Sports drinks and dental

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ABSTRACT: ***Purpose:*** To discuss the composition and rationale for the use of sports drinks along with recent studies investigating the relationship between sports drinks and dental erosion. ***Methods:*** A review of the literature of sports drinks and dental erosion was done. ***Results:*** For most athletes and individuals engaged in physical activity, the use of sports drinks does not provide a benefit over water. Furthermore, although there is much *in vitro* evidence that acidic drinks such as wine, fruit juices and carbonated soft drinks have erosive potential and there are relationships between consumption of these drinks and erosion, only one study has reported an association between sports drinks and dental erosion. Other factors such as drinking habit and salivary production may be more important determinants of dental erosion. (*Am J Dent* 2005;18:101-104).

CLINICAL SIGNIFICANCE: Individuals engaged in physical activity may be educated to the lack of benefits of sports drinks over water and should be encouraged to avoid dehydration and swishing acidic drinks in the mouth to prevent dental erosion.

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Composition of sports drinks

The production and sale of sports drinks is a lucrative and competitive industry, as demonstrated by the rapidly growing variety of products being marketed. The worldwide demand for sports drinks is immense; the U.S. market alone is estimated at being worth over $1.5 billion a year. Although there are many different products available to the consumer, there is generally little difference in the composition of different commercially available sports drinks (Table). Although these beverages have been manufactured for individuals involved in physical activity they are being widely used by the general population in preference to carbonated beverages.

Carbohydrate content of sports drinks - The beverages described in the Table contain between 6 and 8% carbohydrate with slight variation in the combination of carbohydrate sources used by manufacturers. The major carbohydrates used in sports drinks are glucose, fructose, sucrose, and the synthetic polymer maltodextrins, also known as glucose polymers. The use of glucose polymers in sports drinks has increased in recent years as they allow for provision of more carbohydrate without a resultant increase in osmolality. When designing the composition of sports drinks, a manufacturer balances the efficacy of the carbohydrate combination with palatability.

Electrolyte content of sports drinks - Small amounts of electrolytes, generally sodium, potassium, and chloride, are added to sports drinks to improve palatability and to, theoretically, help maintain fluid/electrolyte balance. The addition of electrolytes affects beverage osmolality which, in turn, influences the rate of absorption of the fluid and its contents. Of importance to this review are the low levels of calcium, phosphate and fluoride reported in sports drinks.[1]

Rationale for using sports drinks

Sports drinks are typically formulated to: (1) prevent dehydration, (2) supply carbohydrates to augment available energy, (3) provide electrolytes to replace losses due to perspiration, (4) conform to requirements imposed by regulatory authorities and, probably the most important, and (5) be highly palatable. Sports drinks can be classified as having either a low carbohydrate concentration (<10%) or a high carbohydrate concentration (>10%). The higher carbohydrate content drinks are marketed for carbohydrate loading rather than for general consumption before and during exercise. The more popular drinks are those that contain low carbohydrate concentration; these beverages will be the focus of this review.

It is well known that ingesting fluid before and during exercise minimizes the detrimental effects of dehydration on cardiovascular dynamics, temperature regulation and exercise performance. The question of whether sports drinks have additional benefits over water alone has been the topic of hundreds of investigations in the sport science literature. In summary, in certain situations, a sports drink will benefit performance. These situations include when the individual has low initial stored body carbohydrate (glycogen) and/or when the exercise is for a long duration (greater than 1 hour) at a high intensity or longer if the intensity is lower.[2] However, for most individuals engaged in physical activity sports drinks have no performance benefit over water.[2]

Probably the greatest benefit of sports drinks to exercising individuals is that they generally increase voluntary fluid consumption. It is well recognized that people do not consume adequate fluids when involved in physical activity with the rate of voluntary fluid ingestion shown to be usually only 50% of the rate of fluid loss during exercise.[3] This hypohydration can lead to life threatening dehydration with numerous related deaths in the sporting world occurring each year. The hypohydration also leads to decreased salivary flow that results in inadequate rinsing and buffering of demineralizing acids on tooth surfaces increasing the potential for erosion.[4]

The volume and frequency of voluntary fluid consumption is affected by beverage characteristics such as temperature, taste, aroma, mouthfeel, and appearance, with pleasantly flavored, cool sports drinks more likely to be consumed compared to water.[5] Indeed, when the effects of water and three commercial sports drinks on performance and metabolic balance were investigated, the results revealed that all of the drinks were equally effective in maintaining water, electrolyte, mineral bal-

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Table. Comparison of the contents of popular sports drinks.

Sports drinks	Calories (kCal/250ml)	Sodium (mg/250ml)	Potassium (mg/250ml)	Chloride (mg/250ml)	Total CHO (g/250ml)	CHO conc. (%)	Sugars (g/250ml) (w/v)	CHO source
Gatorade	63	103	30	1	15	6.0	14	sucrose (38%) /glucose (34%) / fructose (28%) / maltodextrins (8%)
Powerade	70	70	30	ns	19	7.6	15	High-fructose corn syrup/ maltodextrins (% ns)
Allsport	80	55	55	ns	21	8.4	10	High-fructose corn syrup(56%) / glucose (43%)/ maltodextrins (1%)
Hydrafuel	66	25	30	ns	17	6.8	ns	maltodextrins/glucose/fructose (% ns)
Isostar	70	110	45	8	17	6.8	ns	ns
Exceed	70	50	45	80	17	6.8	ns	maltodextrins/fructose (%ns)
10K	60	55	30	ns	15	6.0	ns	High fructose corn syrup (% ns)
Gatorade (Europe)	50	110	30	8	14	5.6	14	sucrose (38%) /glucose (34%) / fructose (28%) / maltodextrins (8%)
Endura	62	80	160	ns	16	6.4	ns	ns
Xcel	62	47	70	ns	15	6.0	ns	ns
Sponser	ns	69	110	11	16	6.4	ns	ns
Rivella marathon	ns	24	136	4	12	4.8	ns	ns
Sport plus	72	91	54	ns	18	7.2	18	sucrose (71%) /glucose (29%)
Isosport	42	103	29	ns	18	7.2	15	sucrose (43%) /glucose (24%) / fructose (19%) /glucose polymers (14%)
Staminade	51	58	49	ns	13	5.2	13	glucose (100%)

ns = not stated.

ances and physical performance. However, voluntary consumption of the commercial beverages was greater than that of water, suggesting that these drinks were more appealing and would be more beneficial to the subjects.[6]

Acidic drinks and dental erosion

Before discussing studies specific to sports drinks, a review of the literature pertaining to acidic drinks and dental erosion is warranted. There is much *in vitro* and *in situ* evidence that acidic drinks such as wine, fruit juices and carbonated soft drinks have potential to cause dental erosion.[7-16] In addition, a number of epidemiological studies have shown clear relationships between acidic drink consumption and erosion.[17-19] In a recent study of over 400 children in the United Kingdom, significant correlations were found between the prevalence of erosion and the consumption of soft drinks, carbonated beverages and alcohol.[19] The total acid level (titratable acid) of acidic drinks is considered to be more important than pH alone as this determines the concentration of damaging hydrogen ions available to interact with the tooth surface.[20]

Sports drinks and dental erosion

Given that dental erosion has become a significant clinical problem it is surprising that only a small number of studies have investigated the relationship between the use of sports drinks and dental erosion. A few animal and *in vitro* studies have been conducted investigating the erosive potential of sports drinks.

The pH and titratable acidity of fruit juices, fruit drinks, carbonated beverages and sports drinks have been compared.[21] The author found that all drinks had about the same pH (between 2.9 and 4.0), however fruit juices had much higher titratable acidity, approximately 2-3 times higher than the other three groups of products indicating a greater erosive potential. The erosive potential of eight popular brands of sports drinks were compared in a U.K. study with similar results.[1] The pH of the drinks ranged between 2.4 to 4.5 with surprising variability in the titratable acidity between the drinks. The authors concluded that although all drinks had erosive potential there were considerable differences in this potential between the drinks.

The type of acid used in sports drinks and its role in dental erosion has been investigated by researchers from the University of Helsinki, Finland.[22] They used an *in vitro* bovine enamel model to show that the most common type of acid used in sports drinks, citric acid, had greater erosive potential than the malic acid present in an experimental beverage.

Previously, the same research group had shown[8] that sports drinks had a similar erosive potential to diet cola beverages but not as bad as cola beverages and orange juice. In addition, a study they conducted in rats showed[23] that a sports drink with a pH of 3.2 containing 6% sucrose significantly promoted dental erosion but not caries. Of interest was the finding that fluoride decreased caries induced by powdered food but had no effect on the erosion caused by the sports drink.[23] The same researchers had previously used the same rat model and found that,[24] compared with a group that drank distilled water, a sports drink mixture significantly increased the accumulation of plaque, but again did not affect caries. Addition of fluoride to the sports drink mixture, alone or with magnesium tended to decrease plaque.[24]

There have been two case control studies comparing the effects of sports drinks consumption on dental erosion.[18,25] Dental erosion was investigated in 106 cases with erosion and 100 randomly selected controls from the same source population in Finland.[25] All cases and controls were evaluated by the recording of structured medical and dietary histories and by examination of the teeth and saliva. The authors reported an adjusted odds ratio of four with daily consumption of sports drinks. This related to 32 out of the 106 cases compared to 10 out of the 100 controls reporting daily consumption of a

sports drink. This is the only study that has reported an association between sports drinks consumption and dental erosion. It has been noted in another study[26] that the cases in this study were adults with severe erosion and therefore the results may not be generalizable.

The second case control study was from the U.K. and showed no relationship between dental erosion and the consumption of sports drinks in 309 gender and age matched children.[18] Structured dietary histories were used to determine the type and frequency of intake of acidic foods and drinks together with any drinking habits that prolonged exposure of the teeth to dietary acids. Results showed that the children with erosion drank acidic beverages significantly more frequently than children who either had caries or were caries-free. Children with erosion also drank milk or water significantly less often than the control groups, and were more likely to have a swishing or holding habit associated with drinking. Fruit and vinegar consumption was higher in the erosion group, as was the taking of vitamin C supplements. The results of this study suggest that the increased consumption of acidic foods and drinks, particularly when associated with a swishing or holding habit, may contribute to the development of erosion in some children.

Sports drinks and dental erosion in athletes

Many athletes, especially endurance athletes experience long periods of hypohydration during training and competition. It is recognized that this increases the risk of dental erosion due to a decrease in salivary flow resulting in inadequate rinsing and buffering of demineralizing acids on tooth surfaces.[4] Given the importance of dental erosion to athletes, it is surprising that only three published studies[26-28] have investigated sports drink intake and dental erosion in these individuals.

The first study[27] was conducted in 20 cyclists and 25 swimmers. A questionnaire was used to document sports drink usage and an oral examination was performed to determine the degree of dental erosion. Salivary flow rate in response to sports drink was also established in these subjects. The authors reported no association between sports drink consumption and dental erosion. They did find that cyclists had significantly more tooth wear into the dentin (17 out of 20) than swimmers (9 out of 25). The pattern of sports drinks consumption was different between the two groups with the swimmers con-suming a greater amount of other drinks that are potentially erosive. There was also a significantly lower salivary flow rate in response to one drink compared to the others. The authors acknowledge that these potentially confounding findings may have impacted on the main findings.

Recently, two studies[26,27] have published data on the relationship between sports drinks consumption and dental erosion. A study[26] from the University of Ohio also used a self-administered questionnaire to gather information on sports drink usage in 304 university athletes. The Lussi index was used in blinded clinical examinations to grade the frequency and severity of erosion, and intraoral color slides were taken of all teeth with erosion. Similar to the findings of Milosevic *et al*,[27] although the prevalence of erosion was high (36.5%), no significant associations were found in regard to the use of sports drinks, quantity and frequency of consumption and years of usage.[26]

Finally, a recent study[28] from Australia also reported no significant associations between dental erosion and the frequency of drinking sports drinks. This study was carried out in 508 members of the university sporting club and used a questionnaire to determine sports drink usage and dental health. Dental erosion was reported by 25.4% of respondents with significant associations found only with age, frequency of drinking juices and tooth sensitivity.

The findings of a lack of association between dental erosion and sports drink consumption indicates that isolating a particular dietary component may be too simplistic. Indeed, sports drinks contain no more acid than a wide variety of drinks including soft drinks, fruit juices, beer and wine. It has been suggested that tooth enamel erosion occurs only in susceptible individuals regardless of food and beverage consumption patterns.[29,30]

Drinking habit and salivary function

Many researchers have suggested that drinking habit, rather than the content of the beverage is more critical to dental erosion.[29,30] To investigate changes in oral pH with beverage consumption, small antimony pH electrodes were used to measure oral pH simultaneously at the surface of four teeth. In addition, measures of salivary flow and buffering capacity were carried out in a group of adolescents either with or without erosion.[31] The erosion patients reported drinking more carbonated drinks, drinking from a can more frequently and they also drank twice as fast as the control subjects. The authors found that oral pH remained lower for longer in the erosion patients and they concluded that drinking habit may play a large influence on dental erosion.

The importance of salivary function in the avoidance of dental erosion was shown in 500 patients referred for excessive tooth wear. Although there was evidence of consumption of highly acidic drinks, some occlusal parafunction, and unacceptable tooth brushing habits, salivary dysfunction was the salient factor predisposing a patient to tooth wear in these syndromal cases.[32]

Sports drinks and dental caries

Dental caries is due to a combination of factors, including colonization of teeth with cariogenic bacteria, type of foods and frequency of exposure of these foods to the cariogenic bacteria, susceptible teeth, toothbrushing frequency and use of fluoride toothpaste.[33,34] Given that caries risk is greatest if sugars are consumed at high frequency and are in a form that is retained in the mouth for long periods there has been concern that sports drinks consumption may promote this disease. Many *in vitro* and *in vivo* tests as well as animal experiments have established that sugar-containing beverages can cause dental caries,[35,36] however, evidence from a number of studies does not support the postulate that sports drink consumption is associated with dental caries.[23,24,27,37] Sports drinks have been shown to have the same cariogenicity as fruit juices, fruit drinks and carbonated beverages[21] and therefore, although evidence supporting their relationship with dental caries has not been found, the caries causing potential cannot be overlooked.

Concluding remarks and recommendations

There is no doubt that the acidic nature of sports drinks has the potential to cause dental erosion with animal and *in*

vitro studies supporting this notion. Two case control studies have reported contradictory findings on the association between sports drink consumption and dental erosion and the three cross sectional studies in athletes have all failed to find a relationship. Combined, these studies indicate that isolating one dietary component as causative of erosion may be simplistic and factors such as drinking habit and salivary production may play a more influential role on the pathology. Given these findings, oral health educators should be reinforcing important practices to sports drink users such as decreasing the time that the sports drink remains in the mouth and avoiding dehydration. Finally, compared to water, the benefits of a sports drink for most recreationally active individuals is negligible.

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References

1. Milosevic A. Sports drinks hazard to teeth. *Br J Sports Med* 1997; 31: 28-30.
2. Coombes JS, Hamilton KL. The effectiveness of commercially available sports drinks. *Sports Med* 2000; 29: 181-209.
3. Pugh LG, Corbett JL, Johnson RH. Rectal temperatures, weight losses, and sweat rates in marathon running. *J Appl Physiol* 1967; 23: 347-352.
4. Woltgens JH, Vingerling P, de Blieck-Hogervorst JM, Bervoets DJ. Enamel erosion and saliva. *Clin Prev Dent* 1985; 7: 8-10.
5. Boulze D, Montastruc P, Cabanac M. Water intake, pleasure and water temperature in humans. *Physiol Behav* 1983; 30: 97-102.
6. Johnson HL, Nelson RA, Consolazio CF. Effects of electrolyte and nutrient solutions on performance and metabolic balance. *Med Sci Sports Exerc* 1988; 20: 26-33.
7. Addy M, Absi EG, Adams D. Dentine hypersensitivity. The effects *in vitro* of acids and dietary substances on root-planed and burred dentine. *J Clin Periodontol* 1987; 14: 274-279.
8. Rytomaa I, Meurman JH, Koskinen J, Laakso T, Gharazi L, Turunen R. *In vitro* erosion of bovine enamel caused by acidic drinks and other foodstuffs. *Scand J Dent Res* 1988; 96: 324-333.
9. Lussi A, Jaggi T, Scharer S. The influence of different factors on *in vitro* enamel erosion. *Caries Res* 1993; 27: 387-393.
10. Rugg-Gunn AJ, Maguire A, Gordon PH, McCabe JF, Stephenson G. Comparison of erosion of dental enamel by four drinks using an intra-oral appliance. *Caries Res* 1998; 32: 337-343.
11. West NX, Maxwell A, Hughes JA, Parker DM, Newcombe RG, Addy M. A method to measure clinical erosion: The effect of orange juice consumption on erosion of enamel. J *Dent* 1998; 26: 329-335.
12. Hughes JA, West NX, Parker DM, van den Braak MH, Addy M. Effects of pH and concentration of citric, malic and lactic acids on enamel, *in vitro*. *J Dent* 2000; 28: 147-152.
13. Lussi A, Kohler N, Zero D, Schaffner M, Megert 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: 110-114.
14. Bartlett DW, Coward PY. Comparison of the erosive potential of gastric juice and a carbonated drink *in vitro*. *J Oral Rehabil* 2001; 28: 1045-1047.
15. Parry J, Shaw L, Arnaud MJ, Smith AJ. Investigation of mineral waters and soft drinks in relation to dental erosion. *J Oral Rehabil* 2001; 28: 766-772.
16. 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: 204-211.
17. Millward A, Shaw L, Smith AJ, Rippin JW, Harrington E. The distribution and severity of tooth wear and the relationship between erosion and dietary constituents in a group of children. *Int J Paediatr Dent* 1994; 4: 151-157.
18. O'Sullivan EA, Curzon ME. A comparison of acidic dietary factors in children with and without dental erosion. *ASDC J Dent Child* 2000; 67: 186-192, 160.
19. 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: 258-261.
20. Zero DT. Etiology of dental erosion. Extrinsic factors. *Eur J Oral Sci* 1996; 104: 162-177.
21. Birkhed D. Sugar content, acidity and effect on plaque pH of fruit juices, fruit drinks, carbonated beverages and sport drinks. *Caries Res* 1984; 18: 120-127.
22. Meurman JH, Harkonen M, Naveri H, Koskinen J, Torkko H, Rytomaa I, Jarvinen V, Turunen R. Experimental sports drinks with minimal dental erosion effect. *Scand J Dent Res* 1990; 98: 120-128.
23. Sorvari R. Effects of various sport drink modifications on dental caries and erosion in rats with controlled eating and drinking pattern. *Proc Finn Dent Soc* 1989; 85: 13-20.
24. Sorvari R, Koskinen-Kainulainen M, Sorvari T, Luoma H. Effect of a sport drink mixture with and without addition of fluoride and magnesium on plaque formation, dental caries and general health of rats. *Scand J Dent Res* 1986; 94: 483-490.
25. Jarvinen VK, Rytomaa, II, Heinonen OP. Risk factors in dental erosion. *J Dent Res* 1991; 70: 942-947.
26. Mathew T, Casamassimo PS, Hayes JR. Relationship between sports drinks and dental erosion in 304 university athletes in Columbus, Ohio, USA. *Caries Res* 2002; 36: 281-287.
27. Milosevic A, Kelly MJ, McLean AN. Sports supplement drinks and dental health in competitive swimmers and cyclists. *Br Dent J* 1997; 182: 303-308.
28. Sirimaharaj V, Brearley Messer L, Morgan MV. Acidic diet and dental erosion among athletes. *Aust Dent J* 2002; 47: 228-236.
29. Murray B, Moss SJ. Sports drinks and tooth decay. *J Am Dent Assoc* 1997; 128: 1200, 1202, 1204.
30. Moss SJ. Dental erosion. *Int Dent J* 1998; 48: 529-539.
31. Moazzez R, Smith BG, Bartlett DW. Oral pH and drinking habit during ingestion of a carbonated drink in a group of adolescents with dental erosion. *J Dent* 2000; 28: 395-397.
32. Young W, Khan F, Brandt R, Savage N, Razek AA, Huang Q. Syndromes with salivary dysfunction predispose to tooth wear: Case reports of congenital dysfunction of major salivary glands, Prader-Willi, congenital rubella, and Sjogren's syndromes. *Oral Surg Oral Med Oral Pathol* 2001; 92: 38-48.
33. Gibson S, Williams S. Dental caries in pre-school children: Associations with social class, toothbrushing habit and consumption of sugars and sugar-containing foods. Further analysis of data from the National Diet and Nutrition Survey of children aged 1.5-4.5 years. *Caries Res* 1999;33:101-113.
34. Tinanoff N, Palmer CA. Dietary determinants of dental caries and dietary recommendations for preschool children. *J Public Health Dent* 2000;60:197-206; 207-209.
35. Bibby BG. The cariogenicity of snack foods and confections. *J Am Dent Assoc* 1975; 90: 121-132.
36. Newbrun E. Dietary carbohydrates: Their role in cariogenicity. *Med Clin North Am* 1979; 63: 1069-1086.
37. Borg A, Birkhed D. Dental caries and related factors in a group of young Swedish athletes. *Int J Sports Med* 1987; 8: 234-235.