ORIGINAL PAPER

DENTAL EROSIVE POTENTIAL OF READY-TO-DRINK AND POWDERED SPORTS DRINKS

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ABSTRACT

Introduction: Dental erosion is a progressive chemical degradation of tooth substance in an acidic environment, which is unrelated to the presence of dental plaque. Dehydration induced by sport activities reduces protective salivary flow and its buffering capacity, which may aggravate the erosive effect of consumed acidic beverages.

Objectives: To evaluate the erosive potential of ready-to-drink and powdered sports drinks.

Material and methods: Seven ready-to-drink sports beverages (Oshee, Isotonic Lemon Taste, Gatorade, Powerade, Isotonic Veroni, Isostar, and 4Move) and four prepared from powder (Isoactive, Race Isotonic Drink ALE, IsoPlus, and Isostar) were analysed. A 1% citric acid was used as a reference. Human enamel specimens (five per group) were exposed to the tested solution in a short pH-cycling model (1 min erosion – 5 min artificial saliva without mucin) repeated five times. Surface microhardness was measured before and after the pH-cycling using a Vickers indenter. A correlation between the pH of the drink and enamel softening was determined.

Results: All tested beverages decreased the enamel microhardness. Gatorade and Powerade had the lowest pH and exhibited the highest erosive potential, comparable with 1% citric acid. In general, the erosive potential of ready-to-drink beverages was higher than powdered drinks, except for Isostar. There was a significant negative correlation between enamel softening and the pH value of the drink ($r = -0.55$).

Conclusions: Sports drinks exhibit different erosive potential related to their pH. Patients frequently consuming these beverages should be aware of the potential risk for dental erosion.

Key words: dental erosion, sports drinks, carbohydrate-electrolyte solution, oral health.

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INTRODUCTION

Sports drinks are noncarbonated carbohydrate-electrolyte solutions whose main purposes are to prevent dehydration (restore or maintain hydration status), to supply energy (maintain blood glucose concentration), and to replenish electrolytes lost through sweat during physical exercise [1].

Although sports drinks were originally developed for professional athletes and active amateur individuals performing intense endurance training, they are also popular within the general population, particularly adolescents and young adults [4, 10].

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According to the European Food Safety Authority (EFSA), in order to bear the name "carbohydrate-electrolyte solution", the beverage should:

1) contain 80-350 kcal/l from carbohydrates, and more than 75% of the energy should be derived from carbohydrates that induce a high glycaemic response, such as glucose, glucose polymers (e.g. maltodextrin), and sucrose;
2) contain between 20 mmol/l (460 mg/l) and 50 mmol/l (1150 mg/l) of sodium;
3) have an osmolality between 200 and 330 mOsm/kg water [7].

Beverages with an osmolality 300 ± 10% mOsm/kg water may be named "isotonic" because their concentration of osmotic active substances per unit of mass is the same as in human plasma. Isotonic or slightly hypotonic solutions are thought to enhance water absorption during exercise [7, 19].

To supress the salty taste of the sport drinks and improve their palatability, citric acid is usually added [6]. The acidulant ingredients play a significant role in the pathogenesis of dental erosion by lowering the pH of the solution and reducing its degree of saturation with respect to dental (enamel) hydroxyapatite. Chemical properties, such as pH value, and calcium and phosphate concentrations, are important in determining the erosive potential [2, 3, 22, 24]. However, on the food package labels such information is usually missing [13].

Sports drinks may be consumed before, during, and after exercise. It is important to note that dehydration induced by strenuous physical activity reduces protective salivary flow and its buffering capacity and may aggravate the erosive effect of the consumed acidic carbohydrate-electrolyte beverage [6]. This factor predisposes athletes to be at a higher risk of developing dental erosion [11]. Due to their high sugar content, sports drinks have cariogenic potential by increasing metabolic activity of *Streptococcus mutans* [26]. However, controversy exists regarding the direct relationship between use of sports drinks and erosive toothwear in cross-sectional observational studies [1, 12, 15, 18, 21].

OBJECTIVES

The aim of this experiment was to determine the erosive potential of commercially available sports drinks in two forms: ready-to-drink and prepared from powder.

MATERIAL AND METHODS

BEVERAGE SELECTION AND PREPARATION

Seven ready-to-drink (Oshee, Isotonic Lemon Taste, Gatorade, Powerade, Isotonic Veroni, Isostar, and 4Move) and four powdered sports drink (Isoactive, Race Isotonic Drink ALE, IsoPlus, and Isostar) were purchased. Data on the composition of the selected products were taken from the food label and shown in Tables 1 and 2. The powdered sports drinks were prepared according to the manufacturers' instructions using a precision laboratory scale and distilled deionised water as a solvent. The pH value of the tested beverages was analysed using a standard pH meter (Five Easy, Mettler Toledo) with a glass electrode (LE409, Mettler Toledo), calibrated with reference buffers of pH 4.00 and pH 7.00, at 21°C. Before measurement, the solutions were mixed thoroughly with a magnetic stirrer. A reference erosive solution was 1% w/v citric acid (Sigma-Aldrich Co., St. Louis, Mo., USA) with pH adjusted to 3.80 with sodium hydroxide.

SPECIMEN PREPARATION

Enamel specimens were prepared from freshly extracted, non-damaged, and caries-free human permanent premolar and molar teeth extracted for orthodontic reasons after patient verbal consent. Enamel slabs were cut from buccal surfaces of the teeth using a low-speed, water-cooled diamond saw (Minitom, Struers, Copenhagen, Denmark). Each specimen was prepared from one tooth. The specimens were embedded in acrylic resin (DuroFast, Struers) in a hot mounting press machine (CitoPress-20, Struers). Afterwards, the enamels were subjected to wet-grinding with abrasive paper (500-2000 grit, Waterproof Silicon Carbide Grinding Paper, Struers, Erkrath, Germany) and polishing with felt paper wet by diamond suspension (1 μm Diamond Paste, Struers). This procedure was performed with a semi-automatic grinding/polishing device (Tegramin-30, Struers). Removal of the outermost enamel was controlled with micrometer and a layer of up to 200 μm was lost. Finally, the specimens were ultrasonically cleaned for 15 min with distilled water to remove the smear layer. Specimens with visible surface defects were discarded. Acceptable specimens having a mean Vickers Hardness Number (VHN) above 380 were selected. The exposed area of enamel was approximately 2-3 mm^2. Prior to use, the prepared enamel slabs were stored in a saturated mineral solution (1.5 mM $CaCl_2$, 0.9 mM KH_2PO_4, 150 mM KCl, 1 mM NaN_3, 20 mM TRIS, pH 7.0) in refrigerator at 4°C.

EXPERIMENTAL DESIGN

Sixty enamel specimens were randomly allocated to one of 12 groups (n = 5) to receive different sports drinks or reference solution. After initial immersion in artificial saliva for 10 min, specimens were subjected to pH-cycling. One cycle consisted of a 1-min exposition to the tested beverage or citric acid solution (10 ml/specimen, 21°C with slow stirring) and 10-min immersion in artificial saliva, which served as a remineralising medium (10 ml/specimen, at 36°C without stirring). The artifi-

TABLE 1. Ready-to-drink (liquid) sports drinks used in the experiment

Brand (manufacturer)	Flavour	Energy (kcal/100 ml)	Carbohydrates (g/100 g)	Protein (g/100 g)	Fat (g/100 g)	Salt (g/100 g)	Electrolytes	Carbohydrate sources and sweeteners
4Move (FoodCare, Zabierzów, Polska)	Lemon	25	6.0	< 0.5	0	0.13	Potassium 13 mg, calcium 1.6 mg, magnesium 0.7 mg	Glucose, maltodextrin, acesulfame K, aspartame
Gatorade (Pepsi Company, Inc.)	Lemon	24	5.9	0	0	0.13	Sodium 52 mg, chloride 47 mg, potassium 12 mg, magnesium 5 mg	Glucose, sucrose, fructose syrup, maltodextrin, sucralose, acesulfame K
Isostar (Novartis International AG)	Lemon	24	6.9	0	0	0.13	Sodium 50 mg, magnesium 12.5 mg, calcium 31 mg	Sucrose, glucose syrup, maltodextrin
Isotonic Lemon Taste (Kaufland Polska)	Lemon	23	5.6	0.5	< 0.5	0.13	ns	Glucose, maltodextrin, aspartame, acesulfame K
Oshee (Oshee Polska)	Lemon	24	5.7	0	0	0.12	ns	Maltodextrin
Powerade ION4 (Coca-Cola Comp.)	Lemon	16	3.9	0	0	0.13	Sodium 50 mg, potassium 12.5 mg, calcium 1.3 mg, magnesium 0.6 mg	Glucose, fructose, sucralose, acesulfame K
Veroni active Isotonic (Zbyszko Company, Radom, Polska)	Lemon	25	6.0	0	0	0.12	ns	Maltodextrin, glucose, aspartame, acesulfame K

ns – not stated

TABLE 2. Powdered sports drinks used in the experiment

Brand (manufacturer)	Flavour	Energy (kcal/100 ml)	Carbohydrates (g/100 g)	Protein (g/100 g)	Fat (g/100 g)	Salt (g/100 g)	Electrolytes	Carbohydrate sources, sweeteners, *special additives	Recommended dilution (g/500 ml)
Isoactive (Activlab, Warsaw)	Lemon	21.0	5.3	0	0	0.176	Sodium 70 mg, potassium 26 mg, chlorides 24 mg, calcium 24 mg, magnesium 12 mg	Glucose, acesulfame K, **Camellia sinensis* extract 10 mg	31.5
Race Isotonic Drink ALE	Lemon	24.0	6.0	0	0	0.116	Sodium 92 mg, potassium 64 mg, calcium 24 mg, magnesium 8 mg	Glucose, fructose, maltodextrin, sucralose	51
IsoPlus (Olimp Sport Nutrition, Dębica)	–	24.4	6.1	0	0	0.116	Sodium 48 mg, potassium 34.3 mg, calcium 10 mg, magnesium 5 mg	Glucose, fructose, maltodextrin, acesulfame K, sucralose, *L-carnitine, *L-glutamine	35
Isostar (Novartis International AG)	Lemon	29.6	7.0	0	0	0.160	Sodium 64 mg, magnesium 12.4 mg, calcium 32 mg	Sucrose, glucose syrup, maltodextrin	40

cial saliva was mixed according to the following formulation: 2700 mg/l porcine gastric mucin, 1270 mg/l KCl, 580 mg/ml NaCl, 340 mg/l Na_2HPO_4, 330 mg/l KH_2PO_4, 200 mg/l urea, 170 mg/l $CaCl_2 \times 2\ H_2O$, 160 mg/l NaSCN, 160 mg/dm³ NH_4Cl, 30 mg/l glucose, and 2 mg/l ascorbic acid, pH adjusted to 6.4. Freshly opened or prepared drinks were used at room temperature (23°C). Before changing solutions, the specimens were immersed in deionised water (100 ml) and gently dried with an air spray.

SURFACE MICROHARDNESS MEASUREMENT

Specimen surface microhardness (SMH) was determined at baseline (SMH 0) and after exposition to sports drinks (SMH 1) by one operator blinded to the group assignment. The indentations were made by Vickers diamond with 100-g load and dwell time of 15 s using a computer-aided FM-700 microhardness tester coupled to FM-ARS software (Future Tech Corp., Tokyo, Japan). Five indentations at an interval of 100 μm were made for each specimen, and the mean SMH was calculated. The percentage SMH change (%SMHC) was determined as follows: $\%SMHC = [(SMH_1 - SMH_0)/SMH_0] \times 100$ [23].

STATISTICAL ANALYSIS

Shapiro-Wilk test was used to test normal distribution of the data and Levene test to verify homogeneity of variance. One-way ANOVA and Tukey's post hoc tests were performed to check statistically significant differences in %SMHC. The level of significance was set at $p = 0.05$. Statistical analyses were carried out using Excel 2007 (Microsoft) and Statistica software (StatSoft, ver. 10.0). The correlation between the pH of the drink and enamel softening was calculated.

RESULTS

Table 3 summarises the results of the acidity and mean percentage surface microhardness change (%SMHC) after exposition to the studied beverages. All the examined solutions caused a significant surface softening ($p < 0.0001$). Powerade and Gatorade had the lowest pH and induced the greatest enamel softening, which was comparable to the reference citric acid solution. The other beverages resulted in significantly lower enamel softening ($p < 0.05$). In a comparison of the ready-to-drink beverages with the drinks prepared from powder, the latter showed significantly lower %SMHC ($p < 0.05$). A negative linear correlation ($r = -0.55$, $p < 0.05$) was observed between the pH value and enamel softening (%SMHC).

DISCUSSION

The present study demonstrated that sports drinks are capable of eroding enamel to different extents, but to a lesser degree than pure 1% citric acid. The erosive potential of the sports drinks could be ascribed to the presence of citric and ascorbic acid in their basic formulations. Chemical dissolution of dental tissue may be caused by H^+ ions and anions capable of binding or complexing calcium.

The highest erosive potential of the Gatorade and Powerade could be explained by their relatively low pH and low calcium content. This observation concurs

TABLE 3. Acidity of the studied beverages, mean (± standard deviation) baseline enamel microhardness (SMH_0), microhardness after short-term erosion-remineralisation cycle (SMH_1), and calculated percentage surface microhardness change (%SMHC)

Group	pH	Physical state at purchase	SMH_0	SMH_1	%SMHC	
Oshee	3.87	Liquid	443.04 ± 10.28	399.20 ± 11.72	−43.84 ± 12.53%	B
Isotonic Lemon Taste	3.92	Liquid	437.04 ± 9.09	400.25 ± 13.96	−36.80 ± 17.63%	B
Gatorade	3.25	Liquid	431.73 ± 10.21	367.49 ± 12.95	−64.25 ± 8.02%	A
Powerade	2.66	Liquid	430.76 ± 15.52	362.36 ± 14.34	−68.40 ± 12.17%	A
Isotonic Veroni	3.98	Liquid	430.90 ± 11.09	401.63 ± 10.33	−29.27 ± 9.24%	B
Isostar	4.02	Liquid	431.02 ± 14.55	398.30 ± 19.54	−32.72 ± 9.97%	B
4Move	3.57	Liquid	440.33 ± 17.60	391.50 ± 15.28	−48.83 ± 9.98%	B
Isoactive	3.82	Powder	430.52 ± 13.36	407.82 ± 11.98	−22.70 ± 7.86%	B
Race Isotonic Drink ALE	4.43	Powder	437.00 ± 14.98	409.75 ± 15.81	−27.25 ± 6.78%	B
IsoPlus	3.42	Powder	452.44 ± 14.82	418.39 ± 19.25	−34.05 ± 7.23%	B
Isostar	3.88	Powder	439.56 ± 17.18	418.12 ± 13.53	−21.44 ± 7.66%	B
1% citric acid	3.80	–	435.04 ± 14.93	364.55 ± 17.90	−70.49 ± 9.54%	A

Values with different letters are significantly different from each other.

with those drawn from other in vitro studies [8, 9, 11, 18, 20]. Of the three most popular sports drinks worldwide (Gatorade, Powerade, and Isostar), the erosive potential of Isostar is significantly lower, which can be explained by its high calcium concentration of 8.20 mmol/l (the calcium concentrations of Gatorade and Powerade are 0.13 mmol/l and 0.25 mmol/l, respectively) [11].

It should be noted that the presence of remineralisation medium in the study protocol may not reflect reduced salivary flow during long physical exercise, and in such instances the microhardness loss would be even higher.

The degree of saturation with respect to hydroxyapatite (DS_{HAP}) is an important parameter related to the rate of erosion [2, 3, 22, 24]. DS depends on the calcium, phosphate, and fluoride concentration and pH of the solution. The concentration gradient of those ions constitutes a thermodynamic driving force for dissolution. In theory, saturated or supersaturated solution ($DS_{HAP} \geq 1.0$) is not expected to induce enamel dissolution. It was found that a threshold condition for citric acid with a pH of 3.3 is defined by a calcium concentration of 120 mM and phosphate concentration of 0.57 mM [7]. Although highly undersaturated (DS_{HAP} ~0.104), this solution does not exhibit significant erosive potential to the enamel. Considering these observations, sports drinks with lower acidity and higher calcium and phosphate content may be safer for teeth [24], and the present study and the others discussed below support this notion.

The powdered sports drink formulas used in the study contained variable amounts of calcium: IsoPlus 2.5 mmol/l, Race Isotonic Drink ALE and Isoactive 6 mmol/l, and Isostar 8 mmol/l. Generally, the calcium content in ready-to-drink formulas is lower, except for Isostar. Sports drinks prepared from powder had lower erosive potential than that of Gatorade and Powerade. Among sports drinks from the Australian market, two with the highest calcium concentration have been shown to have the lowest erosive potential (Endura with 3 mM calcium as calcium amino acid chelate, and Sukkie with 11 mM calcium as calcium lactate). However, due to their relatively high pH, the taste of those drinks was less acceptable than that of more acidic sports beverages [5]. In an in situ study, an experimental carbohydrate-electrolyte sports orange drink with 8.75 mM calcium ingested during exercise had significantly lower erosive potential [25]. The other method that successfully minimised the erosion effect of sports drinks was substituting citric acid with malic acid and increasing the pH [14].

There are conflicting findings on the relationship between the use of sports drinks and erosive toothwear in several cross-sectional observational studies. While some studies have reported a causal relationship [18], others found no significant association between dental erosion and consumption of sports drinks [1, 12, 15, 21]. Bearing in mind the multifactorial aetiology of dental erosion, focusing on a single type of drink may be too simplistic [6]. Moreover, the results of the present study highlight the differences of the erosive potential among different brands of sports drinks and their formulations. This fact should be taken into account in conducting further cross-sectional studies.

CONCLUSIONS

Sports drinks exhibit different erosive potential related to their pH. Patients frequently consuming these beverages should be aware of the potential risk for dental erosion.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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