively associated with initial slurry pH ($r = -0.99$; $p = 0.004$), but were not associated with titratable acidity. For both original and sour candies combined, lesion depths were negatively associated with initial slurry pH ($r = -0.80$; $p = 0.031$), and positively associated with titratable acidity ($r = 0.97$; $p < 0.001$).

With a water solvent (Table 3), lesion depths were greater following exposure to sour candies than to original candies for Mike & Ike® and Twizzlers®, but not for LifeSaversR or Jolly Ranchers®. Lesion depths of original candies were not associated with either initial slurry pH or titratable acidity. Lesion depths of sour candies were not associated with initial slurry pH

($p = 0.165$), but were associated with titratable acidity ($r = 0.99$; $p = 0.031$). For both original and sour candies combined, lesion depths were negatively associated with initial slurry pH ($r = -0.82$; $p = 0.023$), and positively associated with titratable acidity ($r = 0.96$; $p < 0.001$).

Mean lesion depths following exposure to candies dissolved in either artificial saliva or water are presented in Table 4. Lesion depths were greater with a water solvent than with an artificial saliva solvent for all candies except original Twizzlers® and sour Jolly Ranchers®. An example of lesion depths for original and sour Jolly Ranchers dissolved in artificial saliva or water is provided in Figure 1.

DISCUSSION

Our results are consistent with the hypothesis that sour candies are more erosive than their original counterparts, particularly in an artificial saliva solvent. The objective of sour candies is to produce a more intense or longer lasting “tangy” flavor. The desired sourness can be achieved by adding more and/or different dietary acids. The candies studied herein contained fumaric, malic and citric acids; the concentration of each in the representative candies is unknown.

Lesion depths were inversely associated with initial pH and positively associated with titratable acidity in both artificial saliva and water solvents. Compared to water, the artificial saliva solvent was associated with higher pHs and lower titratable acidities for original candies, but not for sour candies. These data are supported by Wetton et al’s observation that human saliva can provide some protection against erosion associated with an in vitro citric acid challenge.²⁷ Our artificial saliva contains sodium bicarbonate; the concentration appeared sufficient to buffer the original candies, but not the sour candies which likely contained more concentrated acids. Furthermore, artificial saliva contained calcium which can bind to dietary acids decreasing the titratable acidity and erosion potential.²⁸ Calcium remaining in solution could also minimize the severity of erosion by leading to earlier saturation during dissolution.²⁸

Our finding that most hard candies dissolved in artificial saliva were less erosive than those in water is supported by Jensdottir et al’s work documenting changes in salivary composition during acidic candy consumption.²² Human saliva produced during candy stimulation had higher concentrations of bicarbonate and protein leading to an increased in vivo buffering capacity. Combined with an increased salivary flow rate, the authors concluded that these changes in salivary composition offer some protection against erosion.²²

Jensdottir et al have also demonstrated that calcium fortification of acidic candies decreases the erosion potential of the candies.²³ Saliva produced by human subjects sucking on the fortified candies had similar drops in pH and phosphate concentrations, but significantly higher calcium concentrations than saliva produced with unfortified candies. The saliva produced by fortified candies was significantly less likely to dissolve hydroxyapatite crystals in vitro. Jensdottir et al’s use of human saliva stimulated by candy is unique.²³

Previous studies in beverages with or without calcium fortification support our findings that calcium present in artificial saliva reduces the extent of erosion observed with original and sour candies. Calcium fortification of 100% juices and other beverages has been associated with decreased erosion, while both calcium and phosphate fortification of soft drinks are associated with a decreased erosion potential.^{14,19,29–31} Using in situ models in the United Kingdom, both Hughes et al²⁹ and West et al³⁰ developed minimally erosive blackcurrant juice drinks and carbonated beverages, respectively, by fortifying the beverages with calcium. We have previously reported that commercially available, calcium-fortified 100% juices from the United States were less erosive to both enamel and root surfaces using an in vitro model; however, the ability of calcium to prevent erosion was not absolute. Larsen and Nyvad³¹

reported that Danish orange juice containing calcium phosphate was less erosive in vitro than orange juice without calcium phosphate. Most investigators have reported that the pH of beverages is inversely associated with their erosion potential; however, associations between titratable acidity and erosion potential are more conflicting.^{14,15,17,31}

The in vitro nature of the study design is our primary limitation and encompasses additional limitations including use of artificial saliva and the arbitrary time of exposure. The in vitro design prevents consideration of continuous saliva secretion in response to the tart stimulation as well as clearance of the dissolved candy through swallowing, and prevents the opportunity for remineralization between exposures. Artificial saliva does not contain proteins, which could provide additional buffering against potential erosion. The arbitrary time of exposure was based on pilot studies to ensure that differences in erosion could be detected, and not meant to mimic clinical conditions. Although the observed erosion is likely exaggerated by these limitations, the potential for both original and sour candies to erode enamel may be clinically relevant.

Dentists and hygienists should query patient's dietary behaviors associated with acidic candies, and provide anticipatory preventive guidelines. Such candies are meant to be sucked upon for slow dissolution within the mouth, and would be expected to have a longer exposure time than is observed with other foods and beverages. Furthermore, holding candies within a cheek pocket or having diminished salivary flow could increase the candies' concentration within the salivary fluid and, subsequently, increase risk of erosion. Sucking acidic candies has been demonstrated to stimulate salivary production and improve salivary buffering capacity in healthy, non-medicated volunteers.²² However, individuals with xerostomia often use such candies to treat their dry mouths, and the limited salivary flow could increase the acid concentration. Sanchez et al reported that children with erosion had lower salivary flow rates and buffering capacities than children without erosion.³²

CONCLUSIONS

We have quantified the erosive potential of acidic candies in vitro. Both original and sour varieties are potentially erosive, with sour candies having a greater erosion potential. Artificial saliva as a solvent was more protective against the erosive effects of original candies than the erosive effects of sour candies.

Acknowledgments

The authors would like to thank Maggie Hogan and Jeffrey Harless for their technical expertise in the laboratory.

Sources of Support: This study was supported by the NIDCR (T32 DE014678-05). The contents are the responsibility of the authors and do not necessarily reflect the official views of the granting organizations.

References

1. Moss SJ. Dental erosion. *Int Dent J* 1998;48:529–39. [PubMed: 9881285]
2. Lussi A, Jaeggi T. Erosion diagnosis and risk factors. *Clin Oral Invest* 2008;12:S5–S13.
3. DeMoor RJG. Eating disorder-induced dental complications: a case report. *J Oral Rehabil* 2004;31:725–32. [PubMed: 15210036]
4. Valena V, Young WG. Dental erosion patterns from intrinsic acid regurgitation and vomiting. *Aust Dent J* 2002;47:106–15. [PubMed: 12139263]
5. Milosevic A, Kelly MJ, McLean AN. Sports supplement drinks and dental health in competitive swimmers and cyclists. *Br Dent J* 1997;182:303–8. [PubMed: 9154709]
6. Wiegand A, Muller J, Werner C, Attin T. Prevalence of erosive tooth wear and associated risk factors in 2–7-year-old German kindergarten children. *Oral Diseases* 2006;12:117–24. [PubMed: 16476031]

7. Dugmore CR, Rock WP. The prevalence of tooth erosion in 12-year-old children. *Br Dent J* 2004;196:279–82. [PubMed: 15017417]
8. Al-Malik MI, Holt RD, Bedi R. The relationship between erosion, caries and rampant caries and dietary habits in preschool children in Saudi Arabia. *Int J Paed Dent* 2001;11:430–9.
9. Chadwick BL, White DA, Morris AJ, Evans D, Pitts NB. Non-carious tooth conditions in children in the UK, 2003. *Br Dent J* 2006;2006:379–84. [PubMed: 16607325]
10. Al Majed I, Maquire A, Murray JJ. Prevalence and risk factors for dental erosion in 5-6 year-old and 12–14 year-old boys in Saudi Arabia. *Community Dent Oral Epidemiol* 2002;30:38–46. [PubMed: 11918574]
11. Harding MA, Whelton H, O'Mullane DM, Cronin M. Dental erosion in 5-year-old Irish school children and associated factors: a pilot study. *Community Dent Health* 2003;20:165–70. [PubMed: 12940307]
12. Al-Dlaigan YH, Shaw L, Smith A. Dental erosion in a group of British 14-year-old school children. Part II: influence of dietary intake. *Br Dent J* 2001;190:258–61. [PubMed: 11303686]
13. Phelan J, Rees J. The erosive potential of some herbal teas. *J Dent* 2003;31:241–246. [PubMed: 12735917]
14. Jensdottir T, Bardow A, Holbrook P. Properties and modification of soft drinks in relation to their erosive potential in vitro. *J Dent* 2005;33:569–75. [PubMed: 16005796]
15. Jensdottir T, Holbrook P, Nauntofte B, Buchwald C, Bardow A. Immediate erosive potential of cola drinks and orange juices. *J Dent Res* 2006;85:226–30. [PubMed: 16498068]
16. Lussi A, Kohler N, Zero D, Schaffner M, Mergert B. A comparison of the erosive potential of different beverages in primary and permanent teeth using an *in vitro* model. *Eur J Oral Sci* 2000;108:110–4. [PubMed: 10768723]
17. Hemingway CA, Parker DM, Addy M, Barbour ME. Erosion of enamel by non-carbonated soft drinks with and without toothbrushing abrasion. *Br Dent J* 2006;201:447–50. [PubMed: 17031352]
18. Milosevic A, Bardsley PF, Taylor S. Epidemiological studies of tooth wear and dental erosion in 14-year old children in North West England. Part 2: the association of diet and habits. *Br Dent J* 2004;197:479–83. [PubMed: 15547608]
19. Davis RE, Marshall TA, Qian F, Warren JJ, Wefel JS. In vitro protection against dental erosion afforded by commercially available, calcium-fortified 100 percent juices. *J Am Dent Assoc* 2007;138:1593–8. [PubMed: 18056104]
20. Rios D, Magalhaes AC, Honorio HM, Buzalaf MAR, Lauris JRP, Machado MAdAM. The prevalence of deciduous tooth wear in six-year-old children and its relationship with potential explanatory factors. *Oral Health Prev Dent* 2007;5:167–71. [PubMed: 17977286]
21. Johansson AK, Lingstrom P, Birkhed D. Comparison of factors potentially related to the occurrence of dental erosion in high-and low-erosion groups. *Eur J Oral Sci* 2002;110:204–11. [PubMed: 12120705]
22. Jensdottir T, Nauntofte B, Buchwald C, Bardow A. Effects of sucking acidic candy on whole-mouth saliva composition. *Caries Res* 2005;39:468–74. [PubMed: 16251790]
23. Jensdottir T, Nauntofte B, Buchwald C, Bardow A. Effects of calcium on the erosive potential of acidic candies in saliva. *Caries Res* 2007;41:68–73. [PubMed: 17167262]
24. Davies R, Hunter L, Loyn T, Rees J. Sour sweets: a new type of erosive challenge? *Br Dent J* 2007;204:E3, 1–4. [PubMed: 18084191]
25. Loewen RR, Marolt RJ, Ruby JD. Pucker-up the effects of sour candy on your patient's oral health. A review of the dental erosion literature and pH values for popular candies. *Northwest Dent* 2008;87:20–1. 24–5, 28–9. [PubMed: 18491469]
26. Al-Helal AS, Armstrong SR, Xie XE, Wefel JS. Effect of smear layer on root demineralization adjacent to resin-modified glass ionomer. *J Dent Res* 2003;82:146–50. [PubMed: 12562890]
27. Wetton S, Hughes J, Newcombe RG, Addy M. The effect of saliva derived from different individuals on the erosion of enamel and dentine. *Caries Res* 2007;41:423–6. [PubMed: 17713344]
28. Featherstone, JBD.; Lussi, A. Understanding the chemistry of dental erosion. In: Lussi, A., editor. *Dental erosion*. Basel, Switzerland: Karger; 2006. p. 66-76. Whitford, GM., editor. *Monographs in oral science*. Vol. 20.

29. Hughes JA, West NX, Parker DM, Newcombe RG, Addy M. Development and evaluation of a low erosive blackcurrant juice drink 3. Final drink and concentrate, formulae comparisons in situ and overview of the concept. *J Dent* 1999;27:345–50. [PubMed: 10377609]
30. West NX, Hughes JA, Parker DM, Moohan M, Addy M. Development of low erosive carbonated fruit drinks 2. Evaluation of an experimental carbonated blackcurrant drink compared to a conventional carbonated drink. *J Dent* 2003;31:361–5. [PubMed: 12799121]
31. Larsen MJ, Nyvad B. Enamel erosion by some soft drinks and orange juices relative to their pH, buffering effect and contents of calcium phosphate. *Caries Res* 1999;33:81–7. [PubMed: 9831784]
32. Sanchez GA, Fernandez de Preliasco MV. Salivary pH changes during soft drinks consumption in children. *Int J Paed Dent* 2003;13:251–7.

Figure 1.
1Enamel lesions produced during 25 hours exposure to candy slurry.

Jolly Ranchers®		
Original		
Artificial Saliva	Sour	
	Jollystandard-saliva sb2	Jollysour-saliva sb2

Water

Jollystandard-water sb2

Jollysour-water sb2

Table 1

Manufacturer and acidic ingredient list for original and sour candies.

Candy	Manufacturer	Candy type	Acidic ingredients
Jolly Ranchers®	Made in Canada for Hershey Foods Corporation, Hershey PA.	<i>Original:</i> Original Flavors	Malic acid
		<i>Sour:</i> Fruit n' Sour Flavor	Malic acid
Life Savers®	Made in Canada for WM Wrigley Jr.; Company Chicago IL.	<i>Original:</i> 5 Flavors	Citric acid
		<i>Sour:</i> Sours	Citric acid, malic acid
Mike & Ike®	Just Born, Inc; Bethelam, PA	<i>Original:</i> Original Fruits	Pear juice, citric acid, malic acid
		<i>Sour:</i> Tangy Twister	Pear juice, fumaric acid
Twizzlers®	Y&S Candies for The Hershey Company; Hershey PA.	<i>Original:</i> Cherry Bites	Citric acid
		<i>Sour:</i> Twerpz	Citric acid

Table 2
Mean (± SD) physiochemical properties of original and sour candies dissolved in artificial saliva or water.

Candy	Artificial Saliva				Water							
	Original	pH	Sour	p- * value	Titratable Acidity [‡] ml KOH	Original	Sour	p- * value	Titratable Acidity [‡] ml KOH	Original	Sour	p- * value
Jolly Ranchers®	3.67 ± 0.31		2.47 ± 0.45	0.019	1.58 ± 0.37	2.38 ± 0.18	2.40 ± 0.10	0.893	2.19 ± 0.06	5.19 ± 0.58	0.012	
Life Savers® [‡]	3.67 ± 0.06		3.2	---	2.02 ± 0.10	2.30 ± 0.26	2.4	---	2.72 ± 2.59	5.37	---	
Mike & Ike®	7.00 ± 0		3.70 ± 0.53	0.037	0	2.90 ± 0.26	2.80 ± 0.30	0.687	0.27 ± 0.06	2.12 ± 0.46	0.018	
Twizzlers®	7.00 ± 0		4.27 ± 0.31	0.004	0	4.50 ± 0.44	2.97 ± 0.35	0.009	0.26 ± 0.05	1.83 ± 0.34	0.015	

* Comparison is for original vs. sour candy; two sample t-test or Wilcoxon rank-sum test.
[‡] ml KOH required to bring 50 mL candy slurry pH to neutral. Each slurry was measured in triplicate.
[#] Sour Life Savers were discontinued during time of study; triplicate analyses are not available.

Table 3

Mean ($\pm$ SD) lesion depths* following 25 hours of exposure to original vs. sour candies dissolved in artificial saliva or water.

Candy	Artificial Saliva		p-value [†]	Water		p-value [†]
	Original	Sour		Original	Sour	
Jolly Ranchers®	67 $\pm$ 6	224 $\pm$ 24	<0.001	275 $\pm$ 95	328 $\pm$ 90	0.393
Life Savers®	69 $\pm$ 5	109 $\pm$ 18	0.037	211 $\pm$ 63	200 $\pm$ 11	0.775
Mike & Ike®	8 $\pm$ 19	94 $\pm$ 30	0.010	66 $\pm$ 9	204 $\pm$ 12	0.012
Twizzlers®	6 $\pm$ 14	32 $\pm$ 25	0.140	23 $\pm$ 15	200 $\pm$ 28	<0.001

* n = 5 teeth per candy exposure. The mean lesion depths of 3 sections/tooth were averaged for each tooth.

[†] Comparison is for original vs. sour candy; two sample t-test or Wilcoxon rank-sum test.

Table 4
Mean ($\pm$ SD) lesion depths* following 25 hours of exposure to candies dissolved in artificial saliva vs. water.

Candy	Artificial Saliva	Water	p-value [†]
Jolly Ranchers®	67 $\pm$ 6	275 $\pm$ 95	0.008
Life Savers®	69 $\pm$ 5	211 $\pm$ 63	0.007
Mike & Ike®	8 $\pm$ 19	66 $\pm$ 9	0.010
Twizzlers®	6 $\pm$ 15	23 $\pm$ 14	0.119
Sour Jolly Ranchers®	224 $\pm$ 24	328 $\pm$ 90	0.060
Sour Life Savers®	109 $\pm$ 18	200 $\pm$ 11	0.002
Sour Mike & Ike®	94 $\pm$ 30	204 $\pm$ 12	0.012
Sour Twizzlers®	32 $\pm$ 25	200 $\pm$ 28	<0.001

* n = 5 teeth per candy exposure. The mean lesion depths of 3 sections/tooth were averaged for each tooth.

† Comparison is for artificial saliva vs. water; two sample t-test or Wilcoxon rank-sum test.