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The Acidic and Erosive Potential of Five Sports Drinks

Jeremy Rees*, Theresa Loyn† and Robert McAndrew#

Abstract - *Sports drinks are becoming increasingly popular as we are all being encouraged to adopt a healthier lifestyle with regular exercise. However, many of these products are based on acidic fruits and may contribute to erosion. The aim of this study was to screen a number of these products for their potential to cause enamel erosion in vitro. The erosive potential of a number of readily available sports drinks was assessed in the laboratory by measuring their pH, neutralisable acidity and their ability to erode enamel. These were compared to a positive control, orange juice and a negative control, water. The pH of the sports drinks ranged from 3.16–3.70 with their neutralisable acidity ranging from 9.74–13.44 mls of 0.1M NaOH. The amount of enamel removed following 1-hour immersion in the sports drinks ranged from 1.18–5.36 microns. In comparison, the orange juice control had a pH of 3.68, a neutralisable acidity of 19.68 mls of 0.1 M NaOH and removed 3.24 microns of enamel. Many of the sports drinks tested were found to be erosive. This information will be of use to clinicians when counselling patients with tooth surface loss who use fruit based sports drinks regularly.*

KEY WORDS: Dental erosion, dental enamel, non-carious tooth surface loss

INTRODUCTION

Dental erosion is defined as an irreversible loss of dental hard tissues due to a chemical process without the involvement of microorganisms[1]. This process may be caused by extrinsic or intrinsic agents. Extrinsic agents include acidic food stuffs, beverages and snacks consumed as part of the daily diet. Extrinsic erosion may also occur following environmental exposure to acidic agents[2,3]. Intrinsic causes are associated with gastric acid and may present intra-orally following vomiting, regurgitation, gastro-oesophageal reflux or rumination[4].

The popular literature and media extol the virtues of a healthy lifestyle. Regular exercise and a healthy diet are being endorsed by central government in an attempt to prevent obesity and life threatening diseases such as diabetes and heart disease. Strenuous exercise quickly results in dehydration and depletion of energy stores which can lead to reduced physical and mental performance. Although these effects can be combated by the regular ingestion of water both during and after exercise, there is some evidence to show that commercially available sports drinks are more effective than water at maintaining optimal performance levels and augment recovery following exercise[5,6]. Sports drinks are essentially water based but also contain carbohydrates as a ready energy source, electrolytes that replace lost ions and B group vitamins that help release energy[6]. They are also isotonic; this encourages rapid absorption once ingested. However, all these drinks are based on natural fruits and therefore may have an erosive potential.

Sports drink use amongst athletes is very common, with over 90% of athletes using these products on a regular basis[7]. These products are also advertised aggressively by the manufacturers' and their use is publicly endorsed by many famous elite athletes. However, the link between the consumption of sports drinks and erosion amongst athletes is still rather tenuous. Some case reports have suggested a relationship between sports drinks consumption and erosion[8–11] and Milosevic[12] has demonstrated an association between erosion and sports drink consumption. However, Mathew *et al*[7] examined a group of over 300 University based athletes in the United States, but could not show a statistically significant association between erosion and the use of sports drinks. One explanation for this is that sports drinks often have a low viscosity[12] and are likely to be cleared quickly from the mouth.

The aim of this study was to compare a number of commercially available sports drinks and compare these with water and orange juice. The hypothesis used in this study was that the sports drinks would not be more erosive than orange juice.

MATERIALS AND METHODS

The sports drinks chosen for inclusion in this study are listed in *Table 1*. These drinks were chosen as they were readily available to the public at a major supermarket. Other sports drinks are powder based requiring the addition of water and therefore the sample tested here may not be totally representative of all sports drinks.

Initial pH

The pH of each of the drinks was tested using an electronic pH meter (Orion Research Inc.) at 37°C on a heated magnetic stirrer. The pH meter was calibrated using test

* BDS, MScD, FDSRCS (Ed), PhD, ILTM
† IBMS
# BDS, MScD, FDSRCS, FDS (Rest Dent), DRD, MRD RCS (Ed), ILTM

Table 1. *Drink contents according to manufacturers' information stated on product label*

Sports drink	*Contents*
Lucozade™ sport orange[¥]	Water, carbohydrate blend (glucose syrup, maltodextrin), citric acid, acidity regulator (sodium citrate), preservatives (potassium sorbate, sodium benzoate), antioxidant (ascorbic acid), sweeteners (aspartame, acesulfame K), flavouring, acacia gum, vitamins (niacin, pantothenic acid, B_6, B_{12}), colour (ß carotene)
Lucozade™ hydroactive fitness water citrus fruits[¥]	Water, glucose syrup, citric acid, acidity regulator (sodium citrate, calcium carbonate), flavourings, sweeteners (aspartame, acesulfame K), flavouring, acacia gum, vitamins (niacin, pantothenic acid, B_6, B_{12})
Lucozade™ sport mixed berry[¥]	Water, carbohydrate blend (glucose syrup, maltodextrin), citric acid, acidity regulator (sodium citrate), preservatives (potassium sorbate, sodium benzoate), antioxidant (ascorbic acid), sweeteners (aspartame, acesulfame K), acacia gum, vitamins (niacin, pantothenic acid, B_6, B_{12}), colour (anthocyanins)
Lucozade™ sport mixed citrus[¥]	Water, carbohydrate blend (glucose syrup, maltodextrin), citric acid, acidity regulator (sodium citrate), preservatives (potassium sorbate, sodium benzoate), antioxidant (ascorbic acid), sweeteners (aspartame, acesulfame K) acacia gum, vitamins (niacin, pantothenic acid, B_6, B_{12}), colour (ß carotene)
Powerade™ ice storm[§]	Water, glucose, maltodextrin, citric acid, acidity regulators (sodium citrate, potassium citrate), flavourings, satbilisers (acacia gum, glycerol esters of wood rosins, MgCl, vitamins (niacin, pantothenic acid, biotin), sweeteners (aspartame, acesulfame K), colour (brilliant blue)

¥. GlaxoSmithKline
§. Coca-Cola UK

solutions of known pH (Fisher Scientific International) before testing the drinks. Each drink was tested using five different samples.

Neutralisable acidity

The neutralisable acidity of each drink was tested by placing 20 mls of the drink in a glass beaker placed in a thermostatically controlled water bath held at 37°C. 0.1M sodium hydroxide solution was gradually added to the drink sample and the pH rise was continuously monitored until the pH increased to neutrality. Each sample was stirred continuously as the solution of sodium hydroxide was added. The volume of sodium hydroxide required to increase the pH of the sample to neutrality was noted; this was repeated five times for each drink.

Enamel erosion

All measurements of enamel loss were made using profilometry according to the method of West[13]. The source of enamel was extracted unerupted third molar teeth from individuals residing in a region with unfluoridated drinking water. Thus the level of fluoride incorporation into enamel was anticipated to be low, but was not further characterised. The specimens were sectioned longitudinally and embedded in a low exotherm epoxy resin (Stycast 1266). The outer surface of the enamel samples were lightly ground with first 600-grit and then 1200-grit abrasive discs (Kemet International) to produce a flat surface. Three baseline readings using a profilometer (Planer Products Ltd.) were recorded for each enamel sample. Only samples with a stylus deflection of less than an average ± 0.30mm deflection were used in the study. The diamond stylus had a tip radius of 20 µm with a head velocity of 10 mm/min. The force of the stylus varied linearly with deflection at a rate of 8 mg/µm up to a maximum of 1 g at 100 µm.

After baseline profiles were determined in duplicate, enamel samples were taped to expose a 2 mm width of enamel (approximate enamel area of 10 mm^2). Five enamel specimens were exposed to 250 mls of each drink and stirred in a thermostatically controlled water bath at 37□C for one hour. Following exposure, the enamel specimens were rinsed in water, dried and the tapes removed. Surface enamel loss was measured on the profilometer in triplicate, with the amount of enamel loss recorded in micrometers. Mean values were calculated from duplicate measurements.

Five enamel specimens were also immersed in Tropicana™ brand orange juice for one hour as a positive control and in deionised distilled water as a negative control.

Statistical analysis of the results for pH, neutralisable acidity and enamel erosion was carried out using analysis of variance followed by Tukey's test. The threshold for statistical significance was set at $p<0.05$.

RESULTS

The results for the initial pH values are given in *Table 2.* The pH of the sports drinks tested ranged from 3.16–3.70 compared to a value of 3.68 for orange juice and 6.58 for water. The pH for all of the sports drink and the orange juice were all highly statistically different from water at the $p<0.001$ level.

The results for the neutralisable acidity values are given in *Table 2.* These values ranged from 9.74 mls for Lucozade™ hydroactive citrus fruit to 13.44 mls for Lucozade™ sport mixed citrus. The neutralisable acidity values for all of the sports drinks and the orange juice were all highly statistically different from water at the $p<0.001$ level. The value for the Hydroactive citrus drink and the Powerade™ drink were statistically lower than the other three sports drinks at the $p<0.001$ level.

The amount of enamel lost following immersion in the various drinks tested is shown in *Table 2.* The amount of enamel removed, ranged from 1.18 to 5.36 µm. In comparison, the orange juice positive control produced a mean surface loss of 3.34 µm. The neutralisable acidity values for all of the sports drinks and the orange juice

Table 2. *Initial pH value, neutralisable acidity and enamel erosion values (SD in parentheses)*

Drink	*pH*	*Neutralisable acidity (mls)*	*Enamel erosion (microns)*
Lucozade™ sport orange	3.34 (0.05)	12.57(1.21)	4.18 (0.70)
Lucozade™ hydroactive citrus fruit	3.70 (0.01)	9.74(0.21)	1.18 (0.22)
Lucozade™ sport mixed berry	3.16 (0.05)	12.40(0.19)	5.36 (2.75)
Lucozade™ sport mixed citrus	3.22 (0.07)	13.44(0.15)	5.34 (2.46)
Powerade™ ice storm	3.24 (0.05)	10.8 (0.6)	3.14 (1.55)
Water	6.58 (0.07)	0.01(0.001)	0.15 (0.03)
Tropicana™ orange juice	3.68 (0.04)	19.68(0.31)	3.24 (0.62)

were all highly statistically different from water at the $p<0.001$ level or $p<0.01$ level.

The enamel erosion values for the Lucozade™ products were significantly differenet from the other sports drinks ($p<0.01$).

DISCUSSION

The aim of this study was to compare and highlight any potential erosive effects of a variety of sports drinks with water and orange juice. Although the pH and neutralisable acidity of some commercially available sports drinks have been assessed previously[12], they had not been compared to orange juice or water.

The initial pH of all the sports drinks were highly acidic. The pH ranged from 3.16–3.70 which was similar to the pH range of 2.38–4.46 reported by Milosevic for sports drinks[12]. The pH values reported here were also well below the known pH for the initiation of erosion, which is thought to be 4.5[13], so that all the sports drinks tested are potentially erosive.

It is also important to quantify the neutralisable acidity of a drink when assessing its erosive potential[14]. The values for the neutralisable acidity varied more widely than the pH values and there appeared to be two distinct groups identified by the analysis of variance. The first group had comparatively low neutralisable acidity values of 9.74–10.8 mls (Lucozade™ hydroactive fitness water and Powerade™ Ice Storm) while the second group had higher neutralisable acidity values of 12.4–13.44 mls (Lucozade™ Sport citrus, mixed berry and mixed citrus). Milosevic[12] tested some Lucozade sport drinks and reported a neutralisable acidity value of 16.3 mls, which is slightly higher than the values reported here.

The first group with the low neutralisable acidity values seemed to be visually similar to flavoured mineral waters with the addition of some simple carbohydrates. Unfortunately, the product labels (*Table 1*) give no additional information about the relative proportions of the various components found in each drink. Fruit flavoured waters are known to be relatively acidic[15] but their erosive potential has not been fully characterised yet.

The pattern for the enamel erosion followed a similar pattern to the neutralisable acidity. Lucozade™ hydroactive fitness water and the Powerade™ showed relatively low levels of erosion (1.2–3.1 µm) compared to the second group of Lucozade™ Sport products (orange, mixed berry and mixed citrus) (4.2–5.4 µm). This latter group also had larger standard deviations, but this is probably a reflection of the measurement of greater amounts of enamel loss, leading to a greater variability in the measurements actually recorded.

The negative control, water, also showed a trace amount of erosion at 0.15 µm. It is interesting to note that this value was very similar to the erosion produced by water (0.14 µm) in a recent clinical study of erosion[17]. As the water used in this study had a neutral pH it is very unlikely that it was producing any actual erosion and the value quoted is the measurement error of the profilometry technique used to measure enamel loss[16].

The Lucozade™ Sport products (orange, mixed berry and mixed citrus) produced a significantly greater amount of erosion than the other drinks tested ($p<0.01$). The reason for this was not immediately obvious, apart from the higher levels of free acid in the drinks shown by the neutralisable acidity values. Visually, the Lucozade™ sport products seemed to be more akin to traditional carbonated fruit drinks which are well known as being erosive[17]. Furthermore, the labels of these drinks showed that these products contain citric acid, the acidity regulator sodium citrate and preservatives such as potassium sorbate and the antioxidant ascorbic acid. All of these additives can add to the erosive potential of these drinks. However, it is possible that other additives, such as acacia gum, may provide some protection against erosion[18].

The erosion results of this *in vitro* study must be interpreted with a certain degree of caution as they will tend to over estimate the amount of enamel lost compared to the clinical case. Firstly, the enamel surface will be covered by a protective pellicle and/or plaque layer and the tooth surface will also be subject to the flushing, buffering and remineralising effects of saliva[19,20]. Addy *et al* [21] have produced some data with orange juice to suggest that the assessment of enamel erosion using *in vitro* profilometry over-estimated erosion by a factor of 10 due to the protective factors mentioned above.

Secondly, the method for assessing enamel erosion may also be criticised as the contact time between enamel and sports drink was one hour. However, it does seem likely that due to reduced rates of oral clearance due to dehydration, contact times of an hour or more may be realistic. However, sports drinks are designed to be taken both during and following strenuous exercise and help prevent general dehydration. The oral consequences of dehydration are that the rate of salivary flow will drop quickly and dramatically[22]. However, once this effect is lost due to dehydration, then the erosive effects of these sports drinks will persist for longer. This effect is also likely to be greater buccally than lingually, as the anatomical position of the ducts of the major salivary glands ensure that the clearance rates of drinks lingually will be eight times faster than buccally[23]. This may lead to greater levels of erosion buccally and labially; as yet this does not seem to have been investigated. Similarly, all the drinks contained simple carbohydrates, principally as glucose syrup. This also poses an increased cariogenic challenge due to the reduced salivary clearance of glucose when dehydrated. However, it must also be bourne in mind that these types of drinks have a low viscosity[12] which will aid oral clearance and this attribute may counteract the effects of low clearance produced by dehydration. Indeed, this may provide an explanation as to why clinical studies have failed to demonstrate a statistically significant association between erosion and the use of sports drinks[7]. A further factor to consider is that drinking habits and style vary between individulas and this will also influenece the site and severity of erosion.

Finally, this study was deliberately carried out at 37°C to allow comparison with previous work [24–27]. However, these sports drinks are usually consumed cold at around 5°C and the drinks will therefore have fewer dissociated H^+ ions and therefore produce less erosion[28]. It would have been interesting to assess the erosion produced by these drinks at different temperatures.

It is also straightforward to project forward the amount of enamel loss suggested by these data. If one takes the worst case scenario of 5μm of enamel loss with the Lucozade sports drinks and make the assumption that this loss happens on a daily basis, then the time taken to loose 2mm of enamel is just under 1.1 years. If this were the case, then the majority of athletes consuming these drinks would have exposed dentine. However, clinical studies have shown that the prevalence of erosion amongst athletes is 37%[7]. The reason for this disparity is almost certain to be due to the protective role of the saliva, pellicle and plaque.

In spite of these obvious shortcomings, this study has found that the contemporary sports drinks are potentially erosive. This information will be of use to clinicians when counseling patients who are susceptible to tooth surface loss who use fruit based sports drinks regularly.

MANUFACTURERS' DETAILS

- pH meter, Model 701A, Orion Research Inc., Boston, USA.
- Fisher Scientific International, Bishop Meadow Road, Loughborough, Leicestershire, UK.
- Stycast 1266, Emerson & Cuming, Nijverheidsstraat, 2431 Westerlo, Belgium.
- Kemet International Ltd., Parkwood Trading Estate, Maidstone, Kent, UK.
- Planer Products Ltd., Sunbury on Thames, UK.
- GlaxoSmithKline, Freepost TK2018, Brentford, UK.
- Coca-Cola UK, 1, Queen Caroline St., Hammersmith, London, UK.
- Tropicana UK Ltd, PO Box 6642, Leicester, UK.

ADDRESS FOR CORRESPONDENCE

Professor Jeremy Rees, Department of Adult Dental Health, Dental School, Wales College of Medicine, Cardiff University, Heath Park, Cardiff CF14 4XY, UK.
E-mail: reesjs1@cardiff.ac.uk

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