THE ROLE OF DIETARY PHOSPHATES IN PREVENTING DENTAL CARIES

by

JEANNE DRAY

B.S., University of Missouri-Kansas City, 1971

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Foods and Nutrition

Kansas State University
Manhattan, Kansas

1976

Approved by:

Beatrice Finkelstein

Major Professor

TABLE OF CONTENTS

INTRODUCTION

Evolution may have dealt mammals a built-in handicap. While reptiles are homodont and polyphydont, mammals are heterodont and diphyodont. There are several reasons for these differences. Reptilian teeth are structurally and functionally adapted for grasping and tearing while mammals employ teeth primarily for chewing. Frequent replacement of teeth would not appear theoretically conducive to a good jaw relationship for mastication (1). Due to these evolutionary determinants, man during the ages has been engaged in a battle to control and curtail dental caries.

According to Carlos (2) the benefits of zero or near zero caries incidence require at least two decades to be fully achieved on a national scale. In theory we know how to prevent caries. The problem is the transition from knowledge to its implementation by people. This requires solutions to problems such as delivery systems, personnel systems, logistics, economics, public priorities, and individual motivations. Current caries research centers on altering each element in the etiologic triad of dental caries: microorganisms, diet and tooth enamel.

The empirical literature tends to demonstrate the extensive effects of nutrition on teeth both during development and after eruption. Probably the most detrimental nutrient is sucrose which is caries-promoting. Navia (3) has recommended that industry manufacture foods and beverages in which sucrose is eliminated, lowered or substituted nutritionally for other sugar combinations.

During the past two decades much data (4, 5, 6, 7) have been reported concerning the role of dietary phosphates in the prevention of dental caries. Therefore, this paper is addressed to a report of research, both animal and human, since 1969. In addition, implications for further research and the application of new findings for consumer benefit are noted.

REVIEW OF LITERATURE

Phosphates as Food Additives

Frequent Intervals

Studies with phosphates indicate that as additives these substances appear most effective when the teeth are exposed to them at frequent intervals. Phosphates exert their effects mainly through local action. When incorporated into sticky and adhesive foods with long oral retention times, they are effective anticaries substances for humans.

Vehicles for Fortification

Phosphates naturally present in foods are relatively inert as anticaries agents. Harris (8) experimentally demonstrated that a cariogenic diet became cariostatic when ashed. This reaction was attributed chiefly to the organic phosphates of foods in the diet. To provide protection against caries these substances can be removed in food processing and replaced by a cariostatic inorganic phosphate.

Vehicles for fortification with phosphate consist of refined cereals, white bread, white rice, sucrose and candy. These are foods consumed daily in significant amounts by large portions of the population. About 80-90 per cent of the phosphorus content of whole wheat or rice is removed when these foods are milled or processed into white flour or polished rice. The resulting loss of phosphorus is often cited as a reason for the cariogenic property of these refined products.

Requirements for Additives

The Council on Foods and Nutrition of the American Medical Association and the Food and Nutrition Board of the National Research Council endorse the addition of nutrients to foods when in keeping with the following requirements (8):

1. "The intake of the nutrient(s) is below the desirable level in the diets of a significant number of people.

2. The food(s) used to supply the nutrient(s) is likely to be consumed in quantities that will make a significant contribution to the diet of the population in need.

3. The addition of the nutrient(s) is not likely to create an imbalance of essential nutrients.

4. The nutrient(s) added is stable under proper conditions of storage and use.

5. The nutrient(s) is physiologically available from the food.

6. There is reasonable assurance against excessive intake to a level of toxicity."

Foods can be fortified with cariostatic phosphates simply, inexpensively and effectively to reduce caries in humans. Many of these substances will not interfere with food flavor or acceptance. These modifications will require no change in food habits. Since production costs are nominal, the food industry could include sufficient quantities of phosphates in processed food without substantial cost increases to the consumer.

Requirements for Clinical Trials

Experiments to determine the anticaries activity of substances are of two types. In vitro experiments determine an agent's chemical, physical and pharmaceutical properties. In vivo tests determine immediate and latent toxicity of substances as well as the inability to inhibit caries.

Testing for caries prevention in humans is best accomplished in children between the ages of 6-12 years. A high incidence of caries occurs during this age period. Also, these age children are readily available for dental examination in school. Age intervals in excess of three years are undesirable. As the child progresses in age there are differences in the type of surface attacked by decay and the number of carious lesions. If broad age ranges are used, it is helpful to stratify the design and analysis of trials and the effects on individual types of teeth (9).

A homogeneous population is more desirable than a heterogeneous one. A given benefit or difference between the test and control groups is more likely to be statistically significant in a homogeneous population. Captive populations like boarding schools and orphanges are homogeneous. Also, the age range is usually small. One disadvantage, however, of a homogeneous group is that it may not be representative of the general population (9).

The method of examination must be standardized for meaningful results. Identical instruments need to be used and each examiner trained in the same manner. Radiographs are necessary, but should not be available to examiners for the clinical examination. A double-blind experiment is preferred. Neither the examiner nor the subject should know whether he is a member of the control or experimental group. An interval of one year between clinical examinations is considered best (9).

Mode of Action

Many theories have been postulated to account for the cariostatic properties of dietary phosphates. To help better understand these theories a brief review of the chemistry of the tooth is provided.

Composition of Tooth

On a weight basis, enamel contains approximately 96 per cent mineral, 3 per cent water and 1 per cent organic material. The dentin contains 70, 10 and 20 per cent of the same materials, respectively. The tooth is thus mainly composed of inorganic material with small amounts of organic material. Of the inorganic materials, calcium and phosphorus make up the major portion. The inorganic portion of enamel is a crystalline chemical, a modified hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$.

Systemic and Local Action

There are two basic ways phosphate exerts its action: systemically and locally. When foods containing phosphate are consumed, the phosphate is absorbed and incorporated into the tooth's metabolic processes. When phosphate is present orally, it reacts with the enamel and prevents its deformation.

One of the most interesting theories concerning the local action of phosphate is reported by Kreitzman (10). He is of the belief that phosphate exerts its local action by curtailing the production of phosphatase enzymes. Trimetaphosphate is thought to bind to the enamel surface making phosphatase and cariogenic microorganisms unavailable to the enamel surface for destruction. When phosphate is removed from tooth enamel during the formation of caries, the affinity that calcium has for phosphate is lost and the demineralization process occurs. The enzyme responsible for the specific cleavage of phosphate from phosphoproteins is phosphoprotein phosphatase. The enzyme with this specificity has been isolated from carious dentin, bacterial plaque and saliva. When phosphate is present in the mouth, this enzyme is functionless.

It is generally agreed (6) that the action of phosphate is local with two possibilities - a direct and indirect action. In the former, phosphate dissolves in oral fluids and alters the environment of teeth. In the latter, the phosphate is absorbed into the blood and returns to the oral cavity in the form of salivary phosphate. This process is called systemic-local by Navia (11). Accordingly, phosphates after absorption influence the salivary glands by altering salivary flow and/or composition. Currently available data (6) lend negligible support to this method of action. In rat studies, the phosphorus level of saliva was not appreciably altered after phosphate supplementation.

Phosphate additives exert their local action in a variety of ways. These are:

1. Phosphates may be incorporated into the plaque. When this occurs, they buffer or neutralize acids secreted by microorganisms.

2. Calcium and phosphate ions present in dental plaque may

counteract or reduce the demineralizing effects of acids produced by fermentation. This occurs through a common ion effect.

3. A high oral phosphate content may cause remineralization of slightly demineralized enamel.

4. Soluble phosphate may increase salivary phosphate which results in lowered CO_3:PO_4 and citrate:PO_4 ratios. Changes in ratios promote mineral deposition of exposed tooth surfaces. At the same time there is a reduction in the solubility of deposited minerals.

5. When enamel is exposed to acid solutions of orthophosphates, a drop in the CO_2 content of the enamel surface may result in a "decrease of the more labile accessible crystal surface". This CO_2 loss is replaced and recrystallized with phosphate (6).

Solubility

Formerly, water solubility of the phosphate compound seemed to be essential for anticaries activity. However, phosphate compounds (tricalcium phosphate, sodium phytate, sodium glycerophosphate, and sodium trimetaphosphate) which have low solubility values significantly inhibit experimental caries (4).

Buffering Action

It has been postulated that phosphates are anticarious because of their ability to buffer oral solutions. Sodium phosphate may exert some buffering action. This is questionable however as the pH of rodent saliva is alkaline (4).

Antibacterial Action

Phosphates are important for the metabolism and reproduction of microorganisms. However, if the phosphorus from the diet is available, tooth phosphorus may not be withdrawn to support bacterial growth. Sodium trimetaphosphate interferes with the colonization of cariogenic bacteria. According to Nizel (4), "If phosphates modify the adsorptive surfaces of the enamel they might decrease plaque formation".

Protein Layer

Pruitt and Jamieson (12) believe the cariostatic effect of phosphate may involve one or both of the following:

1. differential elution of proteins adsorbed on enamel

2. modification of the enamel surface which results in an alteration of the acquired protein layer

Timing

Phosphates seem to exert maximum cariostatic effects on newly erupted maturing tooth enamel. This indicates that phosphates have a topical effect on the tooth (4). Accordingly, for optimum phosphate effect, inclusion of these additives should occur when teeth are erupting, between the ages of six months to 15 years.

Optimal Concentration

Eight tenths to one per cent phosphorus (4, 13) in the diet of the rodent will significantly reduce caries and at the same time will produce no adverse metabolic effects. This is twice the amount needed by rodents for normal mineralization of bones and teeth as well as growth and development. Higher levels produce no additional benefit. This quantity of a sodium phosphate compound may be systemically undesirable.

The phosphorus level in rodent saliva is 1.6 mg. per cent as compared to 12.1 mg. per cent in man (13). To produce the same salivary effect in humans an intake of 20 gm./day of phosphorus would be required. This large amount is objectionable from the standpoint of a grossly distorted Ca:P ratio.

Efficacy of Compounds

The type of cation to which the phosphate anion is bound may significantly determine its anticaries effect in animals. A 1:1 or 2:1 calcium to phosphorus ratio in the diet is most desirable. Systemically, dicalcium phosphate is, therefore, considered the best compound. A comparison of dicalcium phosphate to sodium or potassium phosphate showed the former to be least effective. Dicalcium phosphate has low solubility. This characteristic decreases its availability for caries prevention. Sodium trimetaphosphate has proven to be the most anticariogenic phosphate in rodents and can reduce caries by 80 per cent or more (4).

Animal Vs. Human Studies

In animals, phosphates have consistently been found to significantly reduce caries activity. In humans, however, the evidence is not as clear. Three hypothesized reasons are given for differing results in humans and animals. Nizel (4), Harris (8), and Nikiforuk (13) concur on the first point, i.e. in human studies, phosphate was added to only part of the diet, whereas in animal studies, it was added to the total diet. Secondly, rats eat continuously while man generally eats three to six meals and may snack an equal number of times per day. Rodents, therefore, have a more frequent exposure to phosphates. The third explanation is that in rodents the phosphate level of saliva is low and the pH is high. The rodent's oral environment, therefore, is more conducive to an increased uptake of phosphate.

Compounds Tested

Calcium Glycerophosphate

Grenby (14) fed rats a diet high in sugar and calcium glycerophosphate. The latter was administered in three ways: incorporation into the diet, addition to the drinking water, and direct application to the tooth surface. Calcium glycerophosphate was not effective when added to water, but was protective when consumed or applied topically. Calcium glycerophosphate significantly lowered caries scores in all subjects by reducing the number of gross cavities and smooth-surface caries.

The same researcher obtained comparable results by similarly using calcium glycerophosphate. When this phosphate was consumed at two and four per cent levels, a significant reduction occurred not only in caries scores, but also, in the number of gross lesions. However, smooth surface scores were unaffected. Adding calcium glycerophosphate to the diet at a four per cent level was no more protective than at the two per cent level. Topical application significantly reduced caries in almost all areas.

Previously, protective action of phosphate was shown to be greatest on smooth surfaces and proximal areas. In the above studies the effect of glycerophosphate on smooth surface lesions was variable. Calcium glycerophosphate protected subjects from smooth surface caries only when applied topically.

Bowen[1] fed monkeys a high carbohydrate diet to investigate the effect of calcium glycerophosphate on the incidence of caries. At the end of a 22 month period, the control subjects had 47 carious lesions whereas the experimental animals had only 5. Total phosphate was higher in the plaque of animals receiving the added phosphate.

Syrian hamsters fed glycerophosphate used this substance as effectively as topically applied sodium fluoride. Data from this species of animal were comparable to that of the rat[2]. See Table 1 for a concise review of the cariostatic effects of calcium glycerophosphate on rodent caries.

Phytate

Phytate is strongly adsorbed by hydroxyapatite and reduces the solubility of tooth enamel in an acid media. Magrill (16) determined the role of phytate in inhibiting enamel mineralization. In vitro testing used acid-softened and unsoftened enamel. Irrespective of the treatment, pretreatment of enamel with phytate solution inhibited subsequent mineralization. Many animal experiments, however, have shown that phytate has cariostatic properties (16).

---

[1]Bowen, W.H. (1971) The cariostatic effect of calcium glycerophosphate in monkeys. Car. Res. 5, 7. (Abstr.)

[2]Plathner, C. & Winiker, M. (1971) Animal experiments on the caries-reducing effect of glycerophosphate. Car. Res. 5, 7. (Abstr.)

TABLE 1

Effect of calcium glycerophosphate on caries in animals

Researcher	Animal species	Phosphate %	Route of administration	Cariostasis
Grenby (14,15)	rat	2	diet	S
		4	diet	S
		2	drinking water	NS
		4	topical application	S
Bowen[1]	monkey	1	diet	S
Plathner & Winiker[2]	hamster		diet	S

S, significant

NS, not significant

Grenby[3] (14, 15) tested sodium phytate for caries protection in rats. Phytate was incorporated into the diet, added to drinking water, or topically applied. When sodium phytate was consumed in water it had no significant effect. When incorporated into the diet and applied topically the protective effect was small but significant. Phytate was, also, added to the diet at a level of two per cent or incorporated into the drinking water at levels of one and two per cent. Neither addition significantly affected the incidence of caries. Topical application of 20 or 25 per cent solutions of sodium phytate, however, produced significant caries protection. When two per cent dietary sodium phytate was fed, the number of gross lesions and smooth surface caries were significantly fewer in number. No significant effect was obtained when sodium phytate was added to the drinking water at the level of two per cent. In addition topical application of a 20 per cent solution produced no anticarious effect.

Phytate interferes with calcium absorption. This effect, however, is considered nominal. Prior to current milling methods, phytate was present in all flour and cereals. A calcium deficiency has not been attributed to the consumption of these unrefined products. Table 2 provides a summary of the cariostatic effects of sodium phytate on rodent caries.

Calcium Sucrose Phosphate

Calcium sucrose phosphate is prepared by a patented process that

---

[3]Grenby, T. (1972) Tests of sodium phytate as a protective agent against dental caries in the rat. Car. Res. 6, 82. (Abstr.)

TABLE 2

Effect of sodium phytate

on rat caries

Researcher	Animal species	Sodium phytate %	Route of administration	Cariostasis
Grenby[3]	rat	2	diet	NS
		1 & 2	drinking water	NS
		20 & 25	topical	S
Grenby (14,15)	rat	2	diet	NS
		1 & 2	drinking water	NS
		20	topical	NS

S, significant

NS, not significant

produces a mixture containing calcium salts of various sucrose phosphates plus 15-20 per cent inorganic phosphate. It reduces the rate of dissolution of hydroxyapatite in acid buffers (15).

Grenby (15) demonstrated the effects of calcium sucrose phosphate on teeth in rats. No significant effect on the incidence of caries was observed when calcium sucrose phosphate was incorporated into the diet or drinking water, and when topically applied.

Clarke and Fanning (18) reported that calcium sucrose phosphate has the ability to maintain the pH of the plaque above the critical level for enamel demineralization. This protection occurs for significant periods of time when the calcium sucrose phosphate is administered after a sucrose mouthwash. This same team found that calcium sucrose phosphate when added to a sucrose solution changed the pH from 6.3 to 8.3. The pH of plaque on an electrode was, also, significantly modified when used after a sucrose mouthwash.

When a one per cent concentration of calcium sucrose phosphate was added to a 10 per cent sucrose solution, an alteration occurred in the alkaline direction within the dental plaque. Even though this was tested on one subject, these researchers are of the opinion that calcium sucrose phosphate (1) may prevent demineralization of dental enamel and (2) may assist in repairing or remineralizing hydroxyapatite molecules (18).

Clarke and Fanning (19) monitored the pH of plaque by using a radiotelemetric technique and partial denture design. The pH levels of plaque were recorded for five days with the plaque becoming thicker each day. Both 0.5 and 1.0 per cent calcium sucrose phosphate markedly reduced the acidity of the dental plaque.

Plaque density appears to be a modifying factor in the effectiveness of calcium sucrose phosphate in changing plaque pH. As plaque density increased so did the time required for achieving maximum pH levels in the plaque. As plaque density increased so did the speed and the degree of acid production within the plaque. When the plaque is thick, it may take longer for a maximum pH to be achieved in a 1.0 per cent calcium sucrose phosphate solution (19).

Anticay, a calcium sucrose phosphate - calcium orthophosphate complex, supplies both calcium and phosphate in a soluble form. It is a fine, white, nonhygroscopic powder with a neutral bland taste. It contains approximately 11.5 per cent calcium on a dry weight basis. This complex helps reduce the acid solubility of enamel. It reduces caries in children when added to carbohydrate foodstuffs (20).

Anticay may function in three ways. One, it may slow down the rate of acid solubility of enamel and increase the rate of remineralization by a common ion effect. Second, it may inhibit the formation of plaque and its adherence to an enamel surface. Three, it may inhibit the acid producing process in plaque.

Anticay may, also, buffer the cariogenic acids. If buffering is the major factor in preventing caries, other phosphates could be expected to reduce caries. Clinical studies have not verified this hypothesis. Results of such studies are both inconclusive and inconsistent (18).

Tooth enamel is primarily composed of hydroxyapatite. A continuous exchange of calcium and phosphate ions occurs between the enamel and the aqueous solution with which it is in contact. The equilibrium of calcium and phosphate between the solid and solution phase depends upon the acidity of the solution and the concentration of these ions. As the pH decreases, the concentration of calcium and phosphate ions increases (20).

Anticay is soluble in water at all pH values. Adding Anticay to food at a concentration of one per cent of the carbohydrate weight produces approximately the same concentration in the mouth as a one per cent solution. When the pH at the enamel surface drops to four, Anticay in plaque slows down the rate of acid attack by increasing the concentration of calcium and phosphate ions (20).

Rogerson (20) showed that with adsorption of sugar phosphates, inorganic calcium and phosphate ions occur on the surface of teeth. The organic anions in sugar phosphates hinder the rate of acid dissolution of hydroxyapatite through rapid adsorption. This is important when the residence time in the mouth of any food is considered. "Once adsorbed, the sucrose phosphates will retard acid dissolution of enamel, while the inorganic calcium and phosphate are available to act as inhibitors to acid demineralization or accelerators to the remineralization process" (20).

Gustafson, et al. (21) tested the effect of Anitcay on dental caries by feeding it to golden hamsters. The caries-reducing effect obtained was attributed to the calcium content of Anticay. In another test group, the researchers felt the effect of Anticay was not due to its calcium content solely, but to some unknown influence. Table 3 summarizes the effects of calcium sucrose phosphate on teeth.

TABLE 3

Effect of calcium sucrose phosphate on

caries and plaque pH

Researcher	Type of study	Calcium sucrose phosphate %	Route of administration	Cariostasis	Acidity of dental plaque
Grenby (15)	animal (rat)	2	diet	NS	
		2	drinking water	NS	
		7.5	topical	NS	
Clarke & Fanning (18)	tele-metric	1			S
Clarke & Fanning (19)	tele-metric	0.5,1.0			S
Gustafson, et al. (21)	animal (hamster)	2	diet	S	

S, significant

NS, not significant

Dicalcium Phosphate Dihydrate Chewing Gum

The use of chewing gum as a vehicle for caries-preventive compounds has been studied since 1945. Results have been variable but studies indicate that gum users do not have more caries than non-users (22).

When anhydrous calcium orthophosphate is fed to rats at the 1.75 per cent level in a cariogenic diet caries are reduced by 66.4 - 94.3 per cent. Sugar-agglomerated dicalcium phosphate dihydrate stabilized with tetrasodium pyrophosphate is even more effective in reducing caries in rats. In vitro studies of phosphate salts showed dicalcium phosphate dihydrate (optimum concentration 7.5 - 10.0 per cent) as the most effective agent for the remineralization of enamel. Chewing gum containing dicalcium phosphate dihydrate produces marked elevations in salivary calcium and phosphate which persisted for 5 - 10 minutes after the gum was removed (23).

Richardson, et al. (23) evaluated the anticariogenic effectiveness of a sugar chewing gum containing dicalcium phosphate dihydrate. Eight hundred and fifty children served as subjects for two years. Evaluations at the end of one and two year periods indicate that subjects chewing sugarless or sugar phosphate gum had fewer caries of newly erupted teeth and corresponding surfaces of teeth. Mean increments of proximal caries in newly erupted teeth of users of sugar phosphate chewing gum were slightly lower than those for the sugarless gum users. However, the differences were not significant. Some authors suggest proximal surfaces of erupted teeth may be benefited from chewing sugar phosphate gum (23).

Breakfast Cereals

There has been much concern lately about the many available presweetened breakfast cereals and the effect of their consumption on oral health. Some of these products contain as much as 50 per cent sugar. They are often eaten by children as candy or snacks (24).

In vitro testing on 29 unsweetened and sweetened breakfast cereals recorded streptococcal acid production and enamel dissolution. Data indicate that the amount of enamel dissolution is not directly proportional to the sugar content of the cereal (24).

When different compounds such as sodium phosphate and calcium carbonate were added to presweetened cereals, enamel dissolution was reduced. The type of base cereal grain played an important role in this reduction. The highest enamel destruction occurred with corn-based cereals while the wheat- and oat-based cereals caused lower rates of enamel destruction. Corn-based cereals produced more acid. However, the relationship between acid production and enamel dissolution was not consistent. Cereals with added phosphates or carbonates generally showed higher acid production and lower enamel dissolution (24).

The addition of numerous inorganic products to a mixed corn and wheat, sugar-sweetened cereal showed that dicalcium phosphate dihydrate, calcium carbonate, and calcium hydroxide produced the greatest reductions in enamel dissolution. Some of the salt combinations produced considerable increases in acid production. However, the effects of enamel dissolution did not parallel the effects of acid production.

The calcium content rather than the organic component was reported as the determining factor in enamel dissolution. Calcium carbonate was found to be more effective than any of the phosphates tested. Parallel tests were run on all cereals but without sugar and similar but smaller reductions in dissolution occurred (24).

Choung, et al. (25) conducted two experiments on caries-susceptible rats. In the first, commercial breakfast cereals (Corn Flakes, Cap'n Crunch, and Life) were used as the sole diet. In the second, a mineral-enriched cereal product was used.

Of the diets tested, the one with 8.0 per cent sugar produced the most caries; intermediate was a presweetened cereal containing 43 per cent sugar; and the least number of caries was seen with the mineral-enriched cereal product containing 19 per cent sugar. The lack of correlation between sugar content and caries activity may be the result of the minerals or an unknown component in the cereals. These data agree with those obtained from in vitro studies mentioned previously (25).

Rowe, et al. (26) studied the effect of phosphate-enriched ready-to-eat breakfast cereals over a three year period. Subjects were seventh grade public school children residing in a community with fluoridated water.

Subjects were separated into two groups. One group received the phosphate supplemented ready-to-eat breakfast cereal; the other received market available products. Cereals were consumed as desired. Double blind design examinations were conducted clinically and radiographically at intervals of 0, 12, 24, and 36 months. No significant difference was found as a result of the consumption of phosphate or non phosphate supplemented cereals (26).

Similar results are reported by Peterson (27). Sodium dihydrogen phosphate and disodium hydrogen phosphate were added to presweetened breakfast cereals at a level of one per cent. These products were studied over a two-year period on 421 children, grades 3-8, in Grafton, N.D. Subjects were randomly assigned to two groups. One group received cereal with the phosphate added whereas the second group received the same cereals without an additive.

Radiographic and visual dental examinations were given to all children. No cariostatic effect could be attributed to the addition of phosphate to presweetened breakfast cereals (27).

Brewer, et al. (28) clinically studied the anitcariogenic effects of sodium dihydrogen phosphate-enriched breakfast cereals in institutionalized subjects. Data were derived from 474 subjects living in an institution for the mentally retarded. Subjects of comparable age were randomly distributed into two groups. Some subjects consumed a phosphate enriched cereal whereas others consumed cereal without an additive. All subjects were given a 1-oz. serving of the respective ready-to-eat cereals daily; they consumed the same diet, used a non-fluoride toothpaste, and drank fluoride-deficient water.

At intervals of six months, one year, eighteen months, and two years subjects were examined and radiographed. At the end of six months, subjects receiving the phosphate-enriched cereals had reductions in dental caries increments of 29.2 per cent and 39.1 per cent for DMF teeth and surfaces, respectively. After eighteen months, reductions in caries of 28.6 per cent and 46.1 per cent for DMF teeth and surfaces, respectively, were recorded. After 24 months, reductions of 48.5 per cent and 55.3 per cent were observed. The interproximal surfaces were examined and reductions ranged from 82.1 per cent to 97.4 per cent in the incidence of new interproximal lesions during the course of the study (28).

The anticariogenic effect of the phosphate-enriched cereals was not age related, as cereals reduced caries in all subjects. This study suggests that the continued use of sodium dihydrogen phosphate-enriched cereals on a regular basis prevents new carious lesions. It further suggests that regular ingestion of phosphate-enriched cereals could reduce caries by approximately 50 per cent. Studies performed prior to this one indicate no increased effectiveness from an on going regime of phosphate enriched cereals. However, it must be noted that early studies made no attempt to control the regularity of consumption of phosphate enriched foods (28). Table 4 presents a digest of the above studies relating the use of phosphates in cereals to prevent dental caries.

Sodium Dihydrogen Phosphate

McDonald and Stookey (29) examined the influence of various concentrations of dietary sucrose on the effectiveness of sodium dihydrogen phosphate as an anticarious agent. Rats were divided into six groups according to body weight. Their diets contained yellow corn grits, powdered whole milk, sucrose, alfalfa meal, irradiated yeast, and iodized salt. Modifications were made in both yellow corn grits and sucrose content. In addition, half of the animals were fed diets with phosphates.

TABLE 4

Effect of phosphates added to breakfast

cereals on caries and enamel dissolution

Researcher	Type of study	Sugar content %	Cereals S	Cereals U	Phosphate compound	Caries I	Caries D	Enamel dissolution
Bibby & Weiss (24)	in vitro		X	X	none			NS
			X		$Ca_2HPO_4 \cdot 2H_2O$			S
			X		Ca phytate			S
					Ca_2 fructose phosphate			S
Choung, et al. (25)	animal (rat)	8	X		none	S		
		43	X		none	S		
		19	X		none		S	
Rowe, et al. (26)	human (13 yrs.)		X		not specified	S		
Peterson (27)	human (8-13 yrs.)		X		NaH_2PO_4	S		
			X		Na_2HPO_4	S		
Brewer, et al. (28)	human (all ages)		X		HaH_2PO_4		S	

S, sweetened
U, unsweetened
S, significant
NS, not significant
I, increase
D, increase

The addition of sodium dihydrogen phosphate did not alter body weight gain significantly. When sucrose was increased in the diet from 19.5 to 50 per cent, a significant decrease resulted in weight gain. In addition, increasing the amount of sucrose did not significantly alter the cariogenic properties of the diet. Diets with increased sucrose concentration supplied decreased amounts of corn grits. The presence of corn grits as a diet component is known to initiate occlusal dental caries in the rat (29).

By adding sodium dihydrogen phosphate to the diet containing 19.5 per cent sucrose, a 29.1 per cent reduction in dental caries was noted. With 35 per cent sucrose in the diet plus sodium dihydrogen phosphate, a 19.2 per cent reduction of dental caries occurred. The phosphate addition failed to produce a significant reduction of caries when incorporated into a diet containing 50 per cent sucrose (29).

These data suggest that sodium dihydrogen phosphate reduces caries inversely to the amount of sucrose in the diet. The mechanism for phosphate cariostasis can be accounted for by one or a combination of the following: the sparing of enamel phosphate during bacterial carbohydrate metabolism; an enhanced buffering capacity in the immediate environment of the tooth; or a common ion effect (29).

McDonald and Stookey (30) tested the influence of inherent dietary calcium and phosphorus on the cariostatic properties of sodium dihydrogen phosphate in rats. Animals were separated into six groups according to body weight. They were provided a diet containing bran, corn grits, calcium carbonate, bone meal, whole milk, sucrose, alfalfa meal, irradiated yeast, sodium chloride, sodium dihydrogen phosphate, cellulose, calcium and phosphorus.

The addition of sodium dihydrogen phosphate to the lowest level (.03 per cent) of dietary calcium and phosphorus furnished by the basic components of the diet produced a reduction of 13.4 per cent in the incidence of caries. With a .06 per cent dietary calcium and phosphorus content (the amount recommended for the laboratory rat) and the addition of sodium dihydrogen phosphate a dental caries reduction of 21.8 per cent was observed. Dietary calcium and phosphorus at a 1.2 per cent level with sodium dihydrogen phosphate added, resulted in a 40.2 per cent reduction of dental caries. This additive produced a significant cariostatic effect which increased with larger concentrations of calcium and phosphorus in the diet (30).

Regardless of the amount of calcium and phosphorus in the diet, the addition of sodium dihydrogen phosphate produced a significant cariostatic effect. As a result McDonald and Stookey hypothesize that the phosphorus in the diet is metabolically unavailable and consequently of no local benefit. The sodium dihydrogen phosphate which is soluble is available and, therefore, produces a beneficial effect (30).

When the caries incidence of the three groups without supplemental sodium dihydrogen phosphate was compared, the incidence of dental caries was inversely related to the dietary calcium and phosphorus content. As the dietary calcium and phosphorus content increased there was a decrease in dental caries. Diet components may have played a role in this inverse relationship. Corn particles have been related to pit and fissure lesions. As the concentration of corn decreased, the calcium and phosphorus content increased. Bran was used as a natural source of calcium and phosphorus in diets with higher concentrations of these nutrients. It is widely recognized that diets containing grain hulls are cariostatic. The diet with the highest level of calcium and phosphorus, also, provided the least amount of sucrose (30). The dietary effects of sodium dihydrogen phosphate are summarized in Table 5.

Sodium Trimetaphosphate

Sodium trimetaphosphate (TMP), is an inorganic cyclic phosphate with the empirical formula $Na_3(PO_3)_3$. When caries promoting diets are supplemented with this substance and fed to rats, a cariostatic effect is noted (31). Henry and Navia (32) used sodium trimetaphosphate to test its influence on the early development of rat caries and concurrent microbial changes. Newborn pups with lesion free teeth at an age of 18 days were fed the aforementioned supplemented diet. Buccal smooth surface lesions were evident at 21 days, maximal at 25 days, and declined thereafter. The total counts of anaerobic microorganisms obtained during the eruption of first and second molars (21 days) of TMP-fed animals were significantly lower than total counts of control animals. Alpha-hemolytic bacteria were present in higher concentrations at 21 days of age in control animals. Caries activity was also higher. The changes in alpha-hemolytic streptococci were not clearly attributed to either the phosphate supplement or to the decay process *per se*.

Englander and Keyes (33) determined the effect of phosphate supplements on cavitation in hamsters infected with caries-conducive streptococci. Four types of phosphates were used. This report will note only the effects of TMP. Experiments on hamsters employed

TABLE 5

Effect of sodium dihydrogen

phosphate on caries in rats

Researcher	Group	Sugar %	PO_4 %	Ca %	P* %	P+ %	Caries reduction %
McDonald & Stookey (29)	1	19.5					
	2	19.5	1.0				29.1
	3	35					
	4	35	1.0				19.2
	5	50					
	6	50	1.0				NS
McDonald & Stookey (30)	1	19.5		0.32	0.28	0.28	
	2	19.5	1.0	0.32	0.28	0.53	13.4
	3	19.5		0.62	0.63	0.63	
	4	19.5	1.0	0.62	0.63	0.88	21.8
	5	15.0		1.17	1.21	1.21	
	6	15.0	1.0	1.17	1.21	1.46	40.2

* amount of P contained in basic diet

+ P in basis diet + supplement of sodium dihydrogen phosphate

NS, not significant - caries incidence increased

(1) a caries producing ration supplemented with two per cent TMP daily, (2) a diet supplemented with .5 per cent TMP daily, and (3) a diet with .5 per cent TMP administered intermittently.

The animals receiving two per cent TMP developed a staggering gait, coats were dry and rough, and growth poor. Yet, significantly fewer caries (95 per cent) developed in these animals than occurred in those whose diets were free of TMP (33).

In the second experiment, TMP significantly reduced caries. Animal coats were dull despite the animal's healthy appearance. When .5 per cent TMP was fed intermittently, the anticaries effect was absent (33).

Larson, et al. (34) performed a similar experiment to the one just mentioned. They administered two caries test diets each supplemented with TMP, either continuously or intermittently. An average concentration of either 0.5 or 1.0 per cent of TMP were fed to hamsters. Caries were significantly lower in all groups with TMP as compared to control animals. When TMP was incorporated at each of the aforementioned levels into a basic diet (Diet 585) no significant difference in numbers of caries was noted. Neither concentration nor frequency of TMP intake altered caries activity. Caries development resulting from a basic diet (Diet 2000) containing 56 per cent sucrose was inversely related to the average concentration of TMP. No difference was observed when diets were consumed continuously or intermittently.

TMP was effective in reducing caries. Its effectiveness, however, related to its average concentration and not to frequency of intake. This is in contrast to the study of Englander and Keyes (33). Their data suggest that TMP loses its caries reducing effect when not administered constantly. It should be noted that even though Englander and Keyes compared intermittent with continuous feeding no control of the average intake of TMP per animal was maintained (34).

Larson and associates (35) added TMP to different test diets to study the development of caries in sulci of rat teeth and smooth surfaces. They, also, tested caries susceptibility in animals with the chance of infection versus those inoculated with bacteria. Data were compared with that obtained from animals with unaltered oral environments. Rats fed a coarse particle diet developed predominantly sulcal lesions. No increase in caries resulted from inoculation with an exogenous mixed cariogenic flora including a strain of streptococcus mutans. Uninoculated rats fed a high sucrose diet, also, developed predominantly sulcal lesions while inoculated animals showed some increase in sulci and very pronounced increases on smooth surface caries. The addition of TMP (1.3 per cent level of diet) to both diets significantly reduced sulcal caries and almost completely eliminated smooth surface lesions. The latter occurred infrequently in animals fed Diet 585 but frequently in those fed Diet 2000. Diet 2000 is known to develop lesions on all surfaces of teeth. Diet 585, on the other hand is associated almost exclusively with the development of lesions in the sulci.

It is the opinion of Larson and his associates that TMP is effective in preventing caries development on smooth surfaces. This condition is usually associated with the activity of plaque-forming organisms. These workers found a significantly high increase in smooth surface caries on Diet 2000 with bacterial inoculation. Level of caries was reduced with TMP to the same extent with or without inoculation. TMP, therefore, appears to be less effective in caries prevention associated with the activity of non-specific, non-plaque-forming organisms. The latter is thought to be the causative organisms in lesions of the sulci (35).

Phosphate supplements are considered more effective when added to diets with a high sucrose content. The aforementioned study confirms this hypothesis. Sucrose effectively supports the growth of smooth-surface type organisms in the absence of TMP.

The role of phosphates in reducing experimental caries is not known but there is evidence of a direct local effect. Certain groups of organisms selectively affect the total oral bacterial flora in the rat. The bacterial potential in man on smooth surfaces and sulci has not as yet been ascertained (35).

Pruitt, et al. (11) performed in vitro testing on purified human enamel powder to assay desorbed amylase activity. Sodium trimetaphosphate was the most effective agent. In the mouth, salivary proteins adsorbed on the tooth surface may protect enamel from alteration by phosphate. Solutions of TMP, however, produced the same effect as enamel powder equilibrated with centrifuged whole saliva. Data support the hypothesis that inorganic phosphates produce cariostasis by modifying the composition of the protein layer adsorbed on enamel. In the case of TMP, an alteration in the surface of the enamel occurred with a "resulting change in the affinity of various salivary proteins for the enamel surface" (11). Table 6 provides a summary of these studies.

Bicarbonate-Phosphate

Some researchers (36) have found that bicarbonate-phosphate added to dietary sucrose significantly reduces caries in rats. They have also found that the addition of sodium fluoride to the bicarbonate-phosphate compound further reduces caries. Luoma, et al. (36) added sodium fluoride to the sucrose part of a diet fed to rats. They compared the effect of this with a bicarbonate-phosphate-fluoride supplement added in a similar manner. A greater reduction of caries occurred in the latter instance. A still further reduction was effected when the additive was mixed with sucrose rather than incorporated into the whole diet.

A histopathic study on these rats showed no changes in concentrations of the main cations of blood serum and muscle. When fluoride was incorporated with the dietary sugar, the fluoride content of the bones was elevated many fold.

Luoma et al. (37) compared the effect of a bicarbonate-phosphate combination with and without fluoride on dental caries in the rat. A nutritionally adequate cariogenic diet was used. In some trials a bicarbonate-phosphate (BP) was added to the diet, whereas in other trials the diet was supplemented with BP and sodium fluoride (BPF).

The mean number of fissure caries in lower molars was observed. A 76 per cent decrease occurred in animals consuming the BP supplemented diet whereas a 80 per cent decrease occurred in animals fed the BPF diet. The mean number of approximal lesions involving the

TABLE 6

Effect of sodium trimetaphosphate on caries in rats

Researcher	Sodium trimetaphosphate %	Frequency of feeding	Sugar %	Caries reduction
Henry & Navia (32)	1.3			S
Englander & Keyes (33)	2.0	C		S
	0.5	C		S
	0.5	I		NS
Larson, et al. (34)	0.5	C	25	S
	1.0	C	25	S
	1.0	I	25	S
	2.0	I	25	S
	0.5	C	56	S*
	1.0	C	56	S*
	1.0	I	56	S*
	2.0	I	56	S*
Larson, et al. (35)	1.3		25	S (for sucal caries only)
	1.3		56	S (for smooth surface caries only)

I, intermittent

C, continuous

S*, related to intake rather than frequency

S, significant

NS, not significant

dentino-enamel junction was 65 per cent lower in animals fed the BPF diet. A 32 per cent decrease was noted in the BP fed animals. An increase in bone fluoride of approximately 10 fold was found in animals consuming the BPF diet. No effect on blood constituents was noted with or without these additives. Further, no calcification of internal organs was found. These workers concluded that the bicarbonate-phosphate compound performs its protective function by buffering the acid within the dental plaque. This compound was found to be highly effective in decreasing fissure caries whereas the BPF reduced approximal caries to a greater degree than the BP supplemented diet (37). Table 7 summarizes the cariostatic effects of bicarbonate-phosphate on rats.

Bone Meal

Gustafson, et al. (38) studied a group of substances considered to be responsible for the caries-reducing effect of bone meal in hamsters. A mixture of calcium fluoride, hydroxyapatite and calcium carbonate was used to simulate the composition of commercial bone meal. Components were studied individually as well as in combination. Only calcium fluoride produced a significant caries reduction in all three pairs of molars. Calcium carbonate had no significant effect whereas hydroxyapatite significantly affected only third molars. Since hydroxyapatite is the main component of the inorganic tooth enamel, it may be easily deposited into immature enamel of newly erupted teeth.

When all three substances were combined, only third molars showed significant decreases in caries. Bone meal - on the other hand - when added to the basal diet decreased caries in all molars (38). Results are summarized in Table 8.

TABLE 7

Effect of bicarbonate-phosphate with and without fluoride on caries in rats

Researcher	Group	Bicarbonate Phosphate %	Fluoride %	Cariostasis fissure caries %	Cariostasis approximal caries %
Luoma, et al. (36)	1	none	none	none	none
	2	none	15	67	51
	3	none	15	67	51
	4	4	15	85	87
Luoma, et al. (37)	1	none	none	none	none
	2	4	none	76	32
	3	4	10	80	65

TABLE 8

Effect of bone meal

on caries in hamsters

Researcher	Test Substance	Cariostasis
Gustafson, et al. (38)	calcium fluoride	S(in 3 pairs of molars)
	hydroxyapatite	S(in third molars only)
	calcium carbonate	NS
	bone meal	S(in third molars only)

S, significant

NS, not significant

Dicalcium Phosphate

Ashley, et al. (39), British researchers, investigated the effect of adding three per cent dicalcium phosphate to "boiled sweets" on the incidence of caries in school children during a three year period. In this unsupervised study "boiled sweets" replaced sweets usually consumed by children. Another group consumed a diet with commercially produced sweets. Still another group consumed sweets with three per cent flour added. This combination was used to provide a texture similar to that of sweets supplemented with the experimental additive.

A 15 per cent reduction in caries occurred in subjects consuming sweets supplemented with dicalcium phosphate whereas the level of caries was unaffected in subjects consuming the flour supplement. The addition of dicalcium phosphate produced results similar to those obtained from the use of commercial sweets. The authors express surprise with this finding (39). Table 9 summarizes the effects of dicalcium phosphate on caries.

Sodium Chloride

The basic diet consumed by rats determines the location of caries. Sulcal caries are induced by corn and sugar diets. Smooth surface caries are induced by a whole wheat diet.

A review by Esposito (40) demonstrates the cariostatic effectiveness of phosphate in the forms of Na_2HPO_4 and $Ca(H_2PO_4)_2 \cdot H_2O$. Precipitated basic $CaPO_4$ and $CaHPO_4$ were not cariostatic. By adding NaCl to the diet, $CaHPO_4$ became cariostatic and $Ca(H_2PO_4)_2 \cdot H_2O$ was rendered more cariostatic. Replacing $CaHPO_4$ with Na_2HPO_4 decreased

TABLE 9

Effect of dicalcium phosphate on supplemented sweets on caries incidence in humans

Researcher	Group	Type of sweet	Percentage of DFS increments
Ashley, et al. (39)	1	commercial	62.1
	2	"boiled sweet" plus Ca_2PO_4	62.4
	3	"boiled sweet" plus flour	58.0
	4	"boiled sweet" plus Ca_2PO_4	56.6

DFS, decayed filled surfaces

the cariogenicity of the diet. "Supplementation with NaCl was cariostatic in two diets formulated with and without $CaHPO_4$. The Na content of the persistently cariogenic diets was about one-fifth of that recommended for growth of weanling rats. The cariostatic effect of $CaHPO_4$ probably is influenced by some other mineral, perhaps NaCl, or other factors in the diet" (40). Table 10 summarizes the effects of sodium chloride and phosphates on the incidence of caries in rats.

Acid Beverages

Even though some carbonated beverages are sugarless, they still contain low-pH carboxylic acids which are potentially dangerous to dentition (41). Fumaric, citric, and tartaric acids are commonly found in acidic foods. Fumaric acid produces the greatest enamel dissolution (42, 43). As a result of this Tang and Kool-Aid no longer contain this substance. At the present time, High C and Welch Ade still contain this acid (43).

McDonald and Stookey (42) investigated the effect of commercially available, low pH food items on erosion and experimental dental caries by means of in vitro and in vivo studies. They sought to determine a beneficial effect on teeth from the use of phosphate by conducting several experiments using a sucrose containing soft drink mix, a powdered breakfast orange drink mix, unsweetened orange juice, and sweetened orange juice. Each product tested was fortified with NaH_2PO_4.

Some enamel dissolution occurred with each product, regardless of the presence or absence of sucrose. The major portion of this effect was attributed to the presence of acids. Data suggest phosphate

TABLE 10

Effect of phosphates supplemented with sodium chloride in a caries producing diet in rats

Researcher	Phosphate type	Effect on carries	Effect produced by NaCl supplement
Esposito (40)	Na_2HPO_4	cariostatic	not tested
	$Ca(H_2PO_4)_2 \cdot H_2O$	cariostatic	cariostasis increased
	$CaHPO_4$	cariogenic	cariostatic

may be effective in reducing enamel dissolution which occurs when acid-containing beverages are consumed. Findings indicate that the cariogenic properties of a typical acid-containing beverage may be negated completely by the addition of phosphate (42). Table 11 provides a summary of the effect of low pH food items and sodium dihydrogen phosphate on erosion and dental caries in the rat.

PRACTICAL APPLICATION

Snacking

Snacking has become a way of life for many persons. The food intake of adolescents and older people is often in the form of snacks rather than regular meals. Snack type foods generally contain greater quantities of sugar. This type of eating lends itself to the idea of phosphate supplementation of sugar-containing foods to help reduce dental caries.

Sugar

There are three avenues open for reducing the consumption of refined carbohydrates, i.e. the consumer, the food industry, and the government. For promoting oral health, these routes are preferable to the use of sugar substitutes. Substances used to replace sugar are expensive and often are used in greater amounts because they are not as sweet to the taste. Some produce an unacceptable flavor and texture when added to food. Diarrhea may also occur from their consumption (44).

Calcium sucrose phosphate when added to refined carbohydrate foods will reduce dental caries and at the same time eliminate the

TABLE 11

Effect of low pH foods and sodium dihydrogen phosphate on erosion and dental caries in rats

Researcher	Beverage*	NaH_2PO_4	Mean erosion score	Average numbers of lesions
McDonald & Stookey (42)	SC-PSD mix	0	48.1 ± 4.4	
	SC-PSD mix	X	36.6 ± 4.3	
	PBOD mix	0	11.4 ± 3.0	
	PBOD mix	X	4.8 ± 1.4	
	distilled H_2O	0		6.3 ± 0.5
	PBOD mix	0		12.1 ± 0.5
	PBOD mix	X		5.5 ± 0.7
	distilled H_2O	0		7.7 ± 0.5
	unsweetened orange juice	0		6.6 ± 0.5
	sweetened orange juice	0		8.5 ± 0.7
	PBOD mix	0		9.2 ± 0.5
	PBOD mix	X		6.6 ± 0.4

*SC-PSD mix, sucrose containing powdered soft drink mix

PBOD mix, powdered breakfast orange drink mix

X, addition of NaH_2PO_4

0, no addition

disadvantages of sugar substitutes. Opponents of phosphate additives are of the opinion that this type of food technology will promote a greater use of sugar and sugar containing foods (44).

The following tends to negate this opinion. The annual consumption of sugar as such in the U.S. (100 lbs. per person) has remained almost constant for more than 50 years (45). The maximum consumption of this food has probably been reached. However, large amounts of sugar are currently incorporated into processed foods.

Education

Consumer education concerning the oral hazards of refined carbohydrates is not an easy task. One question to resolve is how to reach the people. It is estimated that approximately 15 to 20 per cent of the population avails itself of routine periodic dental services (46). Therefore, education in the dental office reaches only a minority of the population. Public schools and health organizations are more realistic agencies for education.

If phosphates are added to commercially available caries-promoting food, education on the value of this type of additive is necessary. When fluoride was first added to drinking water, many persons were hesitant and cautious about this procedure and some still are. Some persons will always resist change. Education on the use and role of dietary phosphates is, therefore, important. Television, radio, schools, public health programs, hospitals, and medical and dental centers need to become involved in this type of education.

Over-all Health

Further research is required before the amount of phosphate necessary to combat dental caries is established without danger to over-all health. According to law additives are acceptable only when they induce no ill health.

The most effective phosphate for reducing dental caries is sodium trimetaphosphate. Unfortunately this substance not only increases the phosphate but also sodium intake. Sodium is a nutrient which when consumed in excess may promote hypertension. Much data to date on the value of phosphates come from animal research. Care needs to be taken in applying this data to humans.

SUMMARY

Dental caries can be prevented. However, the problem rests with the implementation of an educational program. Dietary phosphates may be an answer to the problem of dental caries. Fortification of refined carbohydrates at the present time appears to be the most likely vehicle for incorporating phosphate into the diet.

Dietary phosphates are most effective in preventing dental caries when teeth are exposed to them at frequent intervals. Phosphates may exert their action systemically or locally. The latter is considered most likely. Modes of action include: buffering, anti-bacterial, and altering the protein layer on enamel.

Several phosphate compounds (calcium glycerophosphate, phytate, calcium sucrose phosphate, dicalcium phosphate dihydrate, sodium dihydrogen phosphate, sodium trimetaphosphate, bicarbonate-phosphate, bone meal and dicalcium phosphate) have been tested in animals, in humans, and in vitro. Phosphates significantly reduce caries in animals. Sodium trimetaphosphate has proven to be the most effective phosphate for rodents. Calcium glycerophosphate, sodium dihydrogen phosphate, and bicarbonate-phosphate produce cariostasis in rodents. The effect of some phosphates may be enhanced when combined with NaCl. In vitro and animal studies show that when phosphates are added to acid-containing beverages these additives negate the cariogenic properties of the acids. There are no consistent findings regarding the caries reduction of phosphates in humans. Further research is necessary for substantiating the role of phosphates on maintaining the integrity of

teeth in humans.

Since snacking has become a way of life, there is more frequent consumption of foods containing sugar. This substance is one which can initiate dental caries. Therefore, the idea of phosphate supplementation of carbohydrate foods seems logical. However, over-all health must be considered when contemplating the use of phosphates as caries reducing agents. Several cariostatic phosphates contain sodium, a nutrient, when consumed in excess may promote hypertension in some individuals. Further research is necessary to prove that phosphates are systemically safe when used as an additive to promote dental health.

ACKNOWLEDGEMENTS

The author wishes to thank Ms. Beatrice Finkelstein, Major Professor, for her assistance in the preparation of this report. Appreciation should also be extended to Dr. Jane Bowers, acting Head of the Department of Foods and Nutrition and Dr. W.S. Ruliffson, professor of biochemistry, for reviewing the manuscript and serving as members of the committee.

LITERATURE CITED

1. Osborn, J.W. (1973) The evolution of dentitions. Am. Sci. 61, 548-559.

2. Carlos, J.P. (1973) Caries research: the current status. J. Am. Dent. Assoc. 87, 998-999.

3. Navia, J.M. (1973) Prospects for prevention of dental caries: dietary factors. J. Am. Dent. Assoc. 87, 1010-1012.

4. Nizel, A.E. (1972) Phosphates and dental caries. In: Nutrition in Preventive Dentistry: Science and Practice, pp. 182-193, W.B. Saunders Co., Philadelphia.

5. Nizel, A.E. & Harris, R.S. (1964) The effects of phosphates on experimental dental caries: a literature review. J. Dent. Res. 43, 1123-1136.

6. Marquez, E.S. (1972) Phosphate additives in caries prevention: a review of the literature. J. Phil. Dent. Assoc. 24, 35-42.

7. Mandel, I.D. (1970) Effects of dietary modifications on caries in humans. J. Dent. Res. 49, 1201-1212.

8. Harris, R.S. (1970) Fortification of foods and food products with anticaries agents. J. Dent. Res. 47, 1340-1344.

9. Horowitz, H.S., Baume, L.J., Dirks, O.B., Davies, G.N. & Slack, G.L. (1973) Principal requirements for controlled clinical trials of caries preventive agents and procedures. Int. Dent. J. 23, 506-516.

10. Kreitzman, S.N. (1974) Enzymes and dietary factors in caries. J. Dent. Res. 53, 218-225.

11. Navia, J.M. (1970) Evaluation of nutritional and dietary factors that modify animal caries. J. Dent. Res. 49, 1213-1228.

12. Pruitt, K.M., Jamieson, A.D. & Caldwell, R.C. (1970) Possible basis for the cariostatic effect of inorganic phosphates. Nature 225, 1249.

13. Nikiforuk, G. (1970) Posteruptive effects of nutrition on teeth. J. Dent. Res. 49, 1252-1262.

14. Grenby, T.H. (1973) Organic phosphates in the diet as possible protective agents against dental caries in the rat. Proc. Nutr. Soc. 32, 38A-39A.

15. Grenby, T.H. (1973) Trials of three organic phosphorus-containing compounds as protective agents against dental caries in rats. J. Dent. Res. 52, 454-461.

16. Magrill, D.S. (1973) Phytate inhibition of enamel hardening by mineralizing solutions. J. Dent. Res. 52, 1342.

17. Jenkins, G.N. (1970) Enamel protective factors in food. J. Dent. Res. 49, 1318-1326.

18. Clarke, N.G. & Fanning, E.A. (1973) Further consideration of the effects of calcium sucrose phosphate on dental plaque: a telemetric study. Aust. Dent. J. 18, 229-232.

19. Clarke, N.G. & Fanning, E.A. (1971) Plaque pH and calcium sucrose phosphate: a telemetric study. Aust. Dent. J. Feb., 13-16.

20. Rogerson, M.J. (1973) The role of a calcium sucrose phosphate-calcium orthophosphate complex in the reduction of dental caries. Aust. Dent. J. 18, 160-166.

21. Gustafson, G., Stelling, E., Mornstad, H. & Brunius, E. (1973) The effect of the calcium saccharose phosphate preparation anticay on dental caries in the golden hamster. Odontol. Revy. 24, 325-334.

22. Stamm, J.W. (1972) Phosphate supplemented chewing gum. J. Can. Dent. Assoc. 38, 262.

23. Richardson, A.S., Hole, L.W., McCombie, F. & Kolthammer, J. (1972) Anticariogenic effect of dicalcium phosphate dihydrate chewing gum: results after two years. J. Can. Dent. Assoc. 38, 213-218.

24. Bibby, B.G. & Weiss, M.E. (1970) Enamel dissolution by streptococcal fermentation of breakfast cereals. J. Dent. Res. 49, 1481-1486.

25. Choung, U.B., Bibby, B.G. & Losee, F.L. (1973) Some effects of breakfast cereals on caries in rats. J. Dent. Res. 52, 504-507.

26. Rowe, R.H., Anderson, R.H., Wanninger, L.A. & Saari, A.L. (1975) Effect of phosphate-enriched ready-to-eat breakfast cereals on dental caries experience in adolescents: a three-year study. J. Am. Dent. Assoc. 90, 412-417.

27. Peterson, J.K. (1969) North Dakota field test of cariostatic effect of 1 per cent sodium dihydrogen phosphate and disodium hydrogen phosphate added to presweetened breakfast cereals. J. Dent. Res. 48, 1308.

28. Brewer, H.E., Stookey, G.K. & Muhler, J.C. (1970) A clinical study concerning the anticariogenic effects of NaH_2PO_4-enriched breakfast cereals in institutionalized subjects: results after two years. J. Am. Dent. Assoc. 80, 121-124.

29. McDonald, J.L. & Stookey, G.K. (1972) Influence of dietary sucrose concentration on the cariostatic properties of NaH_2PO_4 in the rat. J. Dent. Res. 51, 665.

30. McDonald, J.L. & Stookey, G.K. (1973) Influence of inherent dietary calcium and phosphorus on the cariostatic properties of NaH_2PO_4 in the rat. J. Dent. Res. 52, 79-82.

31. Navia, J.M. (1972) Prevention of dental caries: agents which increase tooth resistance to dental caries. Int. Dent. J. 22, 427-440.

32. Henry, C. & Navia, J. (1969) Sodium trimetaphosphate influence on the early development of rat caries and concurrent microbial changes. Caries Res. 3, 326-338.

33. Englander, H.R. & Keyes, P.H. (1970) Effect of phosphate supplements on cavitation in hamsters infected with caries-conducive streptococci. J. Dent. Res. 49, 140-144.

34. Larson, R.H., Spalter, C.D., Clemmer, B.A. & Scherp, H.W. (1972) Continuous versus intermittent feedings of different levels of trimetaphosphate in relation to caries development in the rat. Arch. Oral Biol. 17, 1537-1541.

35. Larson, R.H., Clemmer, B. & Scherp, H.W. (1972) Reduction of rat caries by trimetaphosphate on different tooth surfaces: variations produced by diet and oral flora. Arch. Oral Biol. 17, 883-887.

36. Luoma, H., Meurman, J.H., Helminen, S.K.J. & Kosikiñen, K. (1972) Modification of dental caries and calculus in rats by fluoride and bicarbonate-phosphate-fluoride additions to dietary sugar. Arch. Oral Biol. 17, 821-828.

37. Luoma, H., Turtola, L., Collan, Y., Meurman, & Helminen, S. (1972) The effect of a bicarbonate-phosphate combination, without and with fluoride, on the growth and dental caries in the rat. Caries Res. 6, 183-192.

38. Gustafson, G., Stelling, E. & Brunius, E. (1972) The effect of an artificial 'bone meal' and its components on caries incidence in the golden hamster. Caries Res. 6, 244-252.

39. Ashley, F.P., Naylor, M.N. & Emslie, R.D. (1974) Clinical testing of dicalcium phosphate supplemented sweets. Br. Dent. J. 136, 361-366.

40. Esposito, E.J. (1971) Effects of sodium chloride and sucrose on caries activity in rats. J. Dent. Res. 50, 850-853.

41. McDonald, J.L., Jr. (1971) Surprising but true: nutrition and the dental hygienist. J. Am. Dent. Hyg. Assoc. 45, 176-181.

42. McDonald, J.L., Jr. & Stookey, G.K. (1973) Laboratory studies concerning the effect of acid-containing beverages on enamel dissolution and experimental dental caries. J. Dent. Res. 52, 211-216.

43. Phosphate Research and Dental Decay. Hearings before the Select Committee on Nutrition and Human Needs of the U.S. Senate, Wash., D.C., pp. 547-596. (1973).

44. Harris, R. (1974) Editorial: research in dental caries. Aust. Dent. J. 19, 131-132.

45. Vail, G.E., Phillips, J.A., Rust, L.O., Griswold, R.M. & Justin, M.M. (1973) Sugar, Candy, Frozen Desserts. In: Foods, pp. 350, Houghton Mifflin Co., Boston.

46. Steele, P.F. (1966) Preventive Dentistry. In: Dimensions of Dental Hygiene, pp. 22, Lea & Febiger, Philadelphia.

THE ROLE OF DIETARY PHOSPHATES IN PREVENTING DENTAL CARIES

by

JEANNE DRAY

B.S., University of Missouri-Kansas City, 1971

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Foods and Nutrition

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

ABSTRACT

Nutrition plays an important role in dental health. Sucrose has been shown to be one of the factors which initiates dental caries. Dietary phosphates added to refined carbohydrates may prove beneficial in preventing dental caries. Phosphates may exert their action systemically or locally. The last is considered most likely. Their modes of action include: buffering, antibacterial, and altering the protein layer on enamel. Several phosphate compounds have been tested in animals, in humans, and in vitro. Phosphates which significantly reduce caries in animals are: calcium glycerophosphate, sodium dihydrogen phosphate, bicarbonate-phosphate, and sodium trimetaphosphate. The last has proven to be the most effective. Phosphates also reduce caries in rodents when combined with sodium chloride. In vitro and animal studies show that when phosphates are added to acid-containing beverages these additives negate the cariogenic properties of the acids. There are no consistent findings regarding the caries reducing action of phosphates in humans. Currently snacking is a prevalent mode of eating and tends to increase the use of sugar-containing foods. Phosphate supplementation of food to reduce dental caries seems credible. However, many phosphates contain sodium. This nutrient when consumed in excess may promote hypertension in some individuals. Further research is necessary to prove phosphates are systemically safe when used as an additive to promote dental health.