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Evaluating the erosive effect of sour candy on human tooth enamel

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The radical increase in consumption of acidic (sour) candies amongst children and teenagers is considered a significant public health concern. The purpose of this study was to evaluate the erosive potential of sour candy in comparison with their regular counterparts at different exposure times. Sixteen prepared tooth samples were randomly assigned into four groups, namely: sour candy (n=8), regular candy (n=8); each of these was prepared to have protected (unexposed) and exposed surfaces in respective candy solutions for 15 min and 2 h (n=4). An Atomic Force Microscope (AFM) was used to measure the surface roughness (Ra) between the exposed and unexposed enamel surfaces for each sample group. The mean Ra measured was used for statistical analysis whilst the elemental loss was assessed using Energy Dispersive Spectroscopy (EDX). The findings showed that sour candy significantly eroded the exposed enamel samples (P<0.01). Overall, the samples exposed to the sour candy for 2 h had the highest eroded Ra values. The study suggests that frequent and long-time consumption of sour candies may pose a negative impact on the tooth as they are found to be highly erosive.

Key words: Candy; erosion, tooth enamel, sour candy.

INTRODUCTION

Oral disease, particularly tooth decay amongst children, youth and adults have remained a growing concern over the last decade in many parts of the world (Frencken et al., 2017; Pine et al., 2004). The World Health Organisation (WHO) confirmed that 60-90% of children suffer from caries associated tooth loss in various developed and developing countries, with an increased incidence of dental caries in many parts of the world (World Health Organization, 2013). More specifically, candy has played a documented role in the cause of tooth erosion and subsequently tooth decay for centuries, having first being made in the 16th century, with sweet manufacturing rapidly developing into an industry during the early 19th century (Petersen et al., 2005). In South

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Africa, the expanding middle-income population are often consumers of high calorie and sugar-containing diets (Petersen et al., 2005; Ronquest-Ross et al., 2015). Furthermore, candy purchase statistics reflect emerging growth in purchase trends, in the growing middle and lower-income groups (Department of Health, 2010). Nowadays, the decrease in the cost of sugar is reportedly fuelling the proliferation of the candy industry (Toussaint-Samat, 2009). While the impact of refined sugars in the bacteria-chemical caries process are well documented (Moye et al., 2014; Moynihan, 2005), the recent proliferation of multiple food acids use as flavour agents, including the advent and populism of sour candy has added another startling dimension to the role of candy in tooth erosion and decay, especially amongst young children, teenagers and young adults, who are the major consumers of such candy (Farias et al., 2013; Gambon et al., 2012).

Interestingly, sour candy has significant types and concentrations of acids to warrant an investigation of its impact on tooth enamel (dos Reis Oliveira et al., 2018; Lazzaris et al., 2015). Whilst sour candy has been scantily available since the early 19^{th} century, there has been a prolific growth of this specific candy type since the latter part of the nineties, where marketing drives are targeted at younger audiences (Farias et al., 2016; Farias et al., 2013; Harris et al., 2015; Petersen et al., 2005). There is growing popularity and demand for this type of candy, driven by consumer demand and clever marketing strategies in combination with Hollywood movies, online gaming and social media (Holst, 2005). Sour candy manufacturers are continually seeking adventurous innovations in taste modification and duration by using higher strength and lower pH acids; in some candy formulations up to four different acid blends are used (Wagoner et al., 2009).

Whilst studies (Aljawad et al., 2017; Davies et al., 2008) have reported that sour candies are more erosive than acidic drinks and beverages; there is, however, limited evidence in the evaluation of the impact of sour candy on tooth enamel. This study, therefore, evaluates the impact of sour candy on tooth enamel. The hypothesis tested was that sour candies are more erosive than regular candies.

Preparation of enamel specimens

Sixteen recently extracted permanent human anterior teeth with no visible defects or prior carious lesions were selected. The enamel specimens (approximately 6 mm x 6 mm x 3 mm) were prepared using a low-speed diamond cutter after the removal of the roots. The prepared enamel specimens were randomly assigned to two different groups based on candy type and pH (Table 1). Each sample was equally divided by placing a central indentation using a low-speed diamond bur to differentiate the surface for exposure. The sample base was placed on a composite resin base for stability, ease of use, and light-cured. A permanent marker was used on the resin base to identify and orientate the specimen. The control surface (unexposed enamel surface) was protected using clear nail varnish (coty topcoat). Samples were subsequently immersed in each of the candy solutions (50 ml) at the specified immersion time intervals under constant agitation (100 rpm at room temperature), then rinsed with deionized water and air-dried. The clear nail varnish was removed using acetone and rinsed again with deionized water and air-dried. The surface of the tooth enamel specimens pre- and post-exposure to the prepared candy solutions were characterized using Scanning Electron Microscope (FESEM; Carl Zeiss, Germany). As a proxy measure, a specimen from each group was analyzed microscopically. The FESEM was operated at controlled atmospheric conditions at 5kV, and images recorded at 1000x magnification.

MATERIALS AND METHODS

Various brands of candy were purchased from grocery stores in Durban, South Africa. The candies were differentiated and marked as sour candy and regular candy types. The candies were subject to pH analysis by dissolving 1 gram candy and 5 ml deionized water. Sour candy pH range was predominantly between pH 2 - pH 3 whilst regular candies were predominantly between pH 4 - pH 6.

Two popular brands of candy were selected from the candy groups; 1. Fun sour worm candy (sour candy A), and 2. Hello kitty Jelly belly (regular candy B). A 50ml solution was prepared for each candy group (A) and (B) and the respective pH was recorded.

Atomic force microscopy (AFM)

Using AFM (Nanoscope; Bruker, Germany), the mean roughness value (Ra) of the specimens were measured on the unexposed and exposed surfaces, to the candy solutions. The instrument was calibrated and set in contact mode with a scanning size of 10 μm and a scan rate of 2.394 Hz. For each specimen section, 4 different measurements of the Ra values were made.

Field scanning electron microscopy (FESEM)

Qualitative assessment of tooth elemental analysis

Elemental characterization of the samples on the unexposed and exposed surfaces to the candies was determined using Energy Dispersive X-ray (EDX) Analysis. Four different sites were measured per sample and the mean difference value between the unexposed and exposed surfaces was used for statistical analysis. Results were obtained as a percentage weight of all elements detected. Data for Carbon (C), Oxygen (O), Phosphorus (P), and Calcium (Ca) are presented due to our interest in the elemental change of calcium and phosphorous that forms the enamel mineral crystallites.

Table 1. Sample groups.

Sample group	Brand name	pH	Number of specimens	Immersion time
Sour candy (A)	1. Fun sour worm candy	2	4	15 min and 2 h
Regular candy (B)	2. Hello Kitty Jelly belly	5	4	15 min and 2 h

Table 2. Mean paired sample test measured for Candy A (sour).

Group		Mean (Ra)	N	Std. Deviation	Std. Error Mean	Significance
Pair 1	Exposed at 15 min	61.5200	4	3.71077	1.85538	0.000
	Unexposed at 15 min	29.5625	4	6.72833	3.36417	
Pair 2	Exposed at 2 h	62.5275	4	12.78485	6.39242	0.015
	Unexposed at 2 h	30.2550	4	3.80693	1.90346	
Pair 3	Exposed at 15 min	61.5200	4	3.71077	1.85538	0.841
	Exposed at 2 h	62.5275	4	12.78485	6.39242	

Statistical analysis

Using a statistical package (SPSS v24; IBM Corp), the mean roughness value (Ra) of the enamel specimens pre and post-exposure was evaluated with a paired sample test. In addition, an independent t-test was performed to compare the mean difference between the two candies (α=0.05).

RESULTS

AFM mean analysis

The mean, standard deviation, and paired sample test results for the tooth specimens exposed to candy A at the specified time interval are noted in Table 2. The results indicate that there was a significant difference between the exposed and unexposed tooth at 15 min exposure time ($P<0.01$). Similarly, a significant difference was noted between the exposed and unexposed tooth surface after 2 h of exposure ($P<0.05$). No significant differences were observed between 15 min and 2 h of exposed tooth samples ($P>0.05$). The mean, standard deviation, and paired sample test results for the tooth specimens exposed to candy B at specified time intervals are noted in Table 3. Regardless of the time of exposure, no significant differences were observed between exposed and unexposed enamel tooth specimens ($P>0.05$).

The mean roughness value (Ra) measured for Candy A and Candy B at specified time intervals of exposure are noted in Table 4. At 15 min, no significant difference were observed between the two candies ($P>0.05$). However, the mean Ra measured for Candy A (62.5±3.7 µm) was statistically higher than those found (43.2±8.5 µm) for Candy B ($P<0.05$). Figure 1 further illustrates the mean Ra value measured for candy A (sour) and B (regular). The higher Ra value measured for candy A was more evident at both the 15 min and 2 h time intervals.

Field scanning electron microscopy (FESEM) observation of specimens

The FESEM images of the specimens exposed to candy A (sour) are noted in Figure 2. At 15 min (Figure 2a1), the enamel crystallites were visible on the surface of the exposed tooth showing pitting and crystal dissolution. These were more evident after 2 h of exposure showing strong demineralization and complete erosion of the enamel prismatic structure (Figure 2b1). Overall, a noticeable difference in the enamel surface of the exposed and unexposed specimens was observed.

The FESEM images of the specimens exposed to candy B (regular) are noted in Figure 3. At 15 min (Figure 3 a1), the enamel was showing signs of demineralization with fragments of enamel crystallites. These were more evident after 2 h of exposure showing strong demineralization of the enamel prismatic structure (Figure 3b1). Overall, a noticeable difference in the enamel surface of the exposed and unexposed specimens was evident. As noted in Figures 2 and 3, the enamel surface appears less smooth following exposure in both groups A (sour) and B (regular) candies. Exposure to both candies even for 15 min renders the tooth surface grainy, texturized, and pitted. These lesions were observed in the exposed surfaces. These characteristics are worsened

Table 3. Mean paired sample test measured for Candy B (regular).

Group		Mean (µm)	N	Std. Deviation	Std. Error Mean	Sig.
Pair 1	Unexposed_15 min	47.9350	4	16.30442	8.15221	0.500
	Exposed_15 min	54.4700	4	7.84551	3.92276	
Pair 2	Unexposed_2 h	34.6425	4	1.68356	0.84178	0.088
	Exposed_2 h	43.2225	4	8.48695	4.24347	
Pair 3	Exposed_15 min	54.4700	4	7.84551	3.92276	0.148
	Exposed_2 h	43.2225	4	8.48695	4.24347	

Table 4. Mean comparison of the roughness value measured for Candy A (s) and B(r).

Time	Group	N	Mean (µm)	Std. Deviation	Std. Error Mean	Sig.
15 min	Candy A (s)	4	61.5200	3.71077	1.85538	0.155
	Candy B(r)	4	54.4700	7.84551	3.92276	
2 h	Candy A(s)	4	62.5275	12.78485	6.39242	0.046
	Candy B(r)	4	43.2225	8.48695	4.24347	

with prolonged exposure as observed in both groups.

Elemental characterisation of specimens

The elemental changes of tooth enamel specimens pre- and post-exposure to candy A are noted in Figure 4. A reduction in the amount of calcium and phosphorus loss was observed after exposure at each time interval. At 15 min, the amount of phosphorus loss was 11.8% whilst 34% was lost after 2h. Equally, 14.1% of calcium was lost at 15 min when compared to 40.3% loss after 2 h. Overall, more calcium and phosphorous were lost after 2 h exposure.

The elemental analysis of tooth enamel specimens pre- and post-exposure to candy B is given in Figure 5. A reduction in the amount of calcium and phosphorus loss was observed after exposure at each time interval. At 15 min, the amount of phosphorus loss was 26.9% whilst 39.1% was lost after 2 h. Equally, 32.1% of calcium was lost at 15 min when compared to 43.75% loss after 2 h. Overall, more calcium and phosphorous were lost after 2 h exposure.

DISCUSSION

The purpose of this study was to evaluate the erosive potential of sour candy in comparison with their regular counterparts at different times of exposure. Based on all the quantitative data generated, the hypothesis stated was accepted as the sour candy (A) was significantly more erosive when compared against the regular candy (B) ($P<0.05$). From the data gathered in the present study, there was a significant dissolution of the tooth enamel after 15 min of exposure to sour candy which is characterized by the high percentage loss of calcium and phosphate. More so, it is reported in the literature that children who consumed sour candies more than twice, once daily and 2-4 times per week are nearly 24, 18, and 8 times more susceptible to dental erosion and subsequent tooth decay due to enamel vulnerability (dos Reis Oliveira et al., 2018). Regardless of the time of exposure, the findings from this study reveal that sour candy had a significant impact on tooth enamel. By contrast, the regular candy showed no significant differences and may be attributed to the pH of the regular candy that is close to the critical pH (5.5). According to Arnold et al. (2007), enamel dissolution or demineralization occurs at a pH below 5.5. Although the exposure time of 15min showed no significant difference between the sour candy (candy A), the regular candy (Candy B), sour candy had significantly higher erosion at 2 h exposure (Table 3). Wagoner (2009) suggested that candies are usually sucked on and slowly dissolved in the mouth over time and that manufacturers continually develop carrier substances to increase the durability of the candy and its flavour that consumers perceive as a higher value for money. It may, therefore, be assumed that the longer exposure of sour candies in the oral

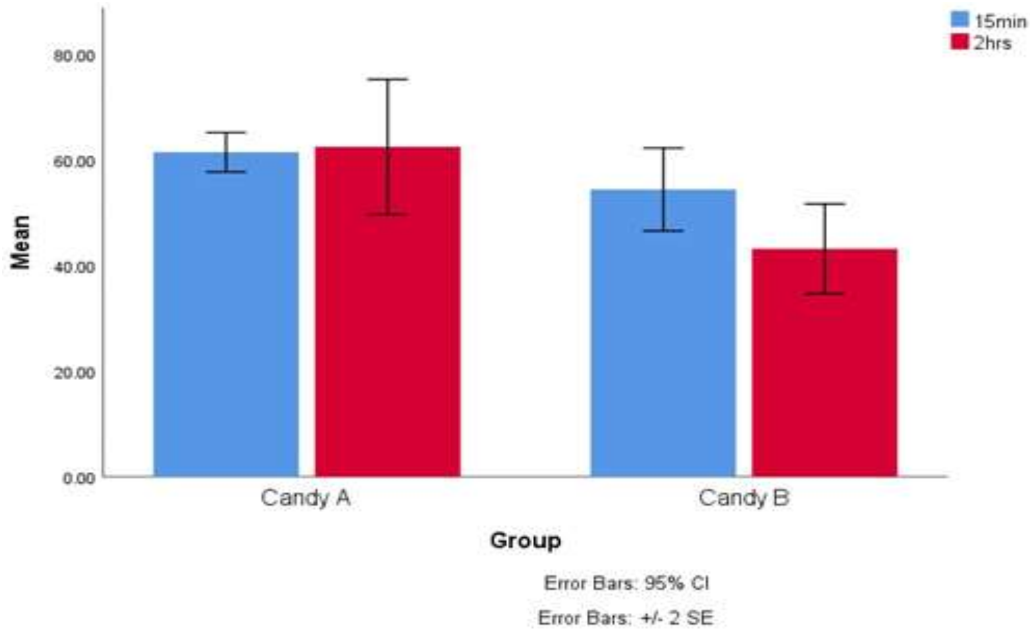

Figure 1. Mean surface roughness values for specimens exposed to candy types A (sour) and B (regular) for 15 min and 2 h.

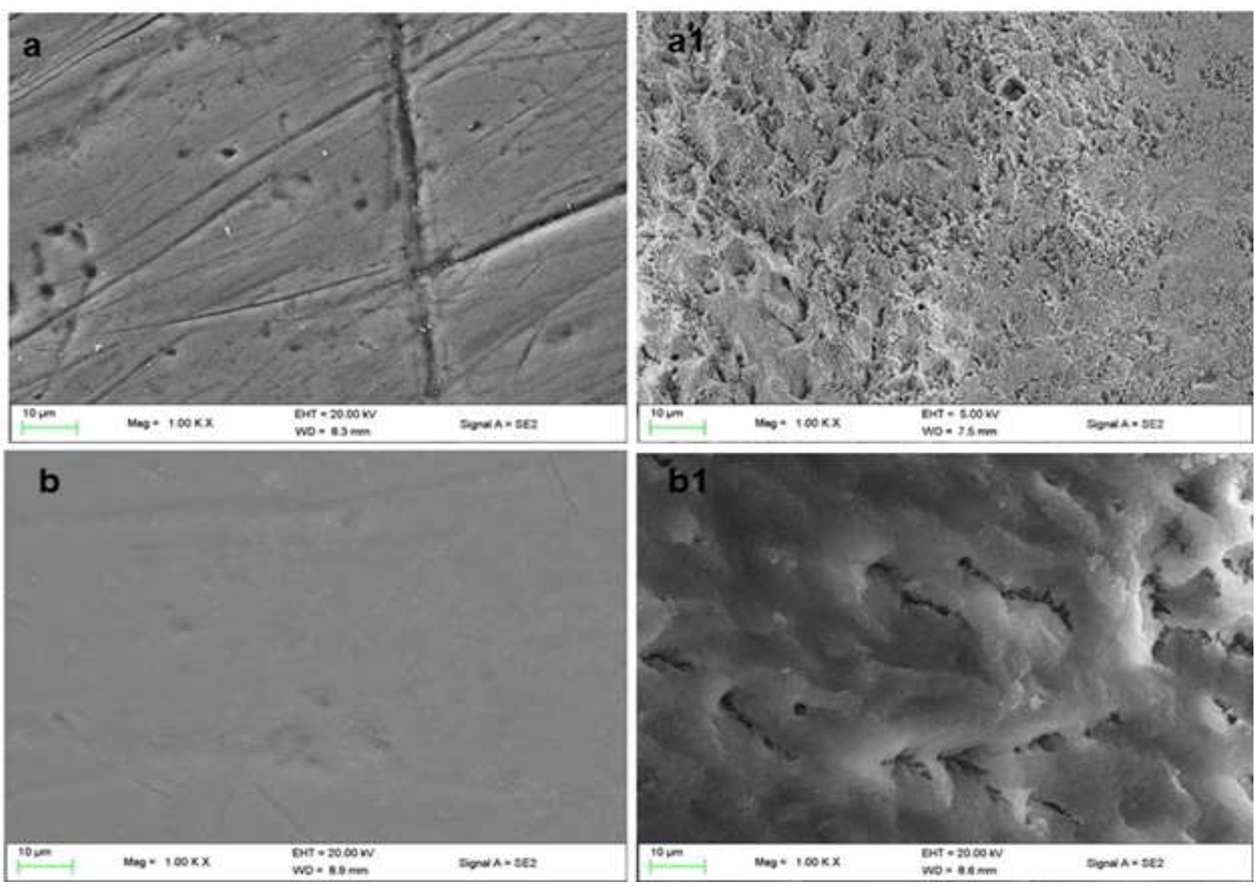

Figure 2. FESEM images of tooth enamel surfaces showing sour candy (a) 15 min unexposed (a1); 15 min exposed (b); 2 h unexposed (b1); 2 h exposed (x1000 magnification).

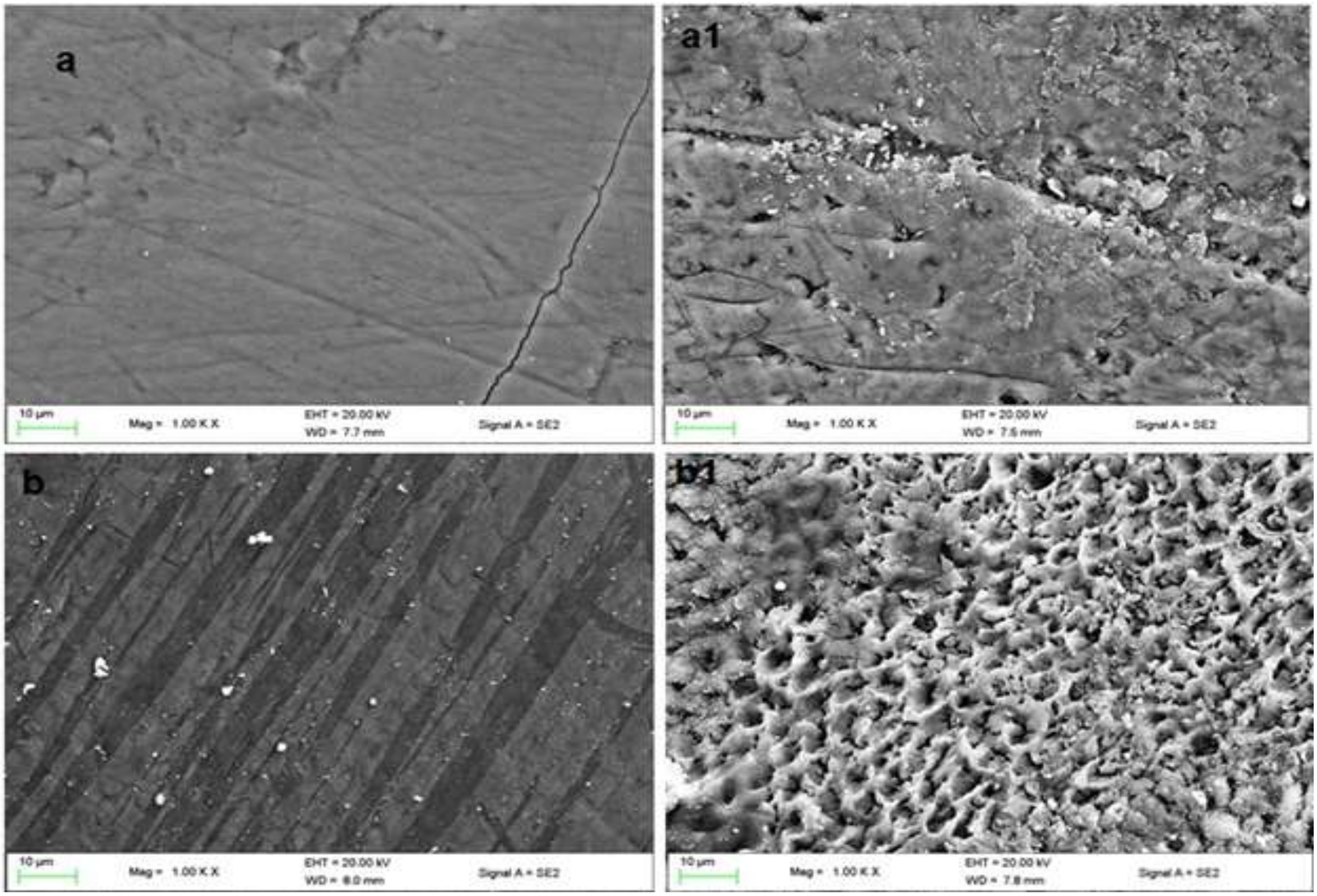

Figure 3. FESEM images of tooth enamel surface pre and post exposed to regular candy (B) (a1) 15 min; (b1) 2 h (x1000 magnification).

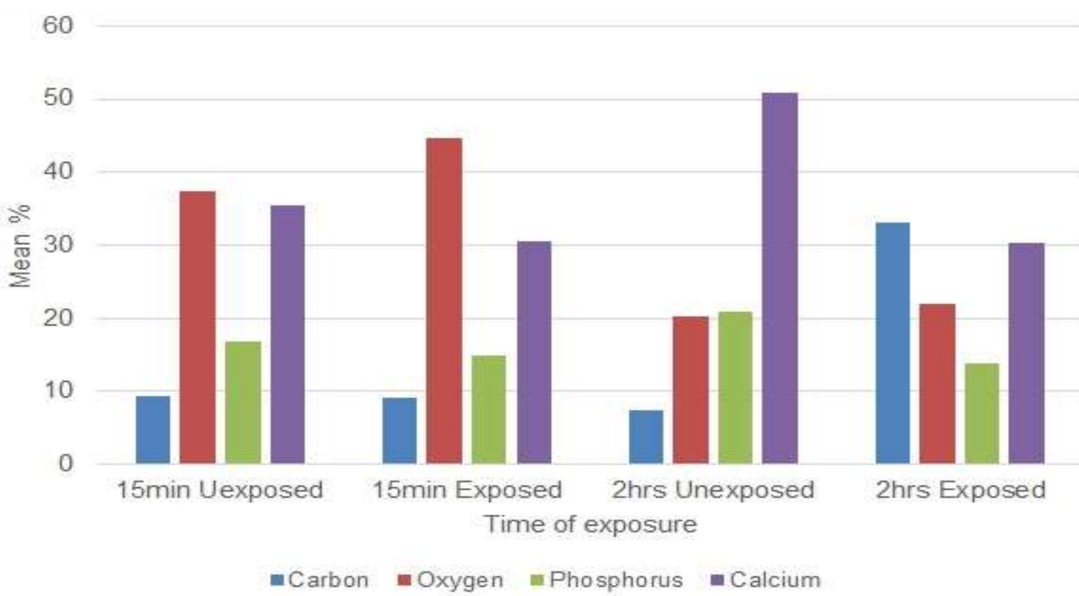

Figure 4. Elemental characterisation of C, O, P and Ca in pre and post exposed enamel to candy A at 15 min and 2 h.

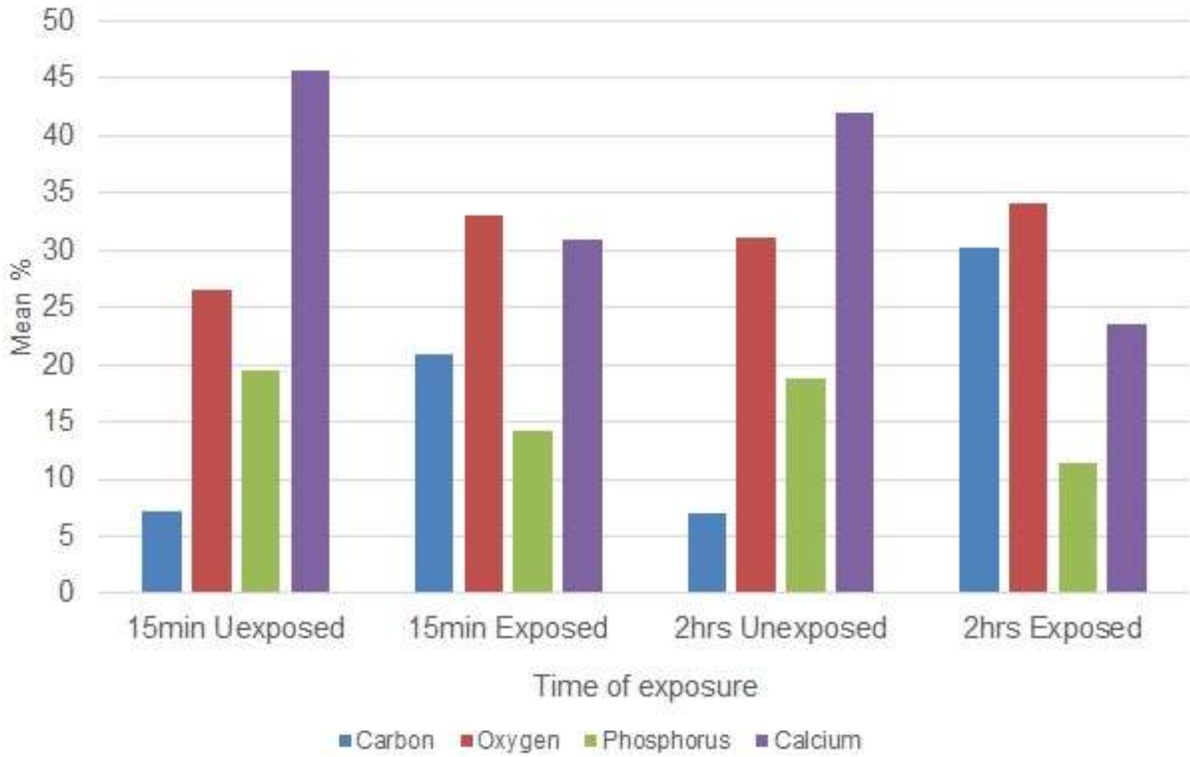

Figure 5. Elemental analysis of enamel mineral loss pre and post exposed to candy B at 15 min and 2 h.

environment would have greater detrimental and irrecoverable damage to teeth enamel as seen in the SEM images. Moreover, a study by Wagoner et al. (2009) observed a greater lesion depth in tooth enamel exposed to sour candies when compared to the regular candies. While saliva is considered a natural buffer to neutralize and maintain oral pH, Wagoner et al. (2009) noted that saliva is less likely to protect the tooth enamel against the erosive effects of sour candies due to the intensity and duration of sour candy acidic insults. Furthermore, a previous study (Brand et al., 2010) have suggested that the consumption time of these candies may reach 15 min, a period in which the oral saliva pH drops, thus failing to buffer the acidic oral environment. In corroboration with Farias et al. (2016) and Lazzaris et al. (2015), the frequent consumption of acidic candies like sour candy may result in irreversible enamel erosion. These identified higher consumption and proliferation of sour candies are becoming a public health concern due to their erosive potential (Lazzaris et al., 2015). Consequently, and congruent to the recommendation made by Wagoner et al. (2009) oral healthcare providers should query the dietary behaviours of their patients, particularly those associated with the consumption of sour candies (Wagoner et al., 2009).

While the above findings suggest that sour candy has the potential to erode tooth enamel, a constraint emerging from this study is the selection of popular candies used in the South African market and not every candy produced thus further research is suggested in the sour candy market. In addition, and from a public health perspective, the general public should be more informed regarding the dental risks associated with all candies with particular reference to its acidic ingredients, and the pH of such candies and the influence these have on tooth decay.

Conclusion

In summary, although the erosive potential observed for sour candy was significantly higher than regular candy, both types of candies possess the potential to erode the tooth enamel. Furthermore, the erosive characteristics of sour candy were observed to be higher within an increase in the exposure time. Hence, this study conclusively suggests that sour candies can potentially contribute to tooth enamel erosion, particularly when frequently consumed and over time.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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CPD questions

1) Sour candies and regular candies both possess erosive potential on teeth enamel. (True / False)

2) Regular candies have a pH of between
a) pH 4-6
b) pH 5-7
c) pH 2-4

3) Modern sour candies have multiple acids that have higher erosive impact to tooth enamel. (True / False)

4) More calcium and phosphorous were lost after 2 hour exposure to both candy solutions. (True / False)

5) Candy consumption time plays a significant role in tooth enamel erosion. (True / False)

6) Wagoner et al. (2009) observed a greater lesion depth in tooth enamel exposed to sour candies when compared to the regular candies. (True / False)

7) Enamel dissolution or demineralization occurs at a pH below 5.5. (True / False)