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The erosive potential of flavoured sparkling water drinks

CATRIONA J. BROWN, GAY SMITH, LINDA SHAW, JASON PARRY & ANTHONY J. SMITH

School of Dentistry, University of Birmingham and Birmingham Dental Hospital, Birmingham, UK

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Objective. The potential role of acidic drinks in the aetiology of dental erosion is well recognized. Whilst the wide-scale consumption of bottled waters is unlikely to contribute significantly to erosion, the role of flavoured sparkling water drinks is unclear. The aim of this study was to determine the pH, titratable acidity and *in vitro* erosive potential of a selection of these drinks drawn from the UK market to identify what dietary advice would be appropriate in relation to their consumption.

Methods. pH was measured using a pH electrode and titratable acidity recorded by titration with 0.1-M NaOH. Erosive potential was assessed using an *in vitro* dissolution assay with hydroxyapatite powder and electron microscopic examination of surface enamel of extracted human teeth, following exposure to the flavoured sparkling waters for 30 min.

Results. All of the flavoured waters tested showed appreciable titratable acidity (0.344–0.663 mmol) and low pH (2.74–3.34). In the hydroxyapatite dissolution assay, all of the waters demonstrated erosive potential (89–143%) similar to or greater than that of pure orange juice, an established erosive drink. Exposure of the extracted teeth to the flavoured waters resulted in surface changes consistent with erosive dissolution.

Conclusions. Flavoured sparkling waters should be considered as potentially erosive, and preventive advice on their consumption should recognize them as potentially acidic drinks rather than water with flavouring.

Introduction

In recent years, erosion has become increasingly recognized as an important cause of tooth tissue loss in all age groups[1]. There is mounting evidence that its prevalence is significant in young people[2]. The National Diet and Nutrition Survey of young people in the UK aged 4–18 years, undertaken in 1997, reported that 58% of 4–6-year-olds and 42% of 11–14-year-olds had erosion affecting the palatal surfaces of their incisors[3]. The UK Child Dental Health Survey of 2003 found that over 50% of 5-year-olds and more than 25% of children aged 12 years and older had tooth tissue loss affecting the palatal surfaces of their primary/permanent upper incisors, respectively[4]. A recent study of 12-year-old children in the UK Midlands reported that almost 60% of these children had evidence of erosion, of whom 49% had erosion on the palatal aspects of maxillary incisors and 2.7% exhibited exposed dentine[5].

Correspondence to:
Catriona Brown, Birmingham Dental Hospital and School of Dentistry, University of Birmingham – Children's Department, St Chad's Queensway, Birmingham B4 6NN, UK. E-mail: catriona.brown@sbpct.nhs.uk *or* catebrown@tiscali.co.uk

An association between the ingestion of acidic foods and drinks and dental erosion has been recognized[6–9]. These dietary components may contribute significantly to the prevalence of tooth wear. Risk factors for erosion include consumption of citrus fruit more than twice a day, a soft drink daily, and sports drinks or apple vinegar weekly[10]. The soft drinks market has increased significantly over the past 50 years and is still escalating. In 2002, the equivalent of 217 L of soft drinks per capita were consumed in the UK alone, compared with 147 L per person 10 years ago[11]. This increase in per capita soft drink consumption has been accompanied by greater diversity in both drinking habits and the range of products in the marketplace. The availability of bottled waters has had a marked effect on the soft drinks market. Over the past few years, there has been rapid growth in bottled waters, which commanded 13% of the soft drinks market in 2002 compared with only 6% in 1992[11]. The erosive potential of these bottled waters appears to be low and they may provide a safe alternative to more erosive acidic beverages[12]. However, it is important that we maintain an awareness of new drink products appearing on the market and consider their potential for contributing to erosion. The sharp growth in bottled water consumption has led to the development of allied drink products as manufacturers strive for a greater share of the market. The sparkling fruit-flavoured water drinks represent such a product range, and are now widely available in Europe and elsewhere.

There is a general perception amongst consumers that fruit-flavoured water drinks are essentially water with subtle flavouring. As a consequence, they are perceived as being dentally safe. The flavouring for these drinks, however, frequently includes citric and other fruit-derived acids. Therefore, it is important to assess the potential of these drinks to contribute to dental erosion. In this study, the authors have aimed to investigate the pH and titratable acidity of a range of sparkling flavoured waters, their *in vitro* dissolution of a mineral (synthetic hydroxyapatite powder) and the ultrastructural changes in the appearance of the enamel surface after treatment with these drinks.

Materials and methods

Bottles of flavoured sparkling waters (Table 1) were sourced directly from retail supermarkets in the UK, together with cartons of pure orange juice (from concentrate) as a positive control drink of established erosive potential[13].

pH and titratable acidity

The pH values (in triplicate) of 11 different flavours of bottled own-brand sparkling water from one supermarket were recorded on opening using a pH electrode (Accumet AR15, Fisher Scientific, Loughborough, UK). This was repeated subsequently at 30 and 120 min, both after opening and resealing of the bottle, and after exposure of the sparkling waters to air (inactive degassing) to mimic *in vivo* drinking from a glass. The titratable acidity (in triplicate) of the 11 sparkling water samples was determined by titration of 5-mL samples with 0.1-M sodium hydroxide and 0.06% (w/v) bromothymol blue indicator dye. This was repeated at 30 min after opening and recapping of the bottle, and after exposure of the sparkling water to air for 30 min.

In vitro *hydroxyapatite dissolution assay*

Three flavours (lemon and lime, grapefruit, and peach) with high titratable acidity/low pH were selected for assessment of their erosive potential using an *in vitro* dissolution assay with hydroxyapatite powder[12]. Each flavour was tested both immediately after opening the bottle of test water and after 30 min of exposure of the sample to air, so as to mimic *in vivo* drinking of these liquids. Pure orange juice (Tesco Supermarkets Ltd, Waltham Cross, Herts, UK) with known erosive potential[13] was used as a positive control drink. To assess possible inter-supplier variability, the hydroxyapatite dissolution assay was performed on four different supermarket brands of one flavour of sparkling water that had high titratable acidity (lemon and lime).

Table 1. Mean pH values and standard deviations recorded for each sparkling water drink over a 2-h period both after resealing the bottle and on leaving the water exposed to air. Each value is based on an average of three replicate recordings.

	Average pH (SD) based on triplicate records					
	Recapped water			Exposed water		
Sparkling flavoured water	0 min	30 min	120 min	0 min	30 min	120 min
Strawberry and Vanilla	3.34 (0.006)	3.32 (0)	3.31 (0.006)	3.34 (0.006)	3.31 (0)	3.27 (0.017)
Lemon and Lime	2.74 (0.015)	2.79 (0.006)	2.76 (0.006)	2.74 (0.015)	2.76 (0.006)	2.77 (0.006)
Peach	2.83 (0.02)	2.83 (0.01)	2.85 (0.01)	2.83 (0.02)	2.8 (0.017)	2.83 (0.01)
Grapefruit	2.74 (0.015)	2.81 (0.006)	2.84 (0.006)	2.74 (0.015)	2.8 (0.01)	2.8 (0.006)
Apple and Cherry	3.03 (0.015)	3.03 (0.006)	3.05 (0)	3.03 (0.015)	2.97 (0.02)	3.04 (0.017)
Elderflower and Pear	3.1 (0.025)	3.11 (0.015)	3.15 (0.01)	3.1 (0.025)	3.05 (0.031)	3.12 (0.021)
Orange and Mango	2.97 (0.05)	3.04 (0.01)	3.01 (0.01)	2.97 (0.046)	3.03 (0.006)	2.98 (0.015)
Mulled Mandarin and Cranberry	3.08 (0.02)	3.07 (0.01)	3.1 (0.02)	3.08 (0.02)	3.08 (0.006)	3.11 (0.012)
Children's Range Orange	3.03 (0.006)	3.08 (0.01)	3.07 (0.012)	3.03 (0.006)	3.08 (0.031)	3.08 (0.006)
Children's Range Strawberry	3.05 (0.044)	3.06 (0)	3.05 (0.01)	3.05 (0.044)	3.08 (0.015)	3.05 (0.025)
Children's Range Blackcurrant	2.99 (0.025)	2.99 (0.006)	3.03 (0.01)	2.99 (0.025)	2.95 (0.026)	3.02 (0.050)

In brief, the assay involved incubation of 10-mg aliquots of hydroxyapatite powder (Bio-Rad Laboratories, Hercules, CA, USA) with 1.5 mL of test solution for 5 min at 37 °C. Following centrifugation and termination of the reaction, aliquots of the supernatant were assayed for phosphorus using an acid-molybdate spectrophotometric method[14]. Ten replicates of each sample were assayed and controls, without incubation, were performed to allow correction for endogenous phosphorus in the samples.

Electron microscopic investigation of the surface enamel of erupted molar teeth following exposure to sparkling flavoured waters in vitro

The same three flavours of sparkling water (lemon and lime, grapefruit, and peach) with high titratable acidity, together with the pure orange juice positive control drink, were examined for their effects on the surface enamel of extracted human teeth to investigate whether they caused erosive changes. Extracted erupted molar teeth (following informed patient consent) were collected in a bacteriostatic solution of 15-mM sodium azide and cleaned with a fluoride-free prophylaxis paste. Erupted teeth showing no clinical evidence of erosion or caries were selected to provide a test substrate representative of *in vivo* conditions. Each tooth was covered in acid-resistant varnish, except for a 5-mm-diameter circular test window, on the buccal/palatal surface. The test area was bisected with a diamond-edged rotary saw blade and the cut surfaces also covered with the varnish. One half of each specimen was exposed to the test drink at 37 °C for 30 min with agitation, whilst the other half did not receive exposure to the test drink. At the end of the exposure period, each tooth specimen was washed with distilled water prior to sputter-coating and examination in the scanning electron microscope (SEM). Each test drink was examined with two teeth.

Results

The pH values recorded for the flavoured water drinks ranged from 2.74 to 3.34, and those with the lowest pH were the lemon and lime, peach, and grapefruit flavours (Table 1). The strawberry/vanilla flavour had the highest pH. The children's range of water drinks showed pH values towards the upper end of the pH values recorded. pH values were similar over the 2-h period whether the bottles were recapped or the drinks were exposed to air.

The various flavoured waters exhibited differing titratable acidity (Table 2), with the children's range of drinks tending to show the least acidity. Following exposure to air, there was a reduction in the titratable acidity recorded.

Table 2. The average number of mmol of 0.1-M NaOH required to neutralize 5 mL of test water drinks on opening, after 30 min from the recapped bottle and after exposure of the water to air for 30 min. Each value is based on an average of three replicate recordings.

	TA (mmol)			
		After 30 min		
Sparkling flavoured water	On Opening	Recapped (T_{30})	Exposure (T_{30})	Average reduction in TA between T_{30} recapped and T_{30} exposed
Strawberry and Vanilla	0.447 (0.035)	0.447 (0.006)	0.273 (0.006)	38.9%
Lemon and Lime	0.663 (0.035)	0.677 (0.067)	0.500 (0.0)	26.1%
Peach	0.518 (0.058)	0.52 (0.03)	0.329 (0.002)	36.9%
Grapefruit	0.597 (0.055)	0.61 (0.044)	0.427 (0.007)	30%
Apple and Cherry	0.511 (0.048)	0.498 (0.023)	0.337 (0.007)	32.3%
Elderflower and Pear	0.472 (0.084)	0.495 (0.062)	0.29 (0.01)	41.4%
Orange and Mango	0.497 (0.032)	0.527 (0.006)	0.35 (0.01)	33.6%
Mulled Mandarin and Cranberry	0.403 (0.050)	0.437 (0.032)	0.291 (0.010)	33.4%
Children's Range Orange	0.405 (0.056)	0.389 (0.022)	0.211 (0.001)	45.6%
Children's Range Strawberry	0.344 (0.063)	0.371 (0.050)	0.193 (0.008)	48%
Children's Range Blackcurrant	0.359 (0.030)	0.345 (0.013)	0.187 (0.002)	45.8%

Titratable acidity (TA).

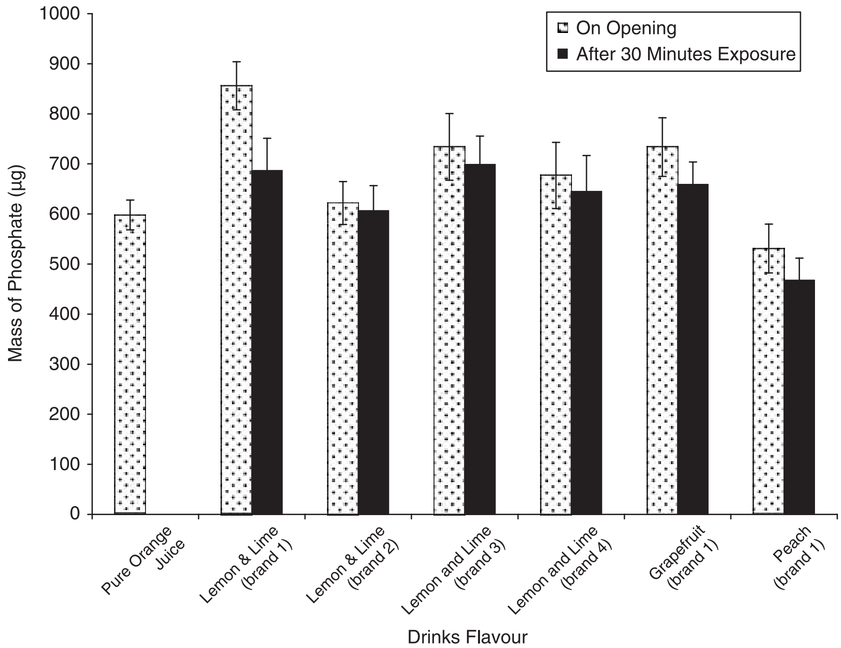

Fig. 1. Mean hydroxyapatite dissolution and standard deviation, expressed as the theoretical mass of phosphate (µg) present in 1.5 mL of test solution, both after the immediate opening of the test liquid and after 30 min of exposure of the carbonated water to air. Each value is based on the average of 10 replicate samples.

Three flavours of the drinks with higher titratable acidity/low pH were assessed for their effects on the *in vitro* dissolution of hydroxyapatite powder, both after immediate opening of the bottled water and after 30 min exposure of the drink to air (Fig. 1). Brand 1 corresponded to the flavours assessed for pH and titratable acidity. All of the drinks exhibited appreciable dissolution potential, which varied between the flavours. The dissolution levels were similar to or greater than the comparator, pure orange juice. These levels were observed to decrease after exposure of the drinks to air for 30 min prior to their use in the dissolution assay, although the magnitude of this varied with the different flavours. Comparison of four different brands of lemon-and-lime-flavoured waters showed that, whilst all exhibited appreciable dissolution of hydroxyapatite, there was some variation between different brands, with the most erosive brand on opening showing approximately 38% more dissolution than the least erosive brand. Such variations between brands were also evident when considering the reduction in dissolution after 30 min exposure to air, which ranged from 2.5% to 20%.

Exposure of an enamel surface (following prophylaxis) to the flavoured water drinks for 30 min resulted in changes in the appearance of the surface with each of the flavours examined. The changes were similar in all cases with pitting of the surface structure of the enamel following exposure to the flavoured waters (a representative image is shown in Fig. 2).

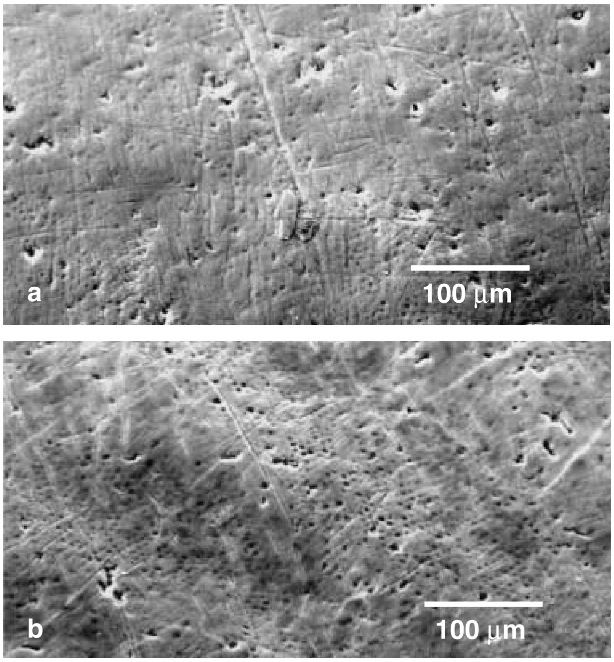

Fig. 2. Scanning electron microscopic appearance of a natural enamel surface (a) before and (b) after exposure to peach-flavoured sparkling water for 30 min (bar = 100 µm).

Discussion

Sparkling flavoured waters are often marketed as a healthy alternative to other carbonated drinks, with the implication that they are essentially water with some flavouring. This study has demonstrated that all of the different flavoured waters examined had low pH values that were considerably less than those previously reported for unflavoured still and sparkling mineral waters[12]. Many of the pH values were in the same range as those reported for cola (2.5) and orange drinks (2.9)[15]. Solutions of this order of pH have been demonstrated to dissolve enamel *in vitro*[12,16] and *in situ*[13]. Titratable acidity has been reported to be a better guide to the erosive potential of drinks because it determines the actual amount of H^+ ions available to interact with the tooth surface[7]. In this study, all of the flavoured waters exhibited appreciable titratable acidity, although the children's range of carbonated waters did show a lower titratable acidity compared to the other flavours, suggesting that their chemical composition is different. Examination of the listed ingredients on the product labels indicated that all of the flavoured waters contained at least one type of fruit juice in conjunction with citric acid alone or in combination with malic acid. Citric acid has a particularly high erosive potential as a result of both its acidic nature and chelating (calcium binding) properties[16,17], and is incorporated into soft drinks because of its refreshing taste[10]. Thus, in composition alone, these flavoured water drinks should be considered as acidic fruit drinks rather than water with flavouring.

Whilst there was not an appreciable change in the pH of the sparkling waters after exposure to air, there was a decrease in titratable acidity ranging from 26% to 48%. This decrease in titratable acidity is assumed to be the result of loss of carbonic acid caused by the carbonated nature of these drinks. Such a range reflects possible variations in the degree of carbonation during manufacture and time since manufacture, since sparkling drinks have a defined shelf-life during which their carbonation is maintained. The children's range of flavoured water drinks still showed lower titratable acidity after exposure to air, suggesting that they contained lower levels of fruit and other acids than the other drinks examined.

The *in vitro* hydroxyapatite dissolution assay used in this study has been previously demonstrated to be a sensitive screening test to discriminate between different erosive solutions and correlates with dissolution of human dental enamel by these solutions[12]. All of the flavoured water drinks examined here were observed to cause hydroxyapatite dissolution of the same order as or greater than the positive control drink, pure orange juice. The latter has been demonstrated to cause erosion of dental enamel *in situ* in human subjects[13]. Whilst biological factors, including saliva, tooth tissue composition and dental anatomy, will modify the erosion process[7,18], the effects of these flavoured waters on hydroxyapatite dissolution confirms their erosive potential. The data indicate that both different flavours and brands of these water drinks show some variations in erosive potential. A decrease in erosive potential ranging from 2.5% to 20% was detected after exposure of the flavoured water drinks to air for 30 min. This decrease was less than that observed for titratable acidity, indicating that the fruit and other acids added for flavouring are of greater importance than carbonation in determining the erosive potential of these drinks.

The SEM examinations of the surface of human enamel after *in vitro* exposure to the various flavoured water drinks and orange juice gave similar pictures of dissolution of the surface, with the underlying prismatic structure of the tissue starting to be revealed.

The effects of exposure of the dentition to these flavoured water drinks *in vivo* would be expected to be dependent on both the amount of drink consumed and its frequency, together with the biological modifying factors[7]. Nevertheless, it is clear that the drinks examined in this study have similar erosive potential to orange juice, and thus, care is required in their consumption as a part of a well-controlled diet.

The flavoured waters examined were representative of those available on the UK market at present. While compositional differences may exist between products in different countries, it is very difficult for the consumer to know which, if any, of these drinks may not be potentially erosive. Any comprehensive survey of individual products from many countries would rapidly become outdated since new products are developed and marketed regularly.

Thus, flavoured sparkling water drinks should be regarded as potentially erosive, and preventive advice on their consumption should recognize them as acidic drinks rather than water with flavouring. It would be inappropriate to consider these flavoured sparkling waters as a healthy dental alternative to other acidic drinks, which are capable of contributing to erosion.

What this paper adds

- The potential role of acidic drinks in the aetiology of dental erosion is well recognized. Sparkling flavoured waters are often marketed as a healthy alternative to other carbonated drinks, with the implication that they are essentially water with some flavouring; however, they frequently include citric and other fruit-derived acids.
- This *in vitro* study investigates the acidic characteristics and mineral dissolution behaviour of a range of flavoured sparkling waters taken from the UK market and demonstrates that these drinks should be considered as potentially erosive.

Why this paper is important to paediatric dentists

- Dental erosion has become increasingly recognized as an important cause of tooth tissue loss and there is mounting evidence that its prevalence is significant in children.
- It is important that health professionals are well informed as to which drinks potentially show erosive potential in order that appropriate preventive dietary advice can be given.
- Flavoured sparkling water drinks should be regarded as potentially erosive, and preventive advice on their consumption should recognize them as acidic drinks rather than water with flavouring.

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