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Relationship between Sports Drinks and Dental Erosion in 304 University Athletes in Columbus, Ohio, USA

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Key Words
Athletes · Dental erosion · Sports drinks

Abstract
Acidic soft drinks, including sports drinks, have been implicated in dental erosion with limited supporting data in scarce erosion studies worldwide. The purpose of this study was to determine the prevalence of dental erosion in a sample of athletes at a large Midwestern state university in the USA, and to evaluate whether regular consumption of sports drinks was associated with dental erosion. A cross-sectional, observational study was done using a convenience sample of 304 athletes, selected irrespective of sports drinks usage. The Lussi Index was used in a blinded clinical examination to grade the frequency and severity of erosion of all tooth surfaces excluding third molars and incisal surfaces of anterior teeth. A self-administered questionnaire was used to gather details on sports drink usage, lifestyle, health problems, dietary and oral health habits. Intraoral color slides were taken of all teeth with erosion. Sports drinks usage was found in 91.8% athletes and the total prevalence of erosion was 36.5%. Nonparametric tests and stepwise regression analysis using history variables showed no association between dental erosion and the use of sports drinks, quantity and frequency of consumption, years of usage and nonsport usage of sports drinks. The most significant predictor of erosion was found to be not belonging to the African race ($p < 0.0001$). The results of this study reveal no relationship between consumption of sports drinks and dental erosion.

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Dental erosion is the nonbacteriogenic, acid-induced loss of tooth structure. The etiology of erosion is multifactorial and not fully understood. Sources of acids that can lead to erosion may be extrinsic or intrinsic. Extrinsic sources of erosive acids include acidic foods and drinks, medications and environmental acids [Birkhed, 1984; Grenby et al., 1989; Grobler et al., 1989, 1990; Zero, 1996]. Intrinsic acids are gastric acids, which come in contact with teeth during regurgitation, reflux disorders and bulimia. The prevalence of erosion ranges between 25 and 60% [Sognnaes et al., 1972; Xhonga and Valdmanis, 1983; Lussi et al., 1991; Smith and Robb, 1996], as reported in the scientific literature based on a wide variety of indices for erosion, different countries and population groups. It is widely believed that the prevalence of erosion is increasing.

Sports drinks are acidic drinks, like fruit juices and carbonated drinks, most of which have a pH below 5.5, the critical pH for enamel demineralization to occur [Birkhed, 1984; Milosevic, 1997; Milosevic et al., 1997]. Sports drinks are used primarily by athletes for the pur-

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pose of rehydration and electrolyte replacement during highly aerobic sports. Despite their indication for use in sports-related activities, sports drinks have been gaining in popularity among children and young adults. Due to the increased popularity of acidic drinks like juices, carbonated drinks and sports drinks and the perceived increase in the prevalence of dental erosion, acidic drinks in general are frequently implicated in the pathogenesis of dental erosion.

A few case reports and studies (mostly in vitro) have reported a relationship between sports drinks and dental erosion [Miller, 1952; Birkhed, 1984; Rytömaa et al., 1988; Sorvari, 1989; Meurman et al., 1990; Lussi et al., 1993; Milosevic, 1997]. The purpose of this study was firstly to determine the prevalence of dental erosion in a sample of athletes at a large Midwestern state university in the USA and secondly to evaluate whether consumption of sports drinks is associated with a significant increase in dental erosion.

Subjects and Methods

An observational, cross-sectional study was conducted at the Ohio State University after obtaining approval from the Institutional Review Board and the Medical Committee of the Athletic Department of the University. Members of university sports teams involved in high intensity sports such as football and lacrosse were invited to participate in the study. Athletes were recruited irrespective of their use of sports drinks in order to obtain as generalizable a sample as possible. Swimmers were excluded from the study to avoid the confounding exposure to chlorinated water. Wrestlers were also excluded due to their reputation for erratic eating and weight control habits.

Informed consent was obtained from all athletes before participation in the study. A self-administered questionnaire was filled out by the subjects which was then reviewed by an assistant and discrepancies clarified. The questionnaire consisted of inquiries pertaining to the subjects' involvement in sports, medical history, dental history, oral symptoms of dental erosion and gastric disorders and details regarding use of sports drinks (table 1). Although the questionnaire was self-administered, the subjects were partially interviewed especially regarding the quantity of sports drink consumed. Subjects were shown samples of standard cups and sports drink bottles to help them better quantify the volume of sports drinks consumed.

The clinical examination was done by one examiner after undergoing training and calibration exercises with one other examiner (coauthor). During the calibration each examiner was blinded to each other's erosion score so that a measure of reliability could be obtained. The clinical examiner was blinded to the results of the questionnaire at the time of dental examination. Subjects were first instructed to brush their teeth using a complimentary toothbrush and tube of toothpaste. This was done to ensure plaque removal to aid in proper visualization. Standard illumination from a dental operatory light was used. The teeth were dried thoroughly prior to evaluation. Clinical photographs were taken of all tooth surfaces with erosion after air-drying. Study casts were made of severe erosion cases using alginate impressions.

Table 1. Questionnaire factors tested for relationship with dental erosion

1	Age
2	Sex
3	Race
4	Sports team (competitive)
5	Sports team (noncompetitive)
6	Number of months of sports activity
7	Sports drink-related factors: Usage or not, sports drink brand name in order of frequency of use, age of onset of sports drink use, nonsport-related/home use of sports drink, frequency and quantity of intake of sports drink, change in frequency or quantity of intake in last 6 months
8	Use and frequency of intake of following drinks: Cola drinks, other soft drinks, fruit juices, lemonade, coffee, plain tea, lemon tea, wine, beer, other alcoholic drinks and apple cider
9	Use and frequency of intake of following food items: Citrus fruits, tomatoes, hard cheese, curried foods, spicy foods, vinegar, pickles, salad with dressing, yogurt, peppermint, sweet and sour sauce, tartar sauce and sour candy
10	Number of meals per day
11	Snacking/drinking between meals
12	Eating disorders
13	Medical disorders/health problems
14	Medications with names and dosage, if any
15	Iron supplement use in the last 5 years
16	Vitamin C use in the last 5 years
17	Multivitamins use in the last 5 years
18	History and frequency of following signs and symptoms: Chest pain, acidic taste, dry mouth, sensitive teeth, heartburn, regurgitation, vomiting and sharp teeth
19	Type of diet: Strict vegetarian, lacto-ovo-vegetarian, nonvegetarian
20	Unusual dietary preferences or habits
21	Indoor swimming, history and frequency
22	Tooth brushing frequency, toothpaste brand
23	Professional or home tooth whitening system
24	History, frequency, age of onset and cessation of clenching and grinding habit
25	Orthodontic treatment, history, onset and duration

The distribution and severity of dental erosion were graded using the Lussi Index [Lussi, 1996]. The third molars, congenitally missing or extracted teeth and teeth with full crown coverage were excluded from data collection. Incisal surfaces of all the anterior teeth were also excluded due to the high incidence of dental attrition at these sites [Millward et al., 1994a; Johansson et al., 1996; Ganss et al., 2001]. Therefore, a maximum of 72 surfaces of teeth were examined per subject for erosion. Each available tooth surface was graded with a score ranging from 0 to 3, based on the Lussi Index. A total erosion

Table 2. Lack of association between sports drink usage and dental erosion among the athletes

	Dental erosion	
	no	yes
Sports drinks usage		
Yes	63.8% (n = 178)	36.2% (n = 101)
No	60.0% (n = 15)	40.0% (n = 10)

p = 0.705.

Table 3. Predictors of dental erosion using Spearman's rank correlation (ρ)

Variable	Erosion (ρ)	p value
Nonblack race	–0.265	<0.001
History of orthodontic treatment	–0.158	0.006
Apple cider	–0.118	0.040
Whitening toothpaste	–0.113	0.050
Sports drink	–0.031	0.591

score was computed for each subject by calculating the sum of the scores of all the available surfaces of the subject's teeth.

Statistical analysis of the data collected from the results of the questionnaire and the clinical examination was done using a stepwise linear regression and Spearman's rho (ρ) correlation analyses using SPSS® version 10 for Windows®. Since the distribution of the erosion scores was skewed, the dependent variable used for the regression analysis was the $\log_{10}$ (the total erosion score + 1), '1' being added to accommodate total erosion scores of '0' in many of the subjects. There were 89 independent measures collected from the questionnaire data. Two separate stepwise linear regressions were performed to test for factors predicting erosion. One analysis tested for the primary effects of sports drinks on erosion scores and the other tested for the effect of sports drinks on erosion while controlling for many other questionnaire factors. Statistical significance was set at alpha = 0.05. A dose-response test was also done with the various measures of the amount of sports drink consumed and erosion score.

Results

A convenience sample of 304 athletes from the Ohio State University participated in the study. Sixty-one percent of the athletes were male and 39% were female. The athletes ranged in age from 18 to 28 years, mean 19 ± 1.4 years. With respect to race, the athletes were 79.6% Caucasian, 15.1% African-American, 1.6% Hispanic, 1.3% Asian and 2.3% belonged to 'other' races. Sports drinks were consumed regularly by a majority of athletes (91.8%). Sixty-three percent of athletes reported that they drank at least 1 liter of sports drink daily. Mean age of onset of sports drinks intake was 10.8 ± 4.4 years. The most popular brands of sports drinks among the athletes at the Ohio State University were Gatorade® and Powerade®. Other brands included Allsport® and Carbofuel®. The mean percentage of study participation from each of the sports teams was 59% with the softball team showing the best participation rate of 85% and the crew team showing the lowest participation rate of 17%.

Dental Erosion Findings

Total prevalence of dental erosion among the 304 athletes was found to be 36.5% (n = 111 subjects) of which 2.3% (n = 7) represented facial erosion, 35.5% (n = 108) occlusal erosion and 0.7% (n = 2) lingual erosion. Enamel erosion was found in 75.2% of the subjects with erosion and the remaining showed dentinal involvement. The tooth most often affected by dental erosion was the mandibular first permanent molar and the most affected tooth surface was the occlusal surface of this tooth. The most severe and extensive erosion was also found on the mandibular teeth. In addition, tooth sensitivity was reported as a symptom by 12.9% of athletes. In addition, 8.8% of athletes had erosion involving the dentin, which can be an indication of need for treatment.

An intraexaminer reliability was conducted by reexamining 39 subjects. The tests showed very good agreement with an intraexaminer kappa statistic of 0.92. Interexaminer reliability was conducted by a coauthor who reexamined a subset of 20 subjects resulting in a kappa statistic of 0.767.

Multiple regression analysis and correlation analysis revealed no relationship between any of the sports drink-related factors and dental erosion. Sports drink-related factors included the quantity of sports drink consumed, home use of sports drink, total number of years of usage of sports drinks and brand name of sports drink. All sports drink-related factors were entered into the stepwise regression analysis and no factors were significant. Table 3 illustrates no significant Spearman rho correlations between sports drink usage and the erosion score. Finally, table 2 shows that out of 279 consumers of sports drinks, 64% did not have any dental erosion and 36% had dental erosion. Conversely, out of the 25 athletes who did not consume any sports drinks, 60% did not have any dental erosion and 40% had erosion ($\chi^2 = 0.14$, p = 0.705).

Table 4. Results of regression analysis

Factor	B (SE)	p value
Nonblack race	0.230 (0.05)	<0.001
Whitening paste	0.145 (0.069)	0.036
Health problems	–0.140 (0.062)	0.025
Iron supplements	–0.113 (0.053)	0.034
Intercept	0.054 (0.202)	

$R^2 = 0.079$; $p < 0.001$.

Table 5. Percentage of athletes with erosion based on their racial group, regular use of whitening toothpaste, health problems and use of iron supplementation

Factors	Erosion, %	p and χ^2
Black race	8.7	$p < 0.001$
Nonblack race	41.5	$\chi^2 = 18.09$
Whitening paste	54.5	$p = 0.068$
Nonusers of whitening paste	35.1	$\chi^2 = 3.32$
History of health problems	21.4	$p = 0.082$
No history of health problems	38.0	$\chi^2 = 3.02$
Iron supplementation	27.5	$p = 0.204$
Nonusers of iron supplementation	37.9	$\chi^2 = 1.61$

Out of the 89 variables or predictors that were analyzed, Spearman's rank order correlations (table 3) revealed nonblack race, use of apple cider, whitening toothpaste and history of orthodontic treatment to be statistically significant factors associated with dental erosion with $p < 0.05$. In the analysis with all the variables, stepwise multiple regression analysis revealed that nonblack race, lack of history of health problems, nonuse of iron supplements, and use of whitening toothpaste were significantly associated with dental erosion (table 4). Additional χ^2 tests of these significant factors were completed against the presence or absence of erosion. Table 5 reveals that nonblack race was significant, but the other factors were not. Some of the other dietary factors that were not statistically significant included carbonated drinks, fruit juices, lemonade, coffee, plain tea, lemon tea, wine, beer, citrus fruits, tomatoes, hard cheese, spicy foods, vinegar, pickles, peppermint, sour candy and salad with dressing. Other history variables that were not statistically significant included snacking between meals, habitual restricting of food/fluids for the purpose of weight loss, use of daily medications, iron supplements, vitamin C, multivitamins and creatine. Medical history of the athletes including history of regurgitation, heartburn, vomiting and chest pain was also not significant. Oral symptoms and habits such as acidic taste in mouth, dry mouth, sensitive teeth, sharp teeth, achy jaw muscles on waking, clenching and grinding habits were also not significantly associated with dental erosion. Recreational swimming by some of the athletes also was not statistically significant. Frequency of tooth brushing was also nonsignificant.

Discussion

The results of our study may not be representative of every university in the USA due to differences in sports drink usage in each university partly due to varying manufacturer sponsorships and enrolment differences as well as individual preferences and lifestyle differences among athletes and coaches. The index we used for assessing dental erosion proved to be a simple and easy index for the sole purpose of grading erosion [Lussi, 1996]. Since there seemed to be a large difference between the small 'peephole' type lesions involving dentin and the extensive dentin-affected erosive lesions involving the majority of the occlusal surface of posterior teeth, grading both these type lesions with the same grade of 2 seemed inadequate. In future studies, a further differentiation between the sizes of dentin-affected erosive areas on occlusal surfaces of posterior teeth is recommended by modifying the Lussi Index.

One of the limitations of our study was recall bias with respect to collection of data from the questionnaire. Recruitment and scheduling of athletes for the study was fraught with difficulties due to their intensive athletic training and study schedules. Fluoride levels in the water supply of the athletes were not specifically evaluated. The public water supply of the city of Columbus, Ohio is fluoridated and it may be acceptable to assume that a majority of the athletes were exposed to fluoridated water in the past. Studying salivary flow rates and buffering capacity of the athletes' saliva would have been useful but it was beyond the scope of our study. Although ideal and more accurate, a weekly dietary record would have been an unrealistic expectation of athletes. The method of consuming the sports drink (such as sipping, holding, swish-

ing, using a straw) was not specifically addressed in the questionnaire, which may have been very useful to the study [Grobler et al., 1985]. Another limitation was the small number of nondrinkers (n = 25). To partially address this limitation, various measures of the amount of sports drink consumed were correlated with the erosion score in order to test for dose-response effects which also confirmed the lack of relationship between consumption of sports drinks and dental erosion.

To the best of the authors' knowledge, the study is the first one to report about dental erosion among athletes in the USA. The prevalence of erosion among athletes who consume more sports drinks than the average population was found to be 36.5%. Unfortunately, no data are available on the prevalence of dental erosion among randomly selected adults or children in the United States. Although it is difficult to accurately compare the results of this study with other prevalence studies due to the differences in indices used, study criteria, diagnostic criteria and tooth surfaces examined, it appears that the prevalence of erosion in our study is similar to, or lower than, the rates reported in other countries [Lussi et al., 1991; Millward et al., 1994b; Milosevic et al., 1994; Nunn, 1996; Smith and Robb, 1996; Bartlett et al., 1998; Al-Dlaigan et al., 2001a; Ganss et al., 2001].

In a recent multicenter study of adolescents, 11–13 years of age, a prevalence of 41% was found in the sample from the USA and a prevalence of 37% was found in the sample from the UK [Deery et al., 2000]. A study on cyclists and swimmers showed the prevalence of erosion to be 100% [Milosevic et al., 1997]. The prevalence of dentinal erosion was found to be 36% in the swimmers and 85% of the cyclists compared to 8.8% dentinal erosion in the present study. A study of the anterior teeth, excluding the incisal edges, of Saudi military men of similar age as our study (19–25 years old) showed a prevalence of erosion as 77% [Johansson et al., 1996].

A few case reports, animal studies, in vitro studies and in vivo studies have considered the erosive potential of sports drinks. In general, all the in vitro studies and animal studies have shown that sports drinks caused dental erosion due to their low pH [Birkhed, 1984; Rytömaa et al., 1988; Grenby et al., 1989; Sorvari, 1989; Meurman et al., 1990; Lussi et al., 1993]. A case control study of adults in Helsinki, Finland reported an odds ratio of 4 with weekly consumption of sports drinks [Järvinen et al., 1991]. It must be noted that the cases in the Helsinki study represented adults with more severe erosion, necessitating referral for treatment and hence, the results cannot be generalizable due to the overrepresentation of severe erosion. Another case control study using 103 pairs of children from Leeds, UK showed no relationship between dental erosion and consumption of sports drinks and other dietary history related to sport [O'Sullivan and Curzon, 2000]. In the UK study of athletes, results showed no association between consumption of sports drinks and erosion [Milosevic et al., 1997]. The four sports drinks used by the athletes in the UK study had a pH below 5.5, a value that at times has been confused as being the definitive indicator of the erosive potential of a beverage. In fact, the pH of 5.5 applies to saliva, not the beverage. Demineralization that leads to erosion is equally dependent upon the absence of calcium and phosphate in oral fluids. While sports drinks formulae vary with respect to the presence and concentration of these salts, saliva that mixes with the beverage helps to maintain a supersaturated state due to the presence of calcium and phosphate, which prevents erosion. This important factor complicates the simplified interpretation that sports drinks, by virtue of an inherent low pH, possess an erosive potential. Potential dental erosiveness of a soft drink is better indicated by its titratable acid content than pH [Grenby et al., 1989; Zero, 1996].

Our study was the second cross-sectional study on athletes to show a lack of relationship between sports drinks and dental erosion. Several in vivo studies have found a relationship between acidic drinks (not sports drinks specifically) and dental erosion [Lussi et al., 1991; Millward et al., 1994b; Al-Dlaigan et al., 2001b]. However, other studies including the present study (with the exception of 'apple cider' with correlation tests only) have not found any relationship between dietary factors and dental erosion [Bartlett et al., 1998; Williams et al., 1999]. The reasons for such differences in study results are not clear but these in vivo studies demonstrate the complexity of the interaction between diet and dental erosion in human beings and the need for further epidemiological studies on large, random samples.

This study was also the first to report a racial predilection for dental erosion. Not belonging to the African race was found to be the best predictor for dental erosion with a high level of significance. It is not clearly understood why black athletes have significantly fewer teeth with dental erosion than nonblacks. It could be a combination of many factors including dietary preferences, cultural, lifestyle and socioeconomic differences between black and nonblack American athletes. Studies have demonstrated that oral hygiene improves with increasing socioeconomic status (SES). This factor could be related to the results of another study, which showed that children from lower

SES groups, with poorer oral hygiene, had less statistically significant dental erosion than children from higher SES groups [Millward et al., 1994a]. However, other researchers have found the opposite result in their studies on British children [Milosevic et al., 1994; Al-Dlaigan et al., 2001a]. Another possible reason could be innate differences in the composition and morphology of dentition among blacks and nonblacks that could affect the susceptibility to dental erosion.

Other unexpected findings from our study were the statistically significant relationship between health problems, iron supplements, and use of whitening toothpaste with dental erosion. These effects were not highly significant and are most likely spurious results due to the large number of variables examined. Health problems and iron supplementation were found to be protective, which is not intuitive. Whitening toothpaste was found to be positively associated with erosion. It has been suggested in the scientific literature that professional and over-the-counter tooth bleaching products could be possible factors in increasing the susceptibility of teeth to dental erosion [Zero, 1996]. Whitening pastes are usually basic and nonacidic in composition, but their role in the pathogenesis of erosion may be due to their high abrasivity and ability to remove or reduce the fluoride-rich surface layer. These factors may promote enamel solubility and remove calcium, phosphate and fluoride, which are essential for remineralization. Although most brands of whitening toothpastes have a lower abrasive index than the maximum of 250 RDH that is allowed by the FDA and ADA, whitening pastes might be too abrasive for those individuals who are susceptible to erosion. The dental literature also indicates that toothbrush abrasion can exacerbate erosion and that erosion and abrasion may be synergistic, potentiating each other's effects [Smith, 1975; Davis and Winter, 1980; Imfeld, 1996; Zero, 1996; Moss, 1998]. The other significant factor to note is that whitening toothpastes are more commonly used by individuals who are meticulous with oral hygiene. Thus, the use of whitening paste may be a reflection of a lifestyle or behavioral attribute of being overzealous about oral hygiene and such individuals may be more prone to erosion [Millward et al., 1994a; Zero, 1996; Moss, 1998; Shaw and Smith, 1999]. Whitening pastes may also be more effective in removing or reducing salivary pellicle, which has been shown to protect teeth from dental erosion [Meurman and Frank, 1991; Kuroiwa et al., 1993; Amaechi et al., 1999]. However, readers are advised to exercise caution in the interpretation and application of this finding due to the small statistical effect in the context of a large number of variables measured. Further studies are highly recommended to test and clarify this finding.

Site specificity of dental erosion is still controversial, especially since studies have reported various tooth surfaces for exhibiting a majority of erosive lesions. Although saliva [Amaechi and Higham, 2001] and the thickness of salivary pellicle [Amaechi et al., 1999] play an important role in erosion, there is still a lack of agreement whether erosion affects any particular tooth surface more than others [Järvinen et al., 1992]. Our study found the occlusal surface to be the most affected by erosion, which is similar to the finding in a few other studies [Linkosalo and Markkanen, 1985; Lussi et al., 1991; Ganss et al., 2001]. We also found that the mandibular first permanent molar was the most affected tooth, which is consistent with other studies [Ganss et al., 2001; Khan et al., 2001]. These researchers also suggested that the mandibular first permanent teeth might be considered as 'marker teeth' for the onset and severity of dental erosion in an individual. Other studies have shown other teeth and other tooth surfaces to be most affected by erosion. This difference is puzzling but one possible theory could be a 'regional variation in dental health' [Robb, 1998]. Future studies may be needed to clarify such differences among different population groups and geographic locations. Fluoridation of water supply, which is common in the US, may have some role to play in this along with the role of attrition, perhaps.

The finding in this study that several athletes with high consumption of sports drinks did not reveal any evidence of dental erosion further emphasizes the significance of host factors interacting with acidic drinks and also stresses the need for further studies in dental erosion with respect to susceptibility, early diagnosis, etiology, treatment and prevention.

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