

Summary of the dental effects of starch

T.H. Grenby

Department of Oral Medicine & Pathology, United Medical and Dental Schools, Guy's Hospital, London SE1 9RT, UK

The objective was to review the literature on the cariogenicity of starches and starch-based foods, comparing starch with other carbohydrates and examining the effects of cooking, hydrolysis and other methods of processing on its dental caries potential. The main findings were that starch in its natural state is not cariogenic or of very low cariogenicity. Starch is not consumed in this form in Western diets, however. Cooking and processing denature it and raise its potential cariogenicity. Mixtures of processed starches and sugars are more highly cariogenic than starches alone, providing the substrate for oral micro-organisms to generate acids that can attack dental enamel. It has been suggested that dental caries attack may also be promoted by processed starches contributing to the persistence or adherence of fermentable foods at susceptible sites on the teeth. It is concluded that although carbohydrates in general have similar nutritional and physiological properties, major differences in dental caries potential exist between starches and common dietary sugars, but the caries potential of the starches can be much altered by processing.

Introduction

Because dental caries levels were very high in the early 1960s (see for example Holloway *et al.*, 1963; McHugh *et al.*, 1964), there was serious concern over the influence of different constituents of the diet, particularly the carbohydrates, on the prevalence of tooth decay. Surveys of dental caries levels in relation to diet did not adequately distinguish between different types of carbohydrates, especially between sugars and starches.

All carbohydrates were grouped together as having the same nutritional and physiological properties, and virtually no information existed specifically on the dental effects of starch. From about 1960 onwards, therefore, research on the cariogenicity of individual carbohydrates was intensified, and it has been continued since then, with most of the main advances made over the

next 30 years or so. This article reviews the findings.

Data from four main experimental approaches have been employed to try to differentiate between food carbohydrates and to investigate the cariogenicity of sugars and starches:

1. Epidemiological surveys of population groups, attempting to relate their dental condition to their diets and eating patterns.
2. Clinical studies of factors believed to be important in the dental caries process in man, relating them to specific constituents of the diet.
3. Evaluation of the cariogenicity of purpose-blended diets in specially bred strains of caries-active laboratory rats under standardized conditions.

4. Experiments *in vitro* measuring factors that play a part in the caries process, such as acid development, dental plaque (polysaccharide) formation, microbial growth and the attack on dental enamel.

Most of the research on the dental properties of starches has been carried out by methods 3 and 4. Surveys (Method 1) would not be capable of identifying the specific dental effect of just one single item of the diet, and clinical studies (Method 2) are expensive to set up, require ethical approval, and of course cannot be used to study the degenerative disease of dental caries directly, so that investigations have to be confined to some factor associated with caries.

Comparison of sugars and starches

In some of the earliest work on this the findings were very clear: sugars (sucrose and glucose) in the diet of caries-active laboratory rats were cariogenic, whereas the level of caries was very low on raw wheat starch (Grenby, 1963). This was confirmed in later experiments and by other workers, e.g. Green & Hartles (1967).

Caries activity levels in seven generations of rats fed on sugar or cornstarch diets for 84 or 150 days were measured by Shaw & Ivimey in 1972. A much higher incidence of occlusal caries on sucrose and glucose diets than on cornstarch was observed, but the smooth-surface caries scores did not show any consistent difference. One factor that may have played a part in this is the fineness of the cornstarch particles, as it has been said that coarse corn particles may be hard enough to initiate lesions by contributing to fracturing of the teeth.

It has proved hard to extrapolate these findings to man, since a normal mixed diet of course contains both sugars and a variety of starches, but in a survey of 405 children Rugg-Gunn *et al.* (1987) observed a trend towards a stronger relationship between sugar intake and dental caries than between starch intake and caries.

Effect of cooking on starch

Of course cooking and processing can be carried out in various ways and under a range of conditions, so that the products can vary widely in the degree of denaturation, gelatinization and retrogradation they have undergone. In one of

the first comparisons, in which 5 parts of wheat starch were cooked with 4 parts of water in a steam oven at 100°C for 90 min, then dried and pulverized, the starch was non-cariogenic, no matter whether cooked or raw. On 66% starch regimes, the caries scores were all very low, averaging 2.1 for raw starch and 2.6 for cooked starch, but were not significantly apart (Grenby, 1965).

A few years later, Frostell & Baer (1971) recorded the caries scores in groups of 23 or 24 rats fed on 66% starch diets for 30 days. Figures for four types of unmodified starch were uniformly low, whereas pregelatinized arrowroot, potato, amioca, tapioca and wheat starches all appeared to be more cariogenic. Their caries potential was presumably related to the pregelatinization process they had been subjected to. The authors believed that gelatinization liberates more amylopectin (branched-chain starch component) than amylose (straight-chain starch component), and that amylopectin is the more cariogenic of the two molecules.

One of the salivary hydrolysis products of starch is maltose. Brudevold *et al.* (1985) noted that cooked starch produced higher salivary maltose concentrations than raw starch, and raw starch had no demineralizing potential. The demineralizing power of cooked starch was related to its rapid hydrolysis but not to its clearance time from the mouth. In later work measuring dental enamel permeability, it was found that the higher the concentration of gelatinized starch in the mouth, the longer the clearance time, and it was concluded that the starch in baked or cooked foods may have significant demineralization potential (Brudevold *et al.*, 1988).

Heating dry wheat starch alters its molecular structure so that it can be readily metabolized by *Streptococcus mutans*, one of the oral microorganisms that participates in the dental caries process (Thomson & Wills, 1976). Some further views on cooked starch were given by Firestone *et al.* (1982), whose time-controlled administration of carbohydrate diets to laboratory rats indicated that cooked wheat starch was cariogenic but less so than sucrose.

Dental properties of high-starch foods

Naturally interest in the dental properties of pure starches has been very limited. Of greater

practical significance are the effects of high-starch foods which are dietary staples in various parts of the world, e.g. bread, rice, potatoes, pasta and other cereal foods.

There has been an unconfirmed assumption that because they are initially low in sugars, they will not be cariogenic, but of course the possibility exists that cooking or gelatinizing the starch can alter this (see preceding section).

Experiments on bread

One of the first high-starch staples to be investigated for its cariogenicity was bread. White and wholemeal flour and bread were evaluated at a level of 66% in the diets of caries-active laboratory rats, and then finally large groups were fed on 100% dried bread diets for 11 weeks from weaning (Grenby, 1966). The incidence of caries was related to the sucrose content of the diet and not to the proportion of flour or bread it contained. The levels of caries were extremely low on both types of bread, with no significant differences observed between white and wholemeal. The findings on the low cariogenicity of flour in the absence of sucrose were corroborated by König & Grenby (1965).

Biscuits

Biscuits (cookies), including crackers, wafers and crispbreads, with levels of starch generally in the range of 40–70%, represent another category of high-starch foods on which dental information was lacking. In the first of a series of experiments evaluating the effects of sweet biscuits (approx. 40% sugars) in two strains of caries-active laboratory rats, the biscuits emerged as highly cariogenic, whereas control diets containing the same amounts of sucrose and starch but not baked into biscuits, had a significantly lower caries potential (Grenby & Paterson, 1972).

These findings were confirmed in later experiments, and it was also shown that digestive biscuits containing 48% starch and with alternative sweeteners replacing sucrose were significantly less cariogenic than conventional digestive biscuits containing the same level of starch (48%) but sweetened as normal with 15% of sucrose (Grenby & Bull, 1977).

Children's rusks

When six different types of cereal-based rusks, total carbohydrate contents 69–79%, were studied in laboratory rats and *in vitro* (Grenby *et al.*,

1989), their cariogenicity generally correlated well with their sucrose content, but it was observed that cereal components in the rusks could play a part in governing their adhesiveness to the tooth surface and their fermentability. The dental health implications of these findings are (a) that the more adhesive carbohydrate foods are to the teeth, the longer the contact time for acids derived or formed from the foods to advance the caries process; and (b) the greater their fermentability, the higher the risk of breakdown of short-chain carbohydrates that can be metabolized by bacterial or salivary enzymes to acids that can attack the mineral matter of the teeth, as in caries. A sucrose-free rusk formulation produced the lowest caries levels of all.

Breakfast cereals

These are another example of high-starch cereal products. The chief feature of interest in relation to their starch content when their dental properties were studied in caries-active rats was the low caries score on a diet formulated with a whole-wheat cereal (81.3% carbohydrate) and zero sucrose (Grenby & Bull, 1978). This was a further indication that processed or cooked starch products in the absence of sucrose have a comparatively low caries potential, but the study went on to show that the inclusion of as little as 9.5% of sucrose in a presweetened breakfast cereal increased caries levels by a highly significant margin.

High-starch snack foods

Many very popular types of savoury snack foods are also high in starches. Particular use is made of cereal and potato starches which are processed in various ways, sometimes under highly disruptive conditions. Research on their dental properties in laboratory animals has shown wide variations in their cariogenic potential, depending partly on the severity of the processing the starch has undergone (Grenby, 1990, 1991). In some cases the caries levels associated with the savoury snacks were very close to those from semi-sweet biscuits.

One stage in the production of the snacks is extrusion cooking, in which a slurry of starch-rich cereal or potato is subjected to conditions of high temperature, high pressure, high moisture and high shear forces. More harshly processed varieties of snacks are double-extru-

ded, gelatinized, expanded and fried. The inference is that all this can increase the susceptibility of the starch to attack by salivary or microbial α -amylase in the mouth. This effect has been studied *in vitro*, and a rise in free maltose, which can be metabolized to cariogenic acids by oral micro-organisms, has been demonstrated (Grenby, 1991).

Intra-oral plaque pH changes were found to be slower after starch snacks than after the consumption of sucrose (Park *et al.*, 1990). Finally, Lingström *et al.* (1989) observed that all processing methods, including extrusion cooking, drum-drying, popping, bread making and steam flaking, raised the fermentability of starch in human dental plaque, and commented that gelatinization was important in determining the extent of hydrolysis of the starch by α -amylase.

Partial breakdown products of starches

One unresolved question that has been raised repeatedly over the last few years is the cariogenicity of maltodextrins and glucose syrups, starch derivatives which have applications in the formulation of a wide variety of foods and drinks. There are many different kinds of these food ingredients, depending on the extent of degradation of the complex starch molecule, and they are characterized by their dextrose equivalent (DE), with a high DE indicating a substantial degree of breakdown of the starch to reducing sugars and a low DE showing less breakdown, i.e. that the material contains a relatively large proportion of higher saccharides (glucose oligomers).

As expected, studies *in vitro* indicated that the greater the proportion of higher saccharides, the less acid developed on incubating them with human dental plaque micro-organisms. Some of the materials were high in trioses, which were found to be readily fermentable by oral micro-organisms. A surprising finding was that caries scores in laboratory rats receiving diets containing maltodextrins or glucose syrups (11–36% sugars) were significantly above those from some common sugars fed at the same levels in the diet (Grenby & Mistry, 1996).

Conclusions

Summarizing these findings, it is clear that although sugars and starches may have similar

metabolic and physiological properties, they show distinct differences in their dental effects. It is well recognised by now that common, easily fermentable sugars are cariogenic. This includes monosaccharides such as glucose and fructose, together with certain disaccharides such as maltose and sucrose, but a more recent finding is that maltotriose (a trisaccharide) is easily fermentable and potentially cariogenic.

In contrast, non-processed wheat starch and cornstarch are not cariogenic, but the complex molecular structure of starch is much changed and distorted by cooking, depending on the severity of the degradative processes of denaturation, gelatinization and retrogradation to which it is subjected. The general opinion from the references cited seems to be that this can raise its cariogenicity, but not to the same level as that of sugars such as sucrose.

Hydrolytic processes liberating various saccharides from the starch to produce a range of maltodextrins and glucose syrups are a different matter. Although a DE 41 glucose syrup was significantly less cariogenic than sucrose when dissolved in the drinking-water of laboratory rats (Grenby & Leer, 1974), the same difference between them was not observed when the diets contained glucose syrups and maltodextrins in solid form (Grenby & Mistry, 1996).

These studies have concentrated on the effects of changes in the saccharide profiles of the starches and the fermentability of the products, but do not give any specific information on the possible physical action of the starch products in influencing adherence to the teeth/clearance times from the mouth. This is a matter requiring further examination. Brudevold *et al.* (1985) commented that the demineralizing power of cooked starch was related to its hydrolysis rate but not to its clearance time, although later it was shown that the higher the concentration of gelatinized starch in the mouth, the longer the clearance time (Brudevold *et al.*, 1988). Adherence can vary with the type of starch and the processing it has undergone. Significant differences in the retention times of children's rusks on the tooth surface were believed to result from the nature of the cereals they were formulated with and the type of starch they contained (Grenby *et al.*, 1989).

The effect of processing can also be seen in experiments on the influence of various types of snack foods on caries levels in laboratory

rats. Extrusion cooking, mostly of potato, maize and wheat starch, can be repeated twice or more to yield second or third generation prefabricated/fried, highly aerated products in a wide variety of shapes, and in some cases their cariogenic potential approaches that of semi-sweet biscuits (Grenby, 1991). This is most probably a consequence of partial amylytic breakdown of the starch to fermentable fragments under the severe conditions of extrusion cooking, with the extruder operating as a continuous chemical reactor. These views were confirmed by Lingström *et al.*, 1989, who linked a number of different processing methods to the raised fermentability of starches.

The consensus from the research carried out and the publications reviewed on this topic is that starches in general are less cariogenic than sugars, but that structural modification by cooking or processing can increase their cario-

genic potential. The significance of this is that starch-rich, high-carbohydrate foods generally derived from vegetable sources such as wheat, potato, rice and maize, form the staple or main element of the average Western diet and of many other diets throughout the world, so that their influence on dental health is of great potential importance. Very little research has been published on the effects of starch in a mixed diet, but one aspect that requires further investigation is its influence on the clearance time of fermentable foods from the mouth, which in turn could help to determine its potential cariogenicity. Western diets are complex and contain many different types of foods, so it is not easy to lay down definitive rules on eating to preserve dental health, but current advice would be to keep sugar intake levels low and to make full use of starchy foods, particularly those that have not been heavily processed.

References

- Brudevold F, Goulet D, Tehrani A, Attarzadeh F & van Houte J (1985): Intraoral demineralization and maltose clearance from wheat starch. *Caries Res.* **19**, 136–144.
- Brudevold F, Goulet D, Attarzadeh F & Tehrani A (1988): Demineralization potential of different concentrations of gelatinized wheat starch. *Caries Res.* **22**, 204–209.
- Firestone AR, Schmid R & Mühlemann HR (1982): Cariogenic effects of cooked wheat starch alone or with sucrose and frequency-controlled feeding in rats. *Arch. Oral Biol.* **27**, 759–763.
- Frostell G & Baer PN (1971): Caries experience of rats fed various starches for study of experimental calculus formation. *Acta Odont. Scand.* **29**, 401–413.
- Green RM & Hartles RL (1967): The effect of uncooked and roll-dried wheat starch, alone and mixed in equal quantity with sucrose, on dental caries in the albino rat. *Br. J. Nutr.* **21**, 921–924.
- Grenby TH (1963): The effects of some carbohydrates on experimental dental caries in the rat. *Arch. Oral Biol.* **8**, 27–30.
- Grenby TH (1965): The influence of cooked and raw wheat starch on dental caries in the rat. *Arch. Oral Biol.* **10**, 433–438.
- Grenby TH (1966): White and wholemeal bread and flour in the diet of caries-susceptible rats. *Br. Dent. J.* **121**, 26–29.
- Grenby TH (1990): Snack foods and dental caries. Investigations using laboratory animals. *Br. Dent. J.* **168**, 353–361.
- Grenby TH (1991): Snack foods and dental health. *Chem. in Britain* **27**, 638–642.
- Grenby TH & Bull JM (1977): Three ways of making sweet biscuits less harmful to the teeth. In *Developments in Food Carbohydrate - I*, ed. GG Birch & RS Shallenberger, ch. 10, pp. 169–184.
- Grenby TH & Bull JM (1978): Dental caries in laboratory rats from breakfast cereals and its control by a calcium glycerophosphate additive. *Arch. Oral Biol.* **23**, 675–680.
- Grenby TH & Leer CJ (1974): Reduction in 'smooth-surface' caries and fat accumulation in rats when sucrose in the drinking-water is replaced by glucose syrup. *Caries Res.* **8**, 368–372.
- Grenby TH & Mistry M (1996): Potential cariogenicity of glucose syrups and maltodextrins. *Caries Res.* **30**, 289, Abstract no. 68.
- Grenby TH & Paterson FM (1972): Effect of sweet biscuits on the incidence of dental caries in rats. *Br. J. Nutr.* **27**, 195–199.
- Grenby TH, Phillips A & Saldanha MG (1989): The possible dental effects of children's rusks: laboratory evaluation by two different methods. *Br. Dent. J.* **166**, 157–162.
- Holloway PJ, James PMC & Slack GL (1963): Dental disease in Tristan da Cunha. *Br. Dent. J.* **115**, 19–25.
- König KG & Grenby TH (1965): The effect of wheat grain fractions and sucrose mixtures on rat caries developing in two strains of rats maintained on different regimes and evaluated by two different methods. *Arch. Oral Biol.* **10**, 143–153.
- Lingström P, Holm J, Birkhed D & Björck I (1989): Effects of variously processed starch on pH of human dental

- plaque. *Scand. J. Dent. Res.* **97**, 392–400.
- McHugh WD, McEwen JD & Hitchin AD (1964): Dental disease and related factors in 13-year-old children in Dundee. *Br. Dent. J.* **117**, 246–253.
- Park KK, Schemehorn BR, Bolton JW & Stookey GK (1990): Effect of sorbitol gum chewing on plaque pH response after ingesting snacks containing predominantly sucrose or starch. *Am. J. Dent.* **3**, 185–191.
- Rugg-Gunn AJ, Hackett AF & Appleton DR (1987): Relative cariogenicity of starch and sugars in a 2-year longitudinal study of 405 English schoolchildren. *Caries Res.* **21**, 464–473.
- Shaw JH & Ivimey JK (1972): Caries in rats with starch as the only dietary carbohydrate. *J. Dent. Res.* **51**, 1507.
- Thomson ME & Wills RB (1976): Heat-processed starch: a possible factor in the aetiology of dental caries. *Arch. Oral Biol.* **21**, 779–780.