

From:
The Department of Oral Microbiology
and the Department of Cariology,
School of Dentistry,
Karolinska Institutet,
Stockholm

DENTAL PLAQUE pH IN RELATION TO INTAKE OF CARBOHYDRATE PRODUCTS

by

GÖRAN FROSTELL

INTRODUCTION

A number of authors have demonstrated a fall of the pH in the dental plaques following consumption of sugars and other carbohydrate products (*i.a.* *Stephan*, 1940, 1944; *Strålfors*, 1950; *Mörch*, 1961; *Frostell*, 1963). This fall is more pronounced in cariesactive persons than in cariesresistant, and it is more pronounced after consumption of food products considered caries promoting than after noncariogenic foods. It is generally considered that a foodstuff containing large amounts of fermentable carbohydrates is more cariogenic than a foodstuff containing only minute amounts of such substances. Consequently, it is believed that foods causing a considerable pH-decrease in the dental plaques for a long time after consumption are generally more cariogenic than a foodstuff giving no or only a slight pH-decrease, or a decrease for only a short period of time. Other factors, however, may also influence the cariogenicity of a foodstuff (*Jenkins*, 1965).

Kleinberg (1961) studied the effect of continuous addition of different concentrations of glucose on the pH of the dental plaques. He found that increasing the glucose concentration resulted in a corresponding decrease in the pH level until a maximum decrease and a steady state was obtained with a concentration of 5 per cent. With a glucose concentration of 50 per cent, the pH level of the steady state was raised.

Received for publication. September 19, 1968.

The aim of the present investigation was to study the effect of different physical and chemical factors on the pH-changes in the dental plaques after intake of sugar solutions and different types of candies and foods. It was the hope of the author that the knowledge so obtained could be of some value for the production of less cariogenic sweets and other foods.

MATERIAL AND METHODS

Patients having a tendency of accumulating dental plaque material were preferably chosen for these experiments. They were between 15 and 50 years of age, all having at least 20 teeth and average to high dental caries activity. All of them had fillings or other restorations.

The patients were told not to brush their teeth for two days before the experiment and to appear in the morning in the laboratory without having eaten or drunk anything with the possible exception of tap water. Dental plaque materials was collected with a blunt instrument from the buccal surfaces and from between the teeth at approximately 20 different spots, the material was pooled in a drop of distilled water and pH was determined immediately in a Beckman Zeromatic pH-meter. Only minute amounts of material were taken from each spot. The patient was then asked to rinse his mouth for 30 seconds with 10 ml of the solution to be tested or to eat and swallow a piece of the candy or food to be tested.

After 2, 5, 10, 20 and 30 minutes new samples were taken from about twenty spots near those tested before. The material was pooled and the pH was determined immediately. After each determination the pH-meter was tested against a buffer pH 6.00. At each experiment a test was also performed with a 5.00 standard buffer. Standard deviation at pH 6.00 calculated on 200 such determinations was ± 0.032 pH-units. Standard deviation of the meter, at pH 5.00 when calibrated at pH 6.00, was ± 0.025 .

Since it was found that an appreciable pH-decrease of long duration generally occurred after a 30 seconds mouth rinse with a 50 per cent sucrose solution, which was to some extent characteristic of the patient, such a test was performed at least once with every patient.

Experiments were performed with either 18, 13 or 10 patients in each experimental group. All comparisons are made on experiments with groups containing the same patients.

The statistical evaluations showed that the differences between the original pH-value obtained before consumption and those obtained at a certain time point on the curves for a series of patients were distributed according to the normal curve and were more representative than the actual corresponding figures. Thus, the differences between pH at a certain time point and original

pH were used directly for statistical determinations. The pH-mean given for each time point is the arithmetical mean of the actual pH-values found, and the statistical deviations given are those within the limits of which the pH-values may be expected to fall in a large series of experiments. An Olivetti Programma Computer has been used for the calculations. Standard deviation of the method was determined at 0,13—0,26 (different for the H-different time points, Frostell, in preparation).

EXPERIMENTS AND RESULTS

1. *Effect of different sucrose concentrations*

Experiments were performed with a group consisting of 18 patients. Each patient rinsed his mouth with 10 ml of a sucrose solution. The concentrations used were:

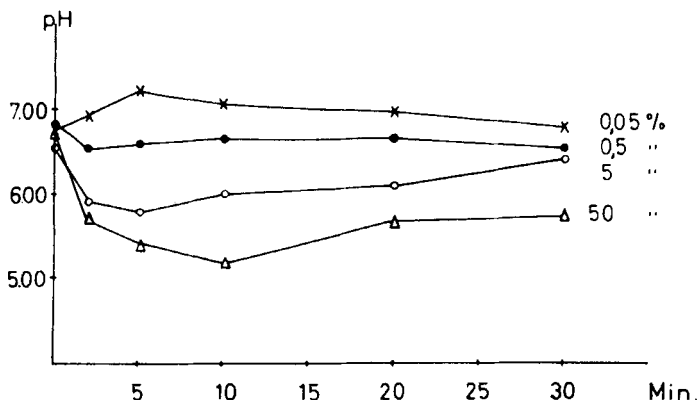


Fig. 1 a. Changes in the pH of the dental plaques of a person after a mouth rinse (30 seconds) with different concentrations of sucrose.

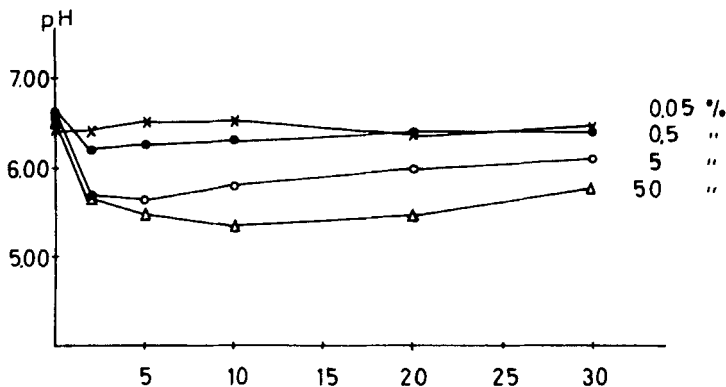


Fig. 1 b. Changes in the pH of the dental plaques after a mouth rinse (30 seconds) with different concentrations of sucrose. Mean of experiments with 18 persons.

Table I.
Composition of the different products
Approximate figures as given by the manufacturers

a) <i>Gum Arabic — sorbitol tablets (US)</i>	
Gum Arabic	54 gram
Sorbitol	45 »
Essence, artificial colour, sweetener	1 »
	100 »
b) <i>Gum Arabic -- sugar tablets (Tenor)</i>	
Gum Arabic	50 gram
Glucose	38 »
Sucrose	6.6 »
Extract glyz.	5 »
Essence, artificial colour	0.4 »
	100 »
c) <i>Hydrogenated potato starch candy (A-plus)</i>	
Product 6563	97 gram
Citric acid	2 »
Essence, artificial colour, sweetener	1 »
	100 »
d) <i>«Conventional candy»</i>	
Sucrose	55 gram
Dextrines	26 »
Dextrose, maltose	18 »
Essence, artificial colour	1 »
	100 »
e) <i>Sponge-cakes</i>	
Sucrose (or product 6563 + sodium cyclamate)	112 gram
Margarine	100 »
Oat meal	150 »
Baking powder	8 »
Vanilline	1 »
2 eggs	
f) <i>Ginger-cakes</i>	
Sucrose (or product 6563 + sodium cyclamate)	260 gram
Margarine	200 »
Oat meal	500 »
Sodium bicarbonate	1/2 teaspoonfull
Cinnamon	2 1/2 »
Ginger	1 »
Clove	1 »
Water	90 gram

g) *Marshmallows*

Sucrose	} (or product 6563, 375 gram + sodium cyclamate)	300 gram
Glucose		75 »
Gelatin		35 »
Crystallized hens egg white		12 »
Water		175 »
Flavors		

h) *Chocolates*

Weight per cent (approximate) and additives in gram per kilogram

	Dark »sugarfree»	Dark with sugar	Light »sugarfree»	Light with sugar
Cocoa-pulp*)	100	45	16.25	10
Cocoa-butter	—	10	33.75	20
Milk powder**)	—	—	50 ***)	30
Sucrose	—	45	—	40

Lecithin	g/kg	3	3	3	3
Na-cyclamate	g/kg	5	—	5	—
Vanilline	g/kg	0.2	0.2	0.2	0.2

*) contains 54 % cocoa-butter

**) » 25 % butter fat and 38 % milk sugar

***) corresponds to 19 % milk sugar in the final product

0.05 per cent; below the lowest concentration that gives optimal acid production in suspensions of dental plaque material (*Frostell, 1964*):

0.5 per cent; a concentration which gives optimal acid production in suspensions of dental plaque material and which is often found in the saliva after consumption of fruits and other »natural» foods (*Lundquist, 1952*);

5 per cent; a concentration at which acid production in suspensions of dental plaque material is still optimal. Salivary concentration of sugar is very often around 5—10 per cent immediately after consumption of candy or sugar-rich foodstuffs;

50 per cent; at this concentration acid production in suspensions of dental plaque material is inhibited. Filled candies, marmalades and marshmallows coming in direct contact with the teeth often contain concentrations of sugar of this magnitude or more.

The results are given in Fig. 1 a and b. The 0.05 per cent sucrose solution often gave a moderate pH-increase in the plaques whereas the other concentrations gave pH-decreases of increasing strength and duration with increasing sugar concentration.

Table II.
Comparison between the results of the different experimental series

Tab. 5 and 6*)	2	5	10	20	30 min
50 % sucrose	0.82	1.07	1.14	0.99	0.71
50 % sucrose pH 7.8	0.35	0.74	0.78	0.68	0.49
Difference	0.47	0.33	0.37	0.31	0.22
t-value	5.17	3.04	3.76	4.37	3.33
Significance level	***	**	**	***	**
Tab. 5 and 7					
50 % sucrose	0.82	1.07	1.14	0.99	0.71
50 % sucrose pH 6.5	0.64	1.00	1.07	0.93	0.69
Difference	0.18	0.07	0.07	0.06	0.02
t-value	1.94	0.81	0.85	0.64	0.26
Significance level	—	—	—	—	—
Tab. 5 and 8					
50 % sucrose	0.82	1.07	1.14	0.99	0.71
50 % sucrose pH 4.9	0.65	0.89	0.91	0.75	0.55
Difference	0.17	0.18	0.23	0.24	0.16
t-value	2.42	2.65	3.53	2.61	2.09
Significance level	*	*	**	*	—
Tab. 5 and 9					
50 % sucrose	0.82	1.07	1.14	0.99	0.71
50 % sucrose pH 3.5	0.77	1.01	1.07	0.84	0.70
Difference	0.05	0.06	0.07	0.15	0.01
t-value	0.64	0.60	0.74	1.58	0.19
Significance level	—	—	—	—	—
Tab. 10 and 11					
50 % sucrose	0.79	1.10	1.11	0.91	0.66
3 % citric acid	1.30	1.15	0.86	0.63	0.35
Difference	+0.51	+0.05	0.25	0.28	0.31
t-value	3.59	-0.36	1.85	2.14	3.07
Significance level	**	—	—	*	**
Tab. 12 and 13					
50 % sucrose	0.76	0.97	1.07	1.00	0.72
50 % sucrose in fat	0.49	0.79	0.75	0.56	0.44
Difference	0.27	0.18	0.32	0.44	0.28
t-value	3.09	1.27	2.36	4.37	3.15
Significance level	**	—	*	***	**

*) These tables may be requested from the author.

Tab. 14 and 15

5 % sucrose	0.76	0.89	0.70	0.51	0.40
5 % sucrose in fat	0.10	0.10	0.15	0.08	0.07
Difference	0.66	0.79	0.55	0.43	0.33
t-value	7.05	7.20	4.04	3.73	1.87
Significance level	***	***	***	**	—

Tab. 16 and 17

50 % sucrose	0.85	1.09	1.19	1.06	0.77
Menthol + eucalyptol	0.57	0.87	0.91	0.78	0.54
Difference	0.28	0.22	0.28	0.28	0.23
t-value	3.71	2.03	2.68	2.99	3.05
Significance level	**	*	*	**	**

Tab. 18 and 19

50 % sucrose	0.82	1.06	1.15	1.01	0.71
45 % sucrose + 5 % carbamide	+0.14	+0.02	0.10	0.27	0.20
Difference	0.96	1.08	1.05	0.74	0.51
t-value	11.11	12.81	19.18	9.52	7.13
Significance level	***	***	***	***	***

Tab. 21 and 22

Sucrose tablets	0.26	0.55	0.57	0.48	0.26
Carbamide tablets	+0.13	+0.07	0.09	0.17	0.19
Difference	0.39	0.62	0.48	0.31	0.07
t-value	5.03	7.25	8.30	4.72	1.46
Significance level	***	***	***	***	—

Frostell 1965, Tab. 1 and 2

Sucrose tablets	0.46	0.53	0.54	0.36	0.19
Sorbitol tablets	+0.36	+0.39	+0.29	+0.11	+0.04
Difference	0.82	0.92	0.83	0.47	0.23
t-value	10.66	9.97	7.15	5.21	5.07
Significance level	***	***	***	***	***

Tab. 25 and 26

Marshmallow, sucrose	0.62	1.00	1.10	0.85	0.49
» 6563	0.27	0.30	0.22	0.19	0.10
Difference	0.35	0.70	0.88	0.66	0.39
t-value	4.71	9.07	10.75	9.75	5.01
Significance level	***	***	***	***	***

2. Effect of buffer capacity and pH of a sugar solution

Sucrose-phosphate buffer solutions containing 0.1 M phosphate buffer and 50 per cent (weight to volume) sucrose were used. The buffers were prepared according to directions given in »Handbook of Chemistry and Physics» (Hodgman, 1948).

The experimental group consisted of 18 people which on different occasions were given 10 ml of each sugar-buffer solution as a mouth rinse.

The results are given in Fig. 2 and Table II. There were only small differences between the buffers pH 3.5, 6.5 and the nonbuffered solution, whereas the pH 7.8 buffer gave significantly less pH-decrease in the plaques than the other three. The pH 4.9 buffer also gave less pH-decrease than the pure sucrose solution.

3. Effect of citric acid

Citric acid is often used in sour sweets and occurs in high concentration in citrus fruits. A solution containing 50 per cent sucrose and 3 per cent citric

- pH 7.8
- " 6.5
- △ " 4.9
- ▲ " 3.5
- × " 50%.

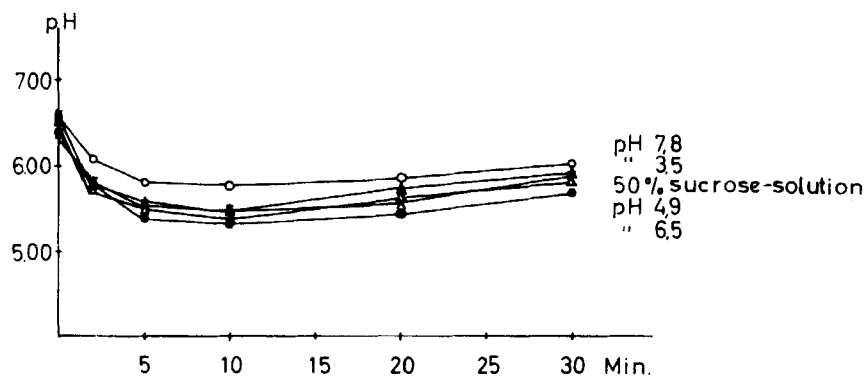


Fig. 2. Changes in the pH of the dental plaques after a mouth rinse (30 seconds) with a 50 per cent sucrose solution and different buffered phosphate-sucrose solutions. Only the results with the alkaline solution differs highly significant from the non-buffered solution. Each curve gives the mean of experiments with 18 persons.

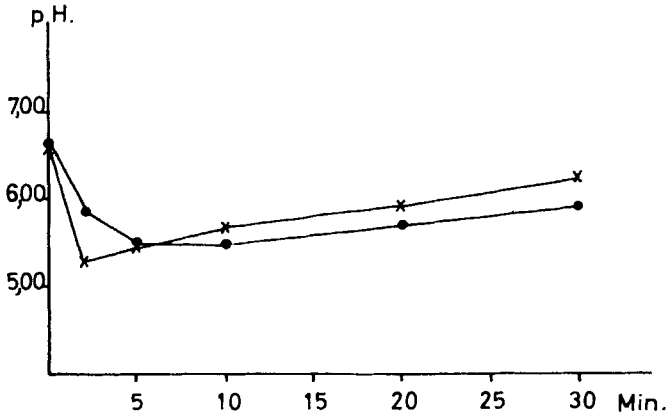


Fig. 3. Changes in the pH of the dental plaques after a mouth rinse (30 seconds) with a 50 per cent sucrose solution (●—●) and a 50 per cent sucrose solution containing 3 per cent citric acid. Each curve gives the mean of experiments with 18 persons.

acid, pH 3.7, was prepared. Experiments were performed with 18 persons and the results were compared with those obtained when the same persons rinsed their mouths with a solution containing 50 per cent sucrose only.

The results are given in Fig. 3 and Table II.

The presence of citric acid in the solution resulted in a significantly deeper pH-decrease in the plaques after 2 minutes but at 10, 20 and 30 minutes the pH was significantly higher.

4. Effect of fat

Sucrose-peanut butter mixtures (5 and 50 per cent, weight per volume) were prepared. The patients were asked to take a 10 ml quantity in the mouth, to chew it and to spit it out after the standard time. Experiments were performed with 10 patients and the results were compared with those of the same persons partaking in the experiments described under 1.

The results are given in Fig. 4 a and b and Table II.

The pH-decrease found after consumption of 5 or 50 per cent sucrose in fat was significantly less than those found after a rinse with the corresponding sucrose concentration in water.

5. Effect of flavors (menthol and eucalyptol)

Many sweets are flavored with menthol or eucalyptol or both. These are believed to be antibacterial and laymen often think that they would make

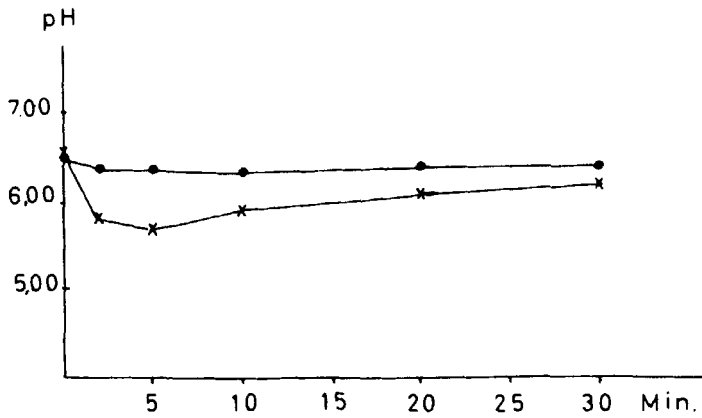


Fig. 4 a. 5 per cent sucrose in fat compared to 5 per cent sucrose in water. ●—● sucrose in fat. Mean of experiments with 10 persons.

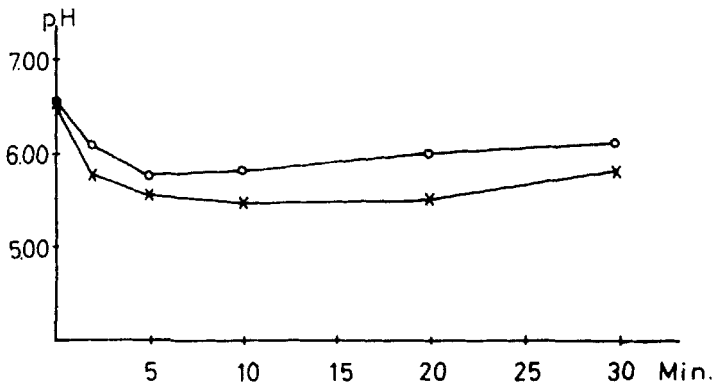


Fig. 4 b. 50 per cent sucrose in fat compared to 50 per cent sucrose in water. ○—○ sucrose in fat. Mean of experiments with 10 persons.

sweets noncariogenic. Experiments were performed with a 50 per cent sucrose solution containing 2 per cent menthol and 2 per cent eucalyptol. These concentrations are approximately the maximum of those used in sweets and the taste was so strong that it was hard to tolerate. The patients were given a 10 ml mouth rinse with this solution and the results were compared with those obtained with a pure 50 per cent sucrose solution (see under 1). A group of 18 persons was tested.

The results are given in Fig. 5 and Table II.

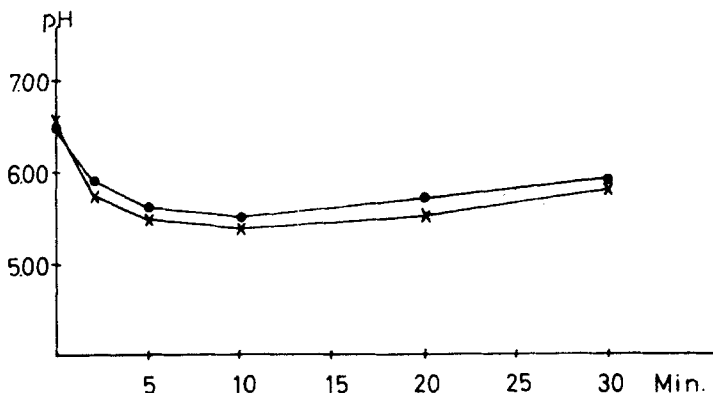


Fig. 5. 50 per cent sucrose plus menthol and eucalyptol compared to 50 per cent sucrose only. Mean of 18 experiments. ●—● sucrose plus menthol and eucalyptol.

There was a significantly smaller pH-decrease at 2, 20 and 30 minutes when the flavors were used compared to the pure sucrose solution whereas the differences at 5 and 10 minutes were statistically probable.

6. Repeated intake of sugar

A study of the effect of repeated intake of sugar was performed with two patients using either a 5 per cent or a 50 per cent sucrose solution. These sugar solutions contained nothing but sucrose and water.

The experiment was started as usual with a mouth rinse and the pH of the pooled plaques was determined at the usual time intervals. Eight minutes after the start of the experiment the patient was given a second mouth rinse with a sugar solution of the same strength as the first one and the pH of the pooled plaque material was determined 2, 5, 10, 20 and 30 minutes after the start of this rinse.

A representative result of these experiments is given in Fig. 6.

There was no additional pH-decrease caused by the second sucrose rinse but the period in which the pH was below the initial value was probably prolonged.

7. Effect of addition of carbamide

Pilot experiments have shown (Frostell and Erickson, 1963) that addition of carbamide (urea) to concentrated sucrose solutions influence the pH-changes in the dental plaques after consumption of such solutions. It was found that

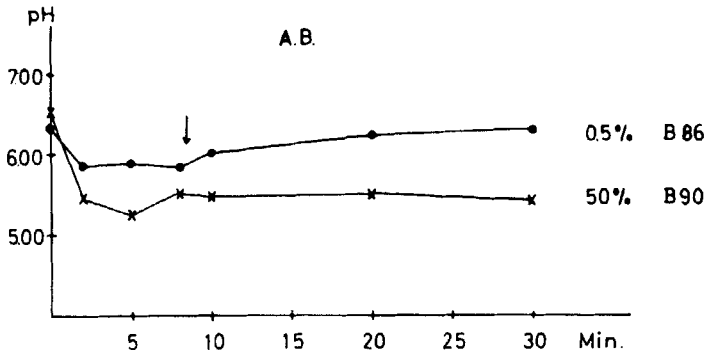


Fig. 6. Repeated rinsing with a sucrose solution, 0.5 per cent and 50 per cent. ●—● 0.5 per cent.

approximately 5 per cent carbamide was required in order to prevent the pH from dropping appreciably (Fig. 7). The authors suggested that carbamide might be added to sweets and other carbohydrate-rich foods in order to make them less cariogenic.

Experiments were performed with 18 persons using a 45 per cent sucrose solution containing 5 per cent carbamide (weight per volume). The results were compared with those obtained with the same group of patients given a 50 per cent sucrose rinse (see under 1).

The results are given in Fig. 8 and Table II.

The addition of carbamide (5 per cent) prevented to a great extent the pH from dropping in the dental plaques. The difference was statistically significant at all time points up to 30 minutes.

8. Effect of addition of carbamide to tablets containing fermentable sugars

In Sweden there is an appreciable consumption of hard or gummy sugar tablets, which is believed to be one of the many causes of the high prevalence of dental caries in the country. It has been proved that in a number of instances misuse of such candy has been associated with a very rapid tooth decay (Ericsson, 1954).

Experiments were performed with 18 persons who were given 2 sucrose tablets (ca 2 gram) at one experiment and 2 sucrose tablets containing 5 per cent carbamide at another experiment. The recipes for these tablets are given in Table I a and b.

The results are given in Fig. 9 and Table II.

The carbamide usually prevented the initial pH-decrease completely. After 10—20 minutes a slight pH-decrease was found.

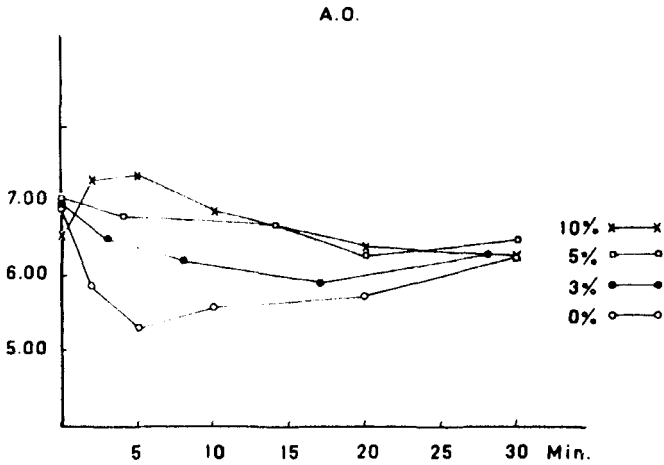


Fig. 7. Effect of addition of different concentrations of carbamide to a 50 per cent sucrose solution used for a mouth rinse. Experiments with one person.

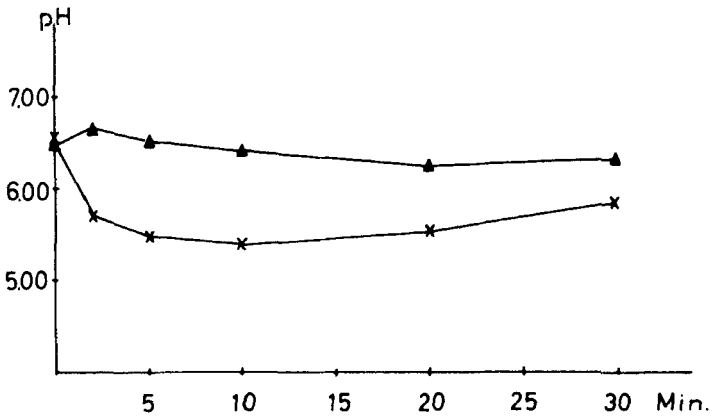


Fig. 8. Effect of addition of 5 per cent carbamide to a 45 per cent sucrose solution used for a mouth rinse. Means of 18 experiments.

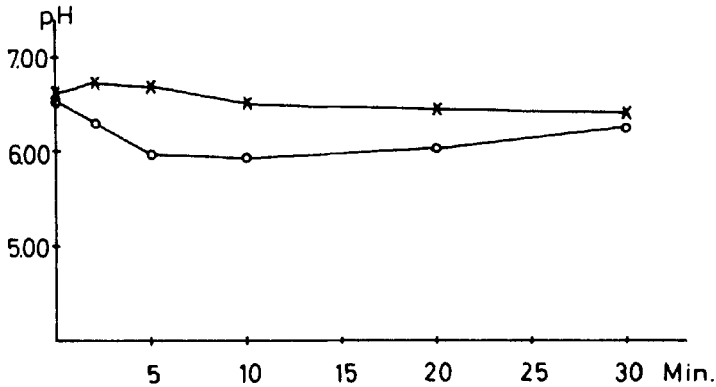


Fig. 9. Changes in the pH of the dental plaques after consumption of sucrose tablets containing 5 per cent carbamide. x—x sucrose-carbamide tablets. o—o sucrose tablets

9. Substitution of fermentable sugars by sorbitol in tablets

Sorbitol is widely recommended as a substitute for fermentable sugars in sweets in order to make them less cariogenic. A group of 18 persons was given 2 gummy tablets containing fermentable sugars at one experiment and 2 tablets containing sorbitol at another. Recipes are given in Table II.

The results, which have been published previously (Tables 1 and 2 *Frostell*, 1965), are given in Fig. 10.

The consumption of sorbitol tablets was usually followed by an increase in the pH of the plaques. The difference between the results with sorbitol tablets and those containing fermentable sugars was significant at all time points (Table II).

10. Substitution of fermentable sugars by hydrogenated dextrines in lozenges

In 1963 a new type of raw product for the candy and food industry — a hydrogenated starch hydrolysate — was developed (Product 6563 or Lycasin, Lyckeby Starch Refining Co, Lyckeby, Sweden), which was believed to be less cariogenic than ordinary sugars. This claim was to some extent supported by results of pilot experiments by *Frostell* (1963, 1965). Biochemical and nutritional studies on the product were carried out by *Dahlquist* and *Telenius* (1965). *Frostell*, *Keyes* and *Larson* (1967) showed that it was less cariogenic in experiments with hamsters and rats than sucrose, glucose, fructose and maltose.

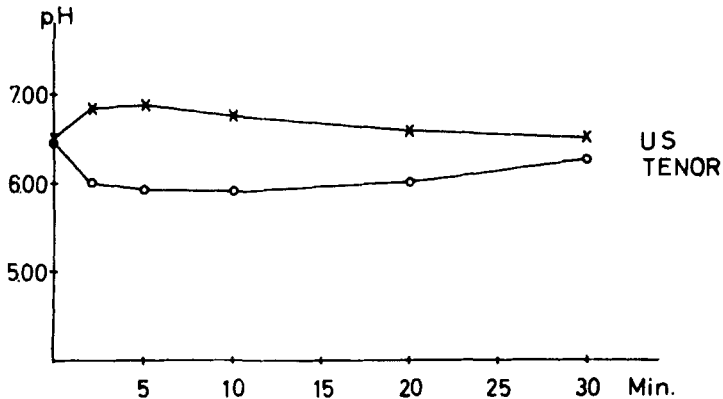


Fig. 10. Changes in the pH of the dental plaques after consumption of sorbitol tablets. Means of experiments with 18 persons.

×—× sorbitol tablets, 2×1 gram
 o—o conventional tablets containing sucrose

A group consisting of 18 persons were given a lozenge »conventional candy» (weight 4.5 gram, recipe given in Table I d) containing fermentable sugars in one experiment and a lozenge containing hydrogenated dextrines in another. (Table I c).

The results are given in Fig. 11 (and Tables 4 and 5, *Frostell* 1965).

No or only a very moderate pH-decrease occurred in the plaque material after consumption of the hydrogenated dextrine candy, whereas consumption of conventional candy was followed by an appreciable pH-decrease. The difference was statistically significant at all time points (Table II). These results have been published in Swedish previously (*Frostell*, 1965).

11. *Substitution of fermentable sugars by hydrogenated dextrines in different types of candy and foods*

Experiments were performed with two or three persons in each group. They were given a conventional candy or food at one experiment and an experimental candy or food at the next in which the fermentable sugars had been substituted by hydrogenated dextrines (Product 6563).

a) *Orange marmalade*, semisolid substance containing strips of orange peel (Findus, Sweden) and an experimental marmalade containing approximately 60 per cent hydrogenated dextrines. The persons were given 10 grams of the marmalade.

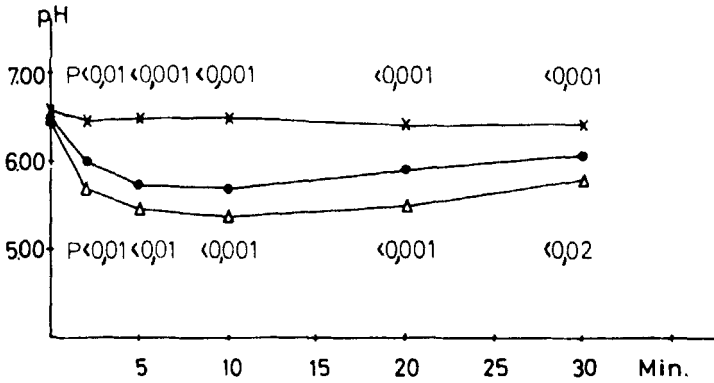


Fig. 11. Changes in the pH of the dental plaques after consumption of candy containing a hydrogenated starch hydrolysate or sucrose. For comparison the results after rinsing with a 50 per cent sucrose solution are given.

- x—x hydrogenated starch hydrolysate
- sucrose lozenges
- Δ—Δ sucrose solution, 30 seconds

The figure under and above the curves give the levels of significance of the difference between the top curve and the middle curve and the bottom curve and the middle curve, respectively.

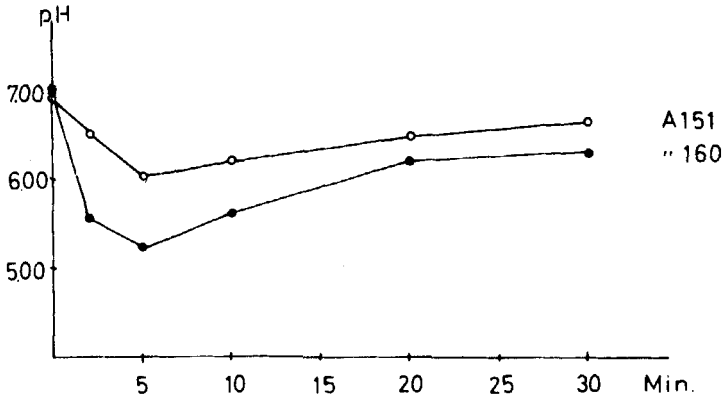


Fig. 12. Changes in the pH of the dental plaques of a person after consumption of marmalade.

- hydrogenated starch hydrolysate marmalade
- sucrose marmalade

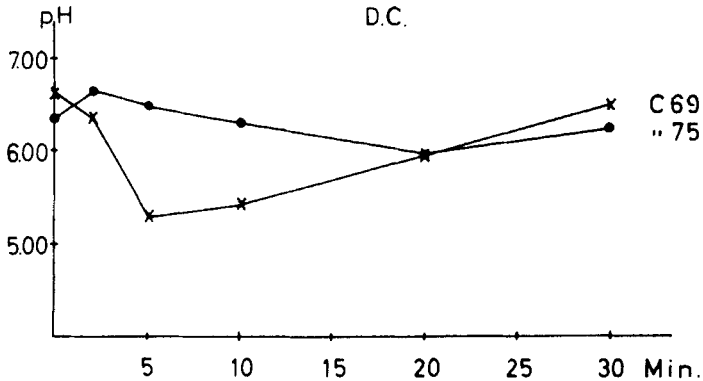


Fig. 13. Changes in the pH of the dental plaques after consumption of sponge-cake.

A representative result is given in Fig. 12.

Consumption of both marmalades was followed by a pH-decrease in the plaque material, the pH-decrease following consumption of the conventional product being more pronounced than that following the experimental product.

b) *Sponge-cake* containing fermentable sugars (recipes given in Table I e) was compared to a similar cake containing hydrogenated dextrines. Experiments were performed with two persons.

A representative result is given in Fig. 13.

The sponge-cake containing sucrose gave an appreciable pH-decrease in the plaque material whereas the substituted product gave no or only a very moderate pH-decrease.

c) *Ginger-cakes* (hard) containing sucrose were compared to similar cakes in which the sucrose was substituted by hydrogenated dextrines. Experiments were performed with 3 persons. Each person consumed 5 grammes. Recipes are given in Table I f.

A representative result is given in Fig. 14.

The changes in pH caused by consumption of ginger-cakes were rather slight. The experimental cake gave a less pronounced pH-decrease than the conventional product. The difference between the curves was, however, small, with exception for the results at 2 and 5 minutes.

d) *Marshmallows* containing fermentable sugars were compared to an experimental product containing hydrogenated dextrines. Experiments were performed with 13 persons. The conventional product is believed to give a high concentration of sugar on the plaque surfaces on the teeth. Recipe is given in Table I g.

The results are given in Fig. 15 and Table II.

The conventional product gave an appreciable pH-decrease in the plaque material whereas the substituted product gave only a slight pH-decrease.

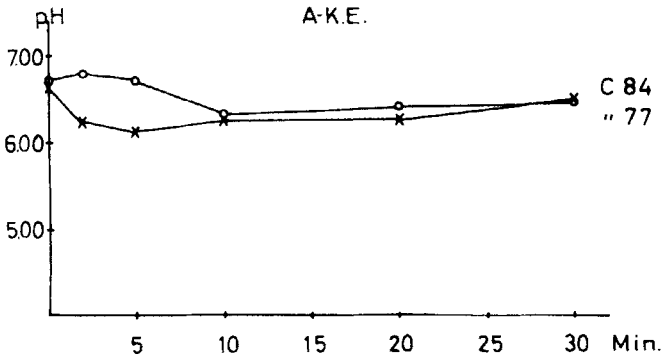


Fig. 14. Changes in the pH of the dental plaques of a person after consumption of ginger-cakes.

- hydrogenated starch hydrolysate cakes
- ×—× sucrose cakes

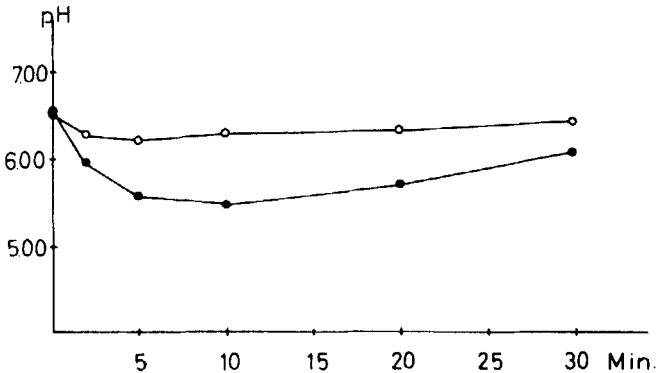


Fig. 15. Changes in the pH of the dental plaques after consumption of marshmallows.

- hydrogenated starch hydrolysate
- sucrose marshmallows

Mean of experiments with 13 persons.

12. Experiments with different types of chocolate

In the Vipeholm study it was found that milk chocolate containing 50 per cent fermentable sugars was cariogenic in persons under 30 years of age but not in older persons. On the other hand frequent consumption of toffees containing sugar increased caries activity much more. However, no direct comparison between chocolate and toffee may be made since the experimental conditions of the groups were not the same.

A number of authors have studied the presence of modifying or caries-inhibiting substances in chocolate and cocoa (Frostell, 1967). Such substances are believed to be fat, polyphenols, theobromin, tannic derivatives and perhaps others (Strålfors, 1967). It has been suggested that the comparatively low cariogenicity of cocoa and cocoa products would depend on the presence of substances which inhibit the acid production in the plaques. A more likely explanation is that the substances mentioned above influence the solubility of the enamel surface (Strålfors, 1967; Frostell, 1967). The high fat content may also be of significance.

Experiments were performed with 4 types of experimentally produced milk chocolates, the compositions of which are given in Table I h. For practical reasons the composition of the different chocolates differ from each other also in other respects than in sucrose concentration. Two types were intended to contain low concentrations of cocoa substances while the two

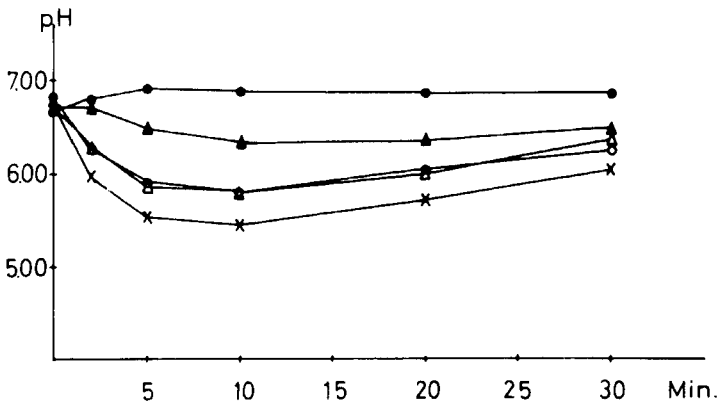


Fig. 16. Changes in the pH of the dental plaques after consumption of different types of chocolate. For comparison the results after rinsing with a 50 per cent sucrose solution are also given. Each curve gives the means of experiments with 18 persons.

- dark sugar-free chocolate
- ▲—▲ light »sugar-free« chocolate (containing 18 per cent lactose)
- dark chocolate containing sucrose
- △—△ light chocolate containing sucrose
- ×—× 50 per cent sucrose solution

others should be rich in such substances. Two types contained approximately 45 per cent of fermentable sugars whereas the two others contained only lactose, which is known to be less rapidly fermented by the oral microorganisms than sucrose, dextrose and fructose (Frostell 1964).

Experiments were performed with 18 persons, who were all given the 4 different chocolates at 4 different experimental occasions. Each piece of chocolate (4.5 grammes) was consumed as usual.

The result of this experimental series has been published elsewhere (Frostell, 1967) and is only briefly summarized here in Fig. 16. The tables may be requested from the author. The chocolate rich in cocoa and poor in fermentable sugars usually gave a pH-increase in the plaques whereas the cocoa-rich, sucrose-rich chocolate and the cocoa-poor, sucrose-rich chocolate gave curves which did not significantly differ from each other. The cocoa-poor, sucrose-poor chocolate (which contained 18 per cent of lactose) gave a less pronounced pH-decrease than the sucrose-rich chocolates.

DISCUSSION

The method used does not give the accurate pH of any special spot on the teeth or in the oral cavity. It will only give an indication in general of what is happening in the dental plaques. However, this method makes it possible to make comparisons between different kinds of carbohydrate foods provided the comparisons are made on a sufficient number of persons on which the foods to be compared are both tested. The results are valid for buccal and lingual plaques and superficial interproximal plaques but probably not to the same extent for plaques around the contact points or in the fissures.

Statistical evaluations based on several thousands of plaque pH-measurements have shown that a mean difference exceeding 0.3 pH-units (provided double experiments have been performed on 18 persons) is usually statistically significant at the one per cent level, whereas those exceeding 0.5 pH-units usually are significant at the 0.1 per cent level.

The experiments with different sucrose concentrations show — contrary to results of *in vitro* experiments on suspensions of oral microorganisms (Frostell, 1964) — that acid production in the plaques increased with increasing sucrose concentrations up to concentrations which are inhibitory in the *in vitro* experiments. The reason for this probably is the fact that in the *in vivo* experiments the substrate has to diffuse into the plaques. The results indicate that sugar concentration in the food is a factor of great importance for the initial acid attack in dental caries.

The experiments with different phosphate buffers must be evaluated with caution. The buffering action of the different buffers — although the total

phosphate concentration was the same in the different solutions — is widely different in the different pH-regions. Only in one pH-region — over pH 7 where the buffering action of the phosphate is appreciable — is there an extensive and highly significant effect of the buffer on the resulting plaque-pH. However, when experiments were performed with citric acid which buffers strongly at pH 3.7, a significant effect on plaque-pH reduction through a 50 per cent sucrose solution could be demonstrated after 2 minutes. After 10, 20 and 30 minutes the plaque-pH was significantly higher in the experiment with citric acid than with the pure sucrose solution. This is believed to be due to a stimulation of the production of alkaline, strongly buffering saliva caused by the citric acid. This belief is supported by the results of experiments with lemon juice and orange juice, which will be published later on.

Thus, it seems that in order to try to reduce the pH-drop in the plaques after consumption of foods containing fermentable sugars by use of buffers, the foods should contain a buffer with its maximum effect in the alkaline range. Acid buffers may, however, have a demonstrable effect on enamel surfaces not covered by plaque material. These views are in good agreement with clinical and experimental observations that acids taken with foods do not increase caries activity but result in erosion and abrasion (*Buonocore and Johansen, 1958, Dalderup, 1960, and others*).

The results of the experiments with sugar in fat are in good agreement with those of *Swenander-Lanke (1965)* and *Gustafson et al. (1955)*. When sugar is mixed with fat it is not as easily released and cannot as easily diffuse into the plaque as when it is dissolved in water.

The results with flavors may be due to stimulation of saliva or to an antibacterial effect in the plaques. Since there was still a significant difference after 30 minutes an antibacterial effect seems probable.

The results of experiments with repeated intake of sugar indicate that plaque-pH decrease is mainly a function of sugar concentration and not of consumption time. When the consumption time is prolonged, the period of pH-decrease in the plaque material is increased but not the pH-decrease itself.

The results with carbamide show that a significant reduction of pH-decrease in the plaques after consumption of foods containing fermentable sugars may be achieved. Experiments on hamsters and rats with sugar-rich diets containing carbamide have given some favourable results, which will be published in the future.

The results with sorbitol tablets are in good agreement with the results of *Fosdick et al. (1957)*.

Sorbitol acts as a laxative when taken in large doses. It is very hygroscopic, a fact which reduces its use in candy industry. For these reasons a hydrogenated potato starch hydrolysate has been developed which is believed to be less cariogenic than sucrose and which is less hygroscopic and laxative than sorbitol. Since 1963, when it first appeared, this product has continuously been developed in order to reduce its content of sorbitol and to increase the content of low molecular dextrines and saccharides. A reduction of the sorbitol content reduces the laxative effect of the product and makes it less hygroscopic. Experiments on hamsters, rats and pigs indicate that the cariogenicity of the product is low compared to sucrose (*Frostell, Keyes and Larson 1967, Frostell, unpublished results*).

A number of pilot experiments have been carried out in order to study the possible usefulness of the product as a substitute for sugar in different kinds of sweets, foods, beverages and medicines. The present results indicate that it is worth while to continue the research in this field.

An important question is whether results obtained by measuring plaque-pH after consumption of various kinds of foods are relevant for judging the cariogenic properties of the foods. It is quite obvious that plaque measurements performed on sufficiently large groups of persons will give an information as to whether a food will provoke an intense initial acid attack or not. A number of other properties of a foodstuff, however, may be of importance for its cariogenicity such as its capacity to stimulate plaque formation and implantation of caries-inducing microorganisms, its tendency to accumulate on and between the teeth and its content of caries inhibiting or solubility reducing substances such as fibers, polyphenols, phytates, theophyllamin, theobromin and perhaps others. The present results with chocolate show that chocolates containing large amounts of fermentable sugars will provoke an appreciable pH-decrease in the dental plaques. In spite of this fact milk chocolate of the same type was not very cariogenic as shown in the Vipeholm study. Since acid production in the plaques was not inhibited even in experiments with the cocoa-rich black chocolate (provided it contained 50 per cent sugar), it is believed that its low cariogenicity is due to its content of substances causing a reduction of enamel surface solubility (*Strålfors, 1967*) and not to an effect on the acid production in the dental plaques (*Frostell, 1967*).

SUMMARY

The changes in pH of the dental plaques after rinsing (30 seconds) with various sugar solutions or consumption of different sweets were determined according to a method elaborated by the author. The plaque pH was de-

terminated 2, 5, 10, 20 and 30 minutes after the beginning of the test. The influence of the following factors was studied: sugar concentration (50, 5, 0.5 and 0.05 per cent), buffer capacity and pH of the sugar solution (0.1 M phosphate buffer, pH 3.5, 4.9, 6.5 and 7.8 in a 50 per cent sucrose solution), citric acid (3 per cent in a 50 per cent sucrose solution), fat (5 per cent or 50 per cent sucrose in peanut butter was compared to 5 per cent and 50 per cent sucrose in water), flavors (menthol and eucalyptol, 2 per cent of each in 50 per cent sucrose), carbamide (5 per cent carbamide in 45 per cent sucrose was compared to a 50 per cent sucrose solution), substitution of sucrose by sorbitol or hydrogenated starch hydrolysate (Product 6563, Lycasin) in tablets, lozenges and different types of candy and foods. Further, some experiments with four different types of chocolate were carried out.

Rinsing with 0.05 per cent sucrose for 30 seconds generally resulted in an increase in pH of the dental plaque whereas the more concentrated solutions induced a decrease in pH of increasing strength and duration with increasing concentration. Addition of 0.1 M phosphate solutions pH 3.5, 4.9 or 6.5 to a 50 per cent sucrose solution had little influence on plaque-pH compared to a nonbuffered solution whereas phosphate buffer pH 7.8 significantly reduced the influence of the sugar on plaque pH.

Addition of citric acid (3 per cent) caused an increased pH-fall in the plaques after 2 minutes but after 10, 20 and 30 minutes the pH was slightly higher than in the control experiments. Flavors (menthol and eucalyptol, 2 per cent of each) caused a significant reduction of the decrease in superficial plaque-pH induced by a 50 per cent sucrose solution.

Five or 50 per cent sucrose in peanut butter fat gave significantly less changes in pH than the same concentrations of sucrose in water.

By addition of 5 per cent carbamide to a 45 per cent sucrose solution or to candies containing sucrose the pH of the dental plaques could be kept almost unchanged in the post-consumption period, i.e. decreases in superficial plaque pH could be almost completely prevented.

Substitution of sucrose by sorbitol in tablets generally resulted in pH-increases in the dental plaque. Substitution of sucrose by hydrogenated starch hydrolysates generally resulted in no or only slight pH-changes in the dental plaques, i.e. the post-consumption decrease in plaque-pH could be practically completely prevented by these substitutions.

Experiments with four types of chocolate showed that the pH-changes in the plaques after consumption was dependent mainly on the sugar concentration whereas the concentration of cocoa did not significantly influence the results.

In the discussion it is pointed out that although the experiments (plaque-

pH measurements) give information as to the extent to which a foodstuff or a solution induces an initial acid attack on the enamel surfaces, it does not give complete information concerning the cariogenicity of the product since this may be dependent on other factors also, for example influence on enamel surface solubility and influence on the oral flora.

RÉSUMÉ

RAPPORTS ENTRE LE pH DE LA PLAQUE BACTÉRIENNE SUR LES DENTS ET LA CONSOMMATION DE PRODUITS À BASE D'HYDRATES DE CARBONE

Les modifications du pH de la plaque bactérienne sur les dents après rinçages (30 secondes) avec différentes solutions sucrées ou après ingestion de diverses sucreries ont été déterminées suivant une méthode élaborée par l'auteur. Le pH de la plaque a été déterminé au bout de 2, de 5, de 10, de 20, et de 30 minutes après le début du test. L'influence des facteurs suivants a été étudiée: concentration du sucre (50 %, 5 %, 0,5 % et 0,05 %), pouvoir tampon et pH de la solution sucrée (tampon de phosphate de 0,1 M p. litre, pH 3,5, 4,9, 6,5 et 7,8, dans une solution de saccharose à 50 %), acide citrique (3 % dans une solution de saccharose à 50 %), matières grasses (comparaison entre 5 % et 50 % de saccharose dans du beurre de cacahuète d'une part et 5 % et 50 % de saccharose en solution aqueuse d'autre part), parfums (menthol et eucalyptol à raison de 2 % chacun dans 50 % de saccharose), urée (comparaison entre 5 % d'urée dans 45 % de saccharose d'une part et une solution de saccharose à 50 % d'autre part), remplacement du saccharose par le sorbitol ou par un hydrolysate d'amidon hydrogéné (produit 6563, Lycasin) dans des tablettes, des pastilles et dans différents types de bonbons et d'aliments. Enfin, quelques expériences ont été effectuées avec quatre sortes différentes de chocolat.

Les rinçages pendant 30 secondes avec le saccharose à 0,05 % déterminaient généralement une élévation du pH dans les plaques, tandis que les solutions plus concentrées causaient un abaissement du pH d'autant plus prononcé et d'autant plus prolongé que la concentration était plus forte. L'addition de solutions de phosphate de 0,1 M p. litre, de pH 3,5, 4,9, ou 6,5 à une solution de 50 % de saccharose influait peu sur le pH de la plaque par comparaison avec une solution non tampon, alors qu'un tampon au phosphate de pH 7,8 réduisait de manière significative l'influence du sucre sur le pH de la plaque.

L'addition d'acide citrique (3 %) causait une accentuation de l'abaissement du pH dans les plaques au bout de 2 minutes, mais au bout de 10, de 20 et de 30 minutes, le pH était légèrement plus élevé que dans les expériences témoins. Les parfums (menthol et eucalyptol, à 2 % chacun)

réduisaient de manière significative l'abaissement du pH produit dans la plaque par une solution de saccharose à 50 %.

Les concentrations de 5 % et de 50 % de saccharose dans le beurre de cacahuète causaient des changements du pH significativement moins importants que ces mêmes concentrations de saccharose en solutions aqueuses.

En ajoutant 5 % d'urée à une solution de 45 % de saccharose ou à des bonbons contenant du saccharose, le pH de la plaque bactérienne pouvait être gardé presque inchangé pendant la période suivant l'ingestion, c'est-à-dire que l'abaissement du pH dans la plaque pouvait être presque entièrement évité.

Le remplacement du saccharose par le sorbitol dans des tablettes déterminait en général une augmentation du pH dans la plaque bactérienne. Le remplacement du saccharose par des hydrolysats d'amidon hydrogénés ne déterminait en général que peu ou pas de changement du pH dans la plaque, c'est-à-dire que l'abaissement du pH dans la plaque pendant la période suivant l'ingestion pouvait en pratique être totalement évité par ces substitutions.

Les expériences effectuées avec quatre types de chocolat ont révélé que les changements du pH dans la plaque après l'ingestion dépendaient principalement de la concentration du sucre, tandis que la concentration du cacao n'avait pas d'influence significative sur les résultats.

Dans la discussion, l'auteur souligne que, bien que les expériences (mesures du pH des plaques) donnent des renseignements sur la mesure dans laquelle un aliment ou une solution cause une attaque acide initiale sur les surfaces d'émail, on ne peut y trouver de renseignements éclairant à fond le pouvoir cariogène du produit, puisque ce pouvoir peut dépendre aussi d'autres facteurs, tels que l'influence sur la solubilité de la surface de l'émail et l'influence sur la flore microbienne buccale.

ZUSAMMENFASSUNG

DENTALE PLAQUE-PH IN RELATION ZUR KOHLENHYDRATEZUFUHR

Die pH-Veränderungen in den dentalen Plaques nach Mundspülungen (30 Sekunden) mit verschiedenen Zuckerlösungen oder nach Konsumtion von verschiedenen Süßigkeiten wurden nach einer Methode ausgearbeitet von dem Verfasser bestimmt. Das Plaque-pH wurde nach 2, 5, 10, 20 und 30 Minuten bestimmt. Man studierte den Effekt von den folgenden Faktoren: Zuckerkonzentration (50, 5, 0,5 und 0.05 Prozent), Pufferkapazität und pH der Zuckerlösung (0.1 M Phosphatpuffer, pH 3,5, 5,9, 6,5 und 7,8 in 50 Prozent Zucker), Zitronensäure (3 Prozent in 50 Prozent Zuckerlösung), Fett (5 oder 50 Prozent Zucker in Fett), Menthol und Eucalyptol

(2 Prozent in 50 Prozent Zuckerlösung), Karbamid (5 Prozent Karbamid in 45 Prozent Zuckerlösung), Substitution von Zucker durch Sorbitol oder einem hydrogenierten Stärkehydrolysat (Produkt 6563, Lycasin) in Tabletten und Bonbons. Ausserdem wurden einige Experimente mit vier verschiedenen Schokoladesorten gemacht.

Mundspülung mit 0.05 Prozent Zucker gab gewöhnlich eine pH-Steigerung während die mehr konzentrierte Lösungen eine pH-Senkung verursachten, die mit zunehmender Konzentration zunahm. Zusatz von 0.1 M Phosphatpuffer mit pH 3.5, 4.9 oder 6.5 zu einer 50-prozentigen Zuckerlösung beeinflusste wenig die resultierende pH-Veränderungen während ein pH 7.8 Puffer die pH-Senkungen signifikant reduzierte.

Zusatz von 3 Prozent Zitronensäure verursachte eine vermehrte pH-Senkung nach 2 Minuten aber nach 10, 20 und 30 Minuten war das pH etwas höher als in den Kontrollexperimenten. Menthol und Eucalyptol verursachten eine signifikante Reduktion der pH-Senkung verursacht von der Zuckerlösung.

Fünf oder 50 Prozent Zucker in Fett verursachte signifikant wenige pH-Veränderungen als dieselben Konzentrationen von Zucker in Wasser.

Durch Zusatz von 5 Prozent Karbamid zu einer 50-prozentigen Zuckerlösung konnte man das pH beinahe unverändert behalten, also die pH-Veränderungen wurden beinahe vollständig verhindert.

Substitution von Zucker mit Sorbitol in Tabletten resultierte gewöhnlich in pH-Steigerungen in den Plaques. Substitution von Zucker mit einem hydrogenierten Stärkehydrolysat gab nur wenige oder gar keine pH-Veränderungen während der Postkonsumtionsperiode, also die pH-Veränderungen wurden beinahe vollständig gehebt.

Experimente mit vier verschiedenen Schokoladesorten zeigten dass die pH-Veränderungen nach der Konsumtion von Zuckerkonzentration abhängig waren aber nicht von der Kakaokonzentration.

In der Diskussion wird vorgehalten, dass obwohl die pH-Messungen eine Information der initialen Säureattacke, die von einem Nahrungsmittel verursacht wird, geben, geben sie jedoch keine kompletten Informationen über die Kariogenität dieses Nahrungsmittels. Die Kariogenität eines Nahrungsmittels ist auch von anderen Faktoren abhängig, z.B. von Einfluss auf die Löslichkeit der Emaljoberfläche und von Einwirkung auf die Mundflora.

REFERENCES

- Bibby B. G. & G. N. Davies*, 1957: Dental caries in rats. Effect of sugar in various forms on the rate of spread of occlusal lesions. IADR. Prep. Abstr. p. 67.
- Buonocore M. & E. Johansen*, 1958: Effect of flavoured beverages, orange juice, sugar solutions on rat caries. J. dent. Res. 37: 963.

- Dahlqvist A. & V. Telenius*, 1965: The utilization of a presumably low-cariogenic carbohydrate derivative. *Acta Physiol. Scand.* 63: 156.
- Dalderup L. M.*, 1960: The effect of citric and phosphoric acids on the teeth. *J. Dent. Res.* 39: 420.
- Ericsson Y.*, 1954: Pastillkaries (Pillule caries). *Sv. Tandläk. Tidskr.* 47: 491.
- Fosdick L.S., H. R. Englander, K. C. Hoerman & R. G. Kesel*, 1957: A comparison of pH-values of in vivo dental plaque after sucrose and sorbitol mouth rinses. *J. Am. Dent. Ass.* 55: 191.
- Frostell G.*, 1964: Quantitative determination of the acid production from different carbohydrates in suspensions of dental plaque material. *Acta Odont. Scand.* 22: 457.
- 1963: Ny typ av s.k. tandvänliga sötsaker (A new type of presumably low-cariogenic sweets). *Sv. Tandläk. förb. Tidn.* 55: 529.
- 1965: Stephankurvans utseende efter förtäring av några olika typer av sötsaker (The shape of the Stephan curve after consumption of different types of sweets). I. Sötsaker innehållande sorbitol eller produkt 6563 (I. Sweets containing sorbitol or product 6563). *Sv. Tandläk. förb. Tidn.* 57: 696.
- 1967: Stephankurvans utseende efter förtäring av några olika typer av sötsaker (The shape of the Stephan curve after consumption of different types of sweets). II. Några olika chokladsorter. (II Some different types of chocolate). *Sv. Tandläk. förb. Tidn.* 59: 572.
- Frostell G. & T. Erickson*, 1963: Tillsättning av karbamid till kolhydrater i kariesförebyggande syfte. (A possible caries prevention through the addition of carbamide to fermentable carbohydrates). *Sveriges Tandl. förb. Tidn.* 55: 223.
- Frostell G., P. H. Keyes & R. H. Larson*, 1967: Effect of various sugars and sugar substitutes on dental caries in hamsters and rats. *J. Nutrition* 93: 1.
- Gustafson G., E. Stelling, E. Abramson & F. Brunius*, 1955: Experiments with various fats in a cariogenic diet. IV Experimental dental caries in golden hamsters. *Acta Odont. Scand.* 13: 75.
- Jenkins N.*, 1965: Natural protective factors of foods. *Symposia of the Swedish Nutrition Foundation III. Nutrition and Caries Prevention.* Almqvist and Wiksell, Uppsala, Sweden.
- Kleinberg I.*, 1961: Studies on dental plaque. I. The effect of different concentrations of glucose on the pH of dental plaque *in vivo*. *J. dent. Res.* 40: 1087.
- Lundqvist L.*, 1952: The Vipeholm Study. *Sv. Tandläk. Tidskr.* Vol. 45, Suppl.
- Mörch Th.*, 1961: The acid potentiality of carbohydrates. *Acta odont. Scand.* 19: 355.
- Stephan R. M.*, 1940: Changes in hydrogen-ion concentration on tooth surfaces and in carious lesions. *J. Am. dent. Ass.* 27: 718.
- Strålfors A.*, 1950: The bacterial chemistry of dental plaques. Thesis, Stockholm, Sweden.
- 1967: Effect on hamster caries by purine derivatives, vanillin and some tannin-containing materials. *Arch. Oral. Biol.* 12: 321.
- Swenander-Lanke L.*, 1965: *Symposia of the Swedish Nutrition Foundation III. Nutrition and caries prevention.* Almqvist and Wiksell, Uppsala, Sweden.

Adress:

*Department of Oral Microbiology,
Karolinska Institutet,
Stockholm 3,
Sweden*