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Salivary pH and Glucose after Consuming Various Beverages, Including Sugar-Containing Drinks

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Abstract. Dental erosion is often seen on the lingual tooth surfaces. For this reason tongue pH after consuming orange juice, Coca-Cola (old and new formula), Coca-Cola Light, Jaffa orange beverage, Hart-Sport sport drink, coffee (with and without sugar), beer, sour milk, and strawberry yoghurt was studied in a test panel. The lowest pH values which also remained low for the longest time were observed after consuming Hart-Sport (pH down to 3.80), orange juice, yoghurt, Coca-Cola, and Jaffa, in comparison with coffee (pH down to 5.26), Coca-Cola Light, and beer ($p < 0.001$). The total glucose concentration in the products and in saliva after consuming them was measured in order to assess the clearance of the products from the mouth. Hart-Sport yielded the highest salivary glucose concentrations (14,000 ppm total glucose) immediately after consuming while yoghurt (4,520 ppm) and coffee with sugar (6,480 ppm) caused the least elevation ($p < 0.05$). All study products, however, were quickly cleared from the mouth and practically no glucose was left in saliva 30 min after ingestion. Since all the studied products caused lowering of tongue pH below pH 5.5, they have the potential to cause adverse effects on the teeth in patients with impaired salivary function. In the healthy subjects in this study, however, the buffering capacity in the mouth was so strong that not even tongue mucosa could be shown to keep low pH levels a couple of minutes after consumption.

Various beverages may cause dental erosion and caries [Bibby, 1975; Newbrun, 1978; Lancet editorial, 1980]. Depending on the chemical composition of the beverage, however, its dental effect may vary. For example, the degree of saturation with respect to the calcium and phosphorus content of the drink may modify erosion observed clinically [Larsen, 1975]. Furthermore, in both in vivo and in vitro studies citric acid has been shown to be most detrimental to dental enamel, when com-

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Table I. Products studied

Product	Manufacturer
Coca-Cola (classic)	Hartwall, Helsinki, Finland
Coca-Cola (new)	The Coca-Cola Corp., Atlanta, GA, USA
Jaffa (orange beverage)	Hartwall, Helsinki, Finland
Hart-Sport (sport drink)	Hartwall, Helsinki, Finland
Coca-Cola Light	The Coca-Cola Corp., Atlanta, GA, USA
Orange juice	Valio, Helsinki, Finland
Strawberry yoghurt	Tuottajain Maito, Herajoki, Finland
Beer	Hartwall, Helsinki, Finland
Sour milk	Valio, Helsinki, Finland
Coffee	Tuko Oy, Helsinki, Finland
Coffee with sugar[1]	Tuko Oy, Helsinki, Finland

[1] Sucrose from sugar cane, BDH Chemicals (Poole, UK). The sugar content was 3 g/100 ml coffee.

pared with orthophosphoric acid or tartaric acid [Graf, 1953; Conboy and Cox, 1971; Bibby, 1983; Imfeld, 1983]. Recently, the question has become relevant again because of the introduction of sport drinks to the public. The formula of these drinks is a balanced electrolyte combination with carbohydrates as the energy source [Rehunen and Liitsola, 1978]. The drink is consumed continuously during an exercise which leads to a prolonged contact time of the drink with the teeth. Subsequently, erosive dental lesions have been reported among athletes and other physically active people [Häkkinen, 1981].

The present study was made to assess oral pH changes immediately after consuming a variety of beverages. The pH was measured directly on the upper surface of the tongue since, in the clinical situation, dental erosion is often seen on tooth surfaces which are in contact with the tongue. Thus, an evaluation could be made to see whether various study products show differences in retaining low salivary pH on the tongue. Clearance of salivary total glucose was assessed in order to evaluate the retaining of the study products in the mouth.

Materials and Methods

Test Products

The drinks tested in this study are listed in table I. All items were freshly purchased and they had been manufactured less than 2 weeks before the investigation. The pH values of all the products were measured with a pH meter (Orion Research, model 211, Cambridge, Mass.). Total glucose contents in test products (free glucose and glucose from sucrose) were analyzed with a Sucrose/Glucose kit of Boehringer Mannheim Biochemica.

Test Panel

Five apparently healthy women with an average age of 30.2 years and without medication formed the test panel. Their basic oral health status was recorded before the study together with the salivary flow rate (resting and paraffin-stimulated saliva), pH, and buffering capacity of the saliva (Dentobuff-kits; Orion Diagnostica, Espoo, Finland). Salivary glucose concentration was analyzed with the Boehringer kit. Salivary lactobacilli and *Streptococcus mutans* counts were assessed by using Dentocult, and Dentocult-SM dip-slides (Orion Diagnostica, Espoo, Finland). Apart from a 2-hour fasting period before each test procedure, the subjects continued their normal dietary and oral hygiene habits.

Determination of the pH Value in the Oral Fluid after Consuming the Study Products

All pH values were measured on the surface of the tongue midline with the aid of a 91-65sc touch

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Table II. Some basic data and salivary characteristics of the subjects in the test panel

Subject	DMFS	DS	CPI[1]	Salivary						
				flow rate, ml/min		pH	buffering capacity[2]	total glucose ppm	DC	SM
				resting	stimulated					
R.T.	54	0	6	0.4	2.0	7.7	6.5	17.0	0	0
S.K.	34	0	0	0.4	1.3	7.7	7.0	1.3	10^6	10^3
U.D.	6	0	6	0.9	3.0	7.7	7.0	0.3	0	10^3
P.O.	12	0	6	0.3	2.7	7.2	6.0	5.0	0	0
P.H.	53	0	2	0.6	2.5	7.0	7.0	0.3	0	10^3

DC = number of lactobacilli per milliliter of saliva; SM = number of *Streptococcus mutans* per milliliter of saliva

[1] Number of code 0 sextants [Ainamo et al., 1982].

[2] The buffering capacity is expressed as the end pH value.

electrode (Orion Research). The measurements were carried out in 11 consecutive days, always at the same time of the day, and 2 h after a meal. The subjects were not allowed to drink anything for 2 h before the testing. Three baseline measurements were made at 1-min intervals before the actual testing. The subjects then consumed 100 ml of the study drink in 1 min and were instructed to move the drink carefully around the mouth before swallowing. The pH values were then measured immediately after swallowing, and at 30-sec intervals up to 5 min; thereafter the measurements were made at 1-min intervals for 10 min. Only one of the drinks was tested each day.

Assessment of the Retention of Glucose after Consuming the Test Products

Only products that were known to contain glucose were studied in this part of the investigation. The study was carried out in 7 consecutive days, always at the same time of the day, and after 2 h of fasting. Before actual testing, 0.5 ml of control saliva was collected without stimulation. Thereafter, everyone in the test panel received 100 ml of test drink of the day, which was consumed within 1 min. Then 1-ml aliquots of resting saliva were taken immediately, and 1, 3, 5, 10 and 30 min after swallowing. The saliva samples were deep-frozen immediately after collecting. Total glucose (free glucose in saliva plus glucose from sucrose) was analyzed with the Boehringer Mannheim kit.

Statistical Methods

A total erosive capacity was separately determined for each study product. This was done by summing means of all pH changes in observation time units either below the critical pH (5.5) or during the 10-min follow-up ($\Sigma\Delta\ t \cdot \Delta pH$). This formula takes into account all the respective pH changes after pH minimum (ΔpH) in relation to time (Δt). Thus, the severity and duration of the effect of study products on tongue pH was evaluated, as suggested by Edgar et al. [1975]. The data were then tested for differences between the pairs of means of the study products (t test). One-way analysis of variance was also employed. For analysis of the glucose clearance, a similar statistical approach was used.

Results

Basic data on subjects of the test panel are given in table II. The pH values and glucose concentrations in the studied products are given in table III. As shown, beer

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and plain coffee did not contain any glucose, Coca-Cola Light and sour milk contained practically no glucose, while glucose concentrations in the other products varied from 1.4% in coffee with sugar to 5% in Coca-Cola (classic). The pH range was from 2.57 (Coca-Cola classic) to 4.97 (coffee with sugar).

Table III. pH and total glucose concentrations of the study products

Product	pH	Total glucose %
Coca-Cola (classic)	2.57	5.0
Coca-Cola (new)	2.62	4.5
Jaffa	2.96	4.2
Hart-Sport	3.12	4.6
Coca-Cola Light	3.15	0.02
Orange juice	3.64	4.2
Yoghurt	3.81	4.6
Beer	4.18	-
Sour milk	4.40	0.003
Coffee	4.87	-
Coffee with sugar	4.97	1.4

The mean control pH values on the tongue surface of the test panel was 6.93. The lowest pH values, as measured on the tongue surface immediately after the swallowing, were produced by the sport drink (pH 3.80 ± 0.45) and also by the orange juice and the strawberry yoghurt (4.04 ± 0.26 and 4.06 ± 0.23, respectively). The pH was less depressed after consuming plain coffee, coffee with sugar, Coca-Cola Light, beer and Coca-Cola (new). In most cases the pH values returned to the base-line level within 2–3 min, and always within 10 min. Following the consumption of Hart-Sport, orange juice, Jaffa and Cola-Cola (new), pH remained at a slightly lower level, but the difference was not statistically significant. The pH changes for the different products are given in figure 1. The lowest pH values also remained at a low level for a longer

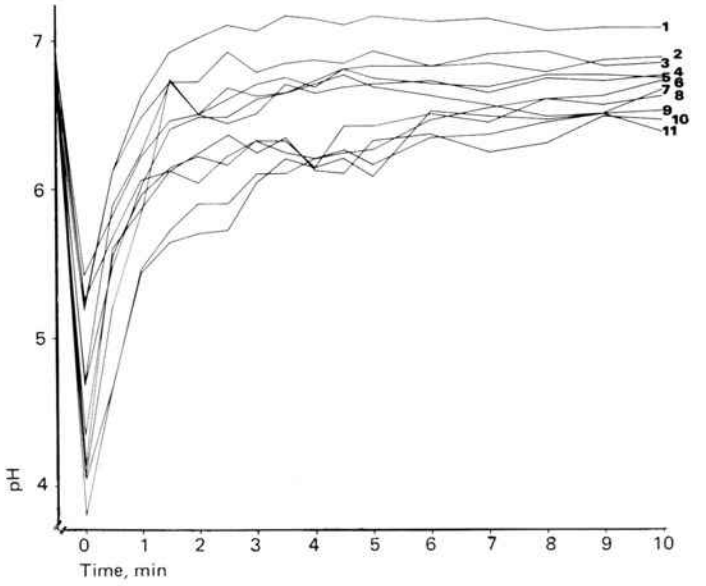

Fig. 1. Mean pH changes in the test panel after consuming the various products. Sum graph without deviations during the 10-min observation, mean baseline value 6.93. All measurements were done with a touch electrode at the midline of the tongue. 1 = Coca-Cola Light, 2 = beer, 3 = coffee, 4 = yoghurt, 5 = sour milk, 6 = coffee with sugar, 7 = Hart-Sport, 8 = Coca-Cola (classic), 9 = orange juice, 10 = Jaffa, 11 = Coca-Cola (new).

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time than the immediate higher pH values. The assessment of the erosive capacity of the study products is given in table IV. A very significant impact of all the study products on the individual pH determinations was shown in the analysis of variance ($p < 0.001$). However, coffee with or without sugar, Coca-Cola Light, and beer formed a drink group which was significantly different from Hart-Sport, orange juice, yoghurt, Jaffa and Coca-Cola classic ($p < 0.001$). The erosive capacity in relation to time gave similar results. Thus, the products Hart-Sport and orange juice differed significantly from the coffee group, Coca-Cola Light, and Coca-Cola new ($p < 0.01$).

Table IV. Lowest mean pH value per product after consuming 100 ml of the test product in 60 s

Product	Lowest pH	Erosive capacity	
		$\Sigma\Delta t \cdot \Delta pH$ (< 5.5)	$\Sigma\Delta t \cdot \Delta pH$ (10 min)
Hart-Sport	3.80	1.01 ± 0.27	1.63 ± 0.24
Yoghurt	4.06	1.00 ± 0.15	1.38 ± 0.32
Orange juice	4.04	0.86 ± 0.33	1.46 ± 0.20
Coca-Cola (class.)	4.36	0.83 ± 0.49	1.23 ± 0.64
Jaffa	4.14	0.81 ± 0.15	1.24 ± 0.38
Sour milk	4.68	0.69 ± 0.24	1.03 ± 0.22
Coca-Cola (new)	4.70	0.64 ± 0.42	0.67 ± 0.53
Beer	5.18	0.41 ± 0.29	0.85 ± 0.40
Coca-Cola Light	5.22	0.37 ± 0.26	0.89 ± 0.24
Coffee with sugar	5.26	0.24 ± 0.20	0.98 ± 0.20
Coffee	5.42	0.11 ± 0.15	0.72 ± 0.18

The mean total erosive capacity ($\Sigma\Delta t \cdot \Delta pH$) was calculated from the added means of all pH changes after pH minimum. The erosive capacity is given either as the sum of pH depressions below 5.5, or as pH changes up to the 10 min of observation.

The mean baseline glucose concentration of the test panel was 4.72 ppm. As shown in table II the variation was from 0.3 to 17 ppm among the subjects. Total glucose concentrations in saliva after consuming the study products and during the 30-min follow-up are given in table V. Hart-Sport sport drink was found to yield the highest glucose concentration immediately after swallowing (1.4 ± 0.59% w/v). The glucose concentration also remained high for a long period. Glucose concentration was least elevated and was rapidly returned to the normal level after consuming the strawberry yoghurt. In all instances, however, total glucose concentrations in saliva returned to the normal level within the 30-min observation. Glucose clearance

Table V. Mean glucose concentrations (ppm, means ± SD) in oral fluid after consuming 100 ml of study products in 60 s

Time min	Hart-Sport	Jaffa	Coca-Cola	Orange juice	Coca-Cola new	Coffee with sugar	Yoghurt
0	14,000 ± 5,908	8,850 ± 4,777	8,320 ± 5,733	6,860 ± 4,444	6,700 ± 4,116	6,480 ± 2,847	4,520 ± 1,548
1	2,700 ± 1,999	2,460 ± 1,474	2,530 ± 2,269	1,460 ± 1,059	2,320 ± 1,783	1,320 ± 858	1,360 ± 733
3	1,030 ± 586	580 ± 552	826 ± 777	518 ± 318	1,096 ± 718	242 ± 192	294 ± 186
5	321 ± 340	301 ± 340	258 ± 246	152 ± 122	276 ± 229	76 ± 97	97 ± 53
10	48 ± 59	55 ± 76	45 ± 36	22 ± 24	44 ± 36	6 ± 10	13 ± 6
30	3 ± 4	7 ± 7	4 ± 3	3 ± 4	3 ± 4	2 ± 3	4 ± 3

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after consuming yoghurt or coffee with sugar showed a statistically significant difference to Hart-Sport when analyzed by means of the t-statistics ($p < 0.05$). However, no statistically significant impact of the study products was found on these results in the analysis of variance.

Discussion

Members in our test panel were healthy women, staff and students at the dental school. Apparently their oral health characteristics (table II) were excellent in comparison with the average in general public. Obvious ethical reasons prevented us from including subjects with existing erosive dental lesions in the test panel. Thus, the results as such may not be directly applicable for patients with poor oral health and/or erosive dental lesions.

It was an unexpected finding to us that the buffering effect was so fast in the tongue mucosa (fig. 1). The deep epithelial folds and papillae in the tongue apparently did not retard the retaining of pH to resting levels. Indeed much more prolonged falls in pH are seen in dental plaque after consuming acidic drinks and food stuffs [Birkhed, 1984; Schachtele and Jensen, 1984]. Thus, the clinical finding that erosive lesions often are located on the lingual surfaces of the teeth is not due to the tongue itself maintaining low pH levels after ingesting acidic drinks and food stuffs. It is possible that tooth surfaces frequently touched by the tongue are prone to mechanical abrasion by the tongue and this aspect together with the frequent acidic milieu in the mouth would explain the observation. Since all the drinks and beverages tested showed pH values less than 5.5, the critical pH for dental enamel (table III), any of them may cause decalcification if allowed to remain in contact with teeth.

The acidic beverages, together with the sport drink and orange juice, were significantly different with regard to the erosive capacity when compared with the other products (table IV). Yet conclusions of the identification of the products most detrimental to the teeth cannot be drawn from these data alone. As shown in table IV, the erosive capacity appeared different if the assessment was based on the pH values below 5.5, compared with that based on all the added means of pH changes during the 10-min follow-up. Probably the first way of assessment is more important with regard to a potential decalcification effect on teeth. The second analysis gives information of the efficiency of the salivary buffering rate of the test products.

Clearance of glucose in the mouth after consuming the study products was very fast (table V). No individual differences in this could be observed even though one member of the test panel had distinctly higher baseline glucose concentration in her saliva than the others (table II). No statistically significant differences could be seen when analyzing the exposure time in an analogous way as the pH values. Indeed, when the retaining of test products was assessed by means of the total glucose concentrations, only traces could be found 10 min after ingestion.

It may be anticipated that if fruit juices, acidic beverages, and sour milk products are consumed in the normal way, i.e. without continuous sipping, they need not have adverse effects on teeth [Jenkins,

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1970, 1981]. However, any of the products is potentially erosive if consumed by patients with impaired salivary function [Tenovuo and Rekola, 1977]. The sport drink, orange juice, acidic beverages, and yoghurt showed lowest pH values which also remained low after consumption when compared with the other products (table IV). However, milk products such as yoghurt and sour milk which both are extensively consumed in Finland, are unlikely to have a local effect on teeth.

Experiments with milk have shown that its high calcium and phosphate concentrations may counteract enamel dissolution [Jenkins and Ferguson, 1966]. Even this should be kept in mind when counseling patients with suspected erosive lesions in their teeth.

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