From the Dental Research Station of the Royal Medical Board,
Vipeholm Hospital, Lund, Sweden.

THE VIPEHOLM DENTAL CARIES STUDY

Survey of the Literature on Carbohydrates and Dental Caries

BENGT E. GUSTAFSSON, M.D.

One of the explanations for the divergence of opinion in the discussion of dental caries may be that from an etiological point of view, caries is not an entity. The enamel, in which the initial and most important phase — the attack on the intact surface — takes place, differs considerably from other tissues. The lack of cells and of blood vessels as well as the abundance of inorganic substances results in the enamel reacting in one and the same way to widely different injurious agents.

The monotypical reaction in the enamel — the carious lesion — is perhaps due to the anatomical and physiological properties of the enamel rather than to a single causal factor.

Despite the lack of unanimity on the etiology of dental caries, it is now almost generally accepted that the amount of dietary carbohydrates plays an important rôle as a causative factor in dental caries.

STEPHAN (1948) classed the different carbohydrates according to their possible importance in the cause of dental caries. He pointed out that the acid-producing micro-organisms in the mouth can readily produce acid from most mono- and disaccharides. Dextrin and starch are converted into acid most readily if they are first boiled. They can then be converted into sugar by the action of salivary *amylase*, which exerts only a slight effect on raw starch. In animal experiments the sugars proved to favour carious activity much more than starch or dextrin.

The relationship between dental caries and sugar intake has been studied by *direct* methods and by *indirect* methods.

The direct method. — Investigations to demonstrate the relationship between caries activity and the dietary sugar in man have been carried out under well controlled conditions. These investigations, which are few, will be discussed in a later section.

The indirect methods. — The many indirect methods may be summarised as follows.

1. In primitive races the frequency of caries is low, but rises as soon as the diet is changed to resemble that of civilised nations, i. e. diets with a usually high sugar-content (PRICE 1935, PEDERSEN 1939 and others).

It may be objected that primitive races are not completely free of caries, so that factors other than the consumption of refined sugar must be capable of causing the disease. It may also be argued that advances in civilisation are accompanied not only by an increase in the sugar consumption but also by several other changes, which may just as well contribute to increase the frequency of caries.

2. Comparison of the frequency of caries in different countries also suggests a relationship between this frequency and the consumption of sugar. Thus, in countries in which the sugar consumption is high, such as Scandinavia, England, Belgium, Holland and U. S. A., the frequency of caries is also highest (WILSKA, 1946). But here, too, factors other than the consumption of sugar cannot be excluded as responsible for this difference.

3. During World War I and World War II the frequency of caries decreased in most countries of Western Europe. This has been ascribed to the decrease in the consumption of sugar during those periods. As far as Norway is concerned, this point received special attention by TOVERUD (1945, 1949) and SOGNNAES (1948 a). In Norway the sugar consumption dropped to about half of the pre-war level and reached a minimum in 1944. The consumption then gradually rose, and in 1949 the amount of sugar supplied to manufacturers of sweets and various kinds of foodstuffs had surpassed pre-war figures. The frequency of caries in children decreased to 20 per cent of the pre-war frequency. SOGNNAES pointed out that the caries curve reached a minimum several years after the deepest drop in the consumption of sugar. For example, the consumption of sugar was lowest in Germany in 1919, while the lowest frequency of caries of permanent teeth of 7-year old children was not recorded until 1924. SOGNNAES suggested the hypothesis that the high consumption of sugar affects the metabolism of the tooth during its development. This is quite a new aspect of the effect of sugar, an aspect more or less in line with the theory supposing that caries is not attributable to local factors only. In Sweden, too, caries activity was found to diminish during World War II (MAUNSBACH *et al.*, 1947).

The validity of conclusions of this type has, however, been questioned

on the grounds that many factors other than the sugar consumption undergo changes in times of war.

4. MANN *et al.* (1947) studied caries activity in patients with pellagra. These individuals consume large amounts of carbohydrates, particularly in the form of sugar and syrup. These patients were caries inactive, an observation that may be explained by the fact that the niacin deficiency in patients with pellagra results in a lack of this substance in the acid-producing oral bacteria, i. e. lack of a substance necessary for the enzymatic production of acids from sugar.

The low caries activity in their series may, however, be related to other local or systemic changes associated with pellagra.

5. The animal experiments were an important link in the investigation of the relationship between carbohydrate intake and caries. These studies have been performed mainly on certain rodents and on monkeys. In 1931 HOPPERT, WEBBER & CANNIFF, showed that a diet containing coarse particles of maize is capable of producing caries-like lesions in the rat. Feeding on finely ground food with a sugar content of anything up to 80 per cent failed to produce caries in the rat (JACKSSON 1930, ROSEBURY & KARSHAN 1931, LILLY 1932). Later, SOGNNAES (1947, 1948 b) suggested that the reason caries did not develop in these experiments was that the animals were not placed on the high sugar diet earlier. He showed that the predisposition to caries increases, if the animals are fed on a high sugar diet already during the development and eruption of the teeth. By this method he was able to produce carious defects essentially resembling those seen in man.

KITE, SHOW & SOGNNAES (1950) performed a very important experiment. They fed animals with a caries-producing diet via the stomach tube but no carious lesions occurred. This result is perhaps one of the most important supports for the opinion that the relationship between caries and the carbohydrate intake is due to local factors active in the oral cavity.

Carious lesions similar to those seen in man have been produced in hamsters by feeding the animals on a diet rich in sugar (ARNOLD 1942, KEYES 1946 and others).

In earlier investigations (HOWE, 1922) a high sugar diet failed to produce caries in the monkey. However, later experiments (SHAW *et al.* 1945) have shown that "synthetic" diets containing a large percentage of sugar will produce caries in about 80 per cent of the animals.

Against experimental studies in animals it might be objected that it is questionable whether the observations made are true also for man.

6. A large portion of the tooth is covered with dental plaques. It has been shown (STEPHAN 1940, FOSDICK *et al.* 1941, STRÅLFORS 1948) that the supply of soluble carbohydrates to these plaques is promptly followed by acid formation. Thus the pH decreases to just below 5 within a few minutes, after which it gradually rises to its previous level within about

an hour. The ingestion of sugar or other soluble carbohydrates may therefore lead to a dissolution of the mineral components of the enamel.

Attempts have been made to get a more definite idea of the initial stages of caries *in vitro*, i. e. by studying the changes arising in an extracted tooth deposited in a mixture of saliva and sugar. However, the changes thus observed lacked many of the characteristic features of genuine carious lesions. TURELL (1950) exposed the surface of an extracted tooth alternately to saliva and to an acidified, highly concentrated solution of sugar. In preliminary studies using this technique he produced changes more closely resembling true caries than did the lesions described in earlier *in vitro* studies.

It has been established that the formation of acid on the surface of the tooth is due to the action of enzymes which can be inhibited by certain agents. The intake of enzyme-inhibiting substances together with the carbohydrates should therefore be able to inhibit this caries-promoting effect provided the chemico-parasitic theory of caries is tenable. With this in mind, such substances have been tried in the prophylaxis of caries (BURRILL *et al.* 1945, DREIZEN *et al.* 1949 and others), but the results hitherto obtained have not been very encouraging. The value of bacteriological and biochemical investigations briefly summarised under subheading 6 is limited by the fact that they deal with only one of the many factors, the importance of which in the etiology of dental caries has not yet been properly elucidated.

CLINICAL STUDIES AND EXPERIMENTAL INVESTIGATIONS IN MAN

The investigations referred to above seem to have produced convincing evidence that the consumption of carbohydrates, especially of sugar, is one of the main factors involved in the cause of dental caries.

Investigations performed under well controlled conditions and giving attention to the relationship between the frequency of dental caries and the supply of carbohydrates are of special importance in the evaluation of the rôle of dietary carbohydrates in the development of tooth decay in man. These investigations fall into three main types.

1. Uniform groups selected from children's homes or from dental clinics were studied for caries activity, and attempts were made to assess carbohydrate consumption of the subjects. The observations made were then analysed for any relationship between caries activity and the carbohydrate consumption. This type of

investigation may be classed under the heading of *studies on caries activity in relation to assessed but not adjusted carbohydrate consumption.*

2. The carbohydrate consumption of the clientele of children's clinics or of children's homes was increased or decreased under well controlled conditions. In some investigations the control groups and the experimental groups were selected from one and same material. This type of investigation might be classed as *studies on caries activity in relation to adjustments in the consumption of carbohydrates.*

3. On the basis of clinical examinations persons with rampant caries, usually with an activity of more than 10 new cavities per person per year, were selected. Afterwards the amount of dietary carbohydrates was decreased for a varying length of time, during which the further course of the caries activity was studied. Investigations of this type may be termed restricted *carbohydrate consumption in the tentative treatment of dental caries.*

CARIES ACTIVITY IN ASSOCIATION WITH UNADJUSTED CARBOHYDRATE INTAKE

BRODSKY (1933) gave attention to the relationship between the consumption of sugar in the form of sweets and dental caries. His series consisted of 319 children out of 600 seen at a pediatric outpatient department. The average age of these children was 11 years. Most of them were observed for 13 months. Every child underwent a general clinical examination and the teeth were examined with probe and mirror as well as by X-ray. Caries activity was then calculated on the basis of the number of new cavities per child per year.

A dietetic expert visited the homes of the children and interviewed the parents in order to get an idea of the environments in which the children lived and of their dietary habits. The parents and the children noted the daily consumption of different foodstuffs including sweets etc. As to the consumption of sweets, this was not specified, but simply noted under a general heading "candy". The author reported that some of the children consumed 1.5—2.0 dollars worth of candy a week without the subsequent development of caries. He expressed the opinion that there is no relationship between the consumption of sweets and dental caries.

It was not the primary purpose of the Swedish so-called *Norrlandsinvestigation*, a large scale medical-dental investigation carried out in the northern part of Sweden (WESTIN, HOLZ & LINDSTRÖM, 1934) to study

the possible relationship between dietary carbohydrates and dental caries, but LINDSTRÖM gave a few details bearing on this point. He says: "Certain observations argue for the old belief that a diet rich in carbohydrates is injurious to the teeth. It should be stressed that this statement is not based on subjects consuming a large amount of sugar and 'sweets' of different kinds but on subjects living on diets classed here as lacto-cereal".

KOEHNE, BUNTING & HADLEY (1934) studied the dietary habits of 9 children without caries and of 9 with active caries over a period of 18 months. Caries activity was assessed bacteriologically and clinically. The dietary habits of the children with active caries was characterised by *inter alia* irregularity of meal times and of the nature of the food. They had a poor appetite at table and ate sweets between meals.

COLLINS, JENSEN & BECKS (1942) studied three groups of undergraduates who had just entered the university.

Group I consisted of 122 caries-free students.

Group II consisted of 122 clinically, but not radiographically caries-free students.

Group III consisted of 122 students with active caries (5 or more open cavities).

These three groups were analysed on the basis of answers to questions about the amount of different foodstuffs included in their usual diet. In all three of the groups the consumption of protein, minerals and vitamins was practically optimal. The daily consumption of sugar included in the food and in sweets and refreshments etc. between meals was as follows: 52 g. in group I; 58 g. in group II; 90 g. in group III. The difference between group I and group III, about 40 g. of sugar per man per day, was the only factor that could be related to the differences in caries activity. It was also noteworthy that some of the subjects in the group with active caries consumed only a small amount of sugar, while some of those in the caries-free group reported a fairly high consumption. The authors took this as a sign that the tolerance to carbohydrate varies widely from one individual to another. A further possibility is that factors other than the consumption of sugar are involved in those persons in whom caries develops despite a low consumption of sugar.

Children's Homes

COLLET (1935) and SCHIØTZ (1936) reported a low caries activity in children's homes in Norway. In COLLET'S series, in which the children spent the day at the institution but slept at home, 14.6 cavities per individual were noted, while the corresponding number was 1.7 in children of equal ages at an institution where the children were boarders. In the latter home the consumption of sugar was low and sweets were forbidden. SCHIØTZ found 70 out of his series of 86 children more than three years of age to be free of caries. In one of the homes in this series

the children received sweets at bed-time. The dietary habits in this home were very regular and most of the sugar consumed was incorporated in the meals.

BREESE (1934) studied 600 individuals of a children's home for several years. He found an average activity of 0.8 new cavity per child per year. The diet was poor in sugar and the children received raw apples instead of sweet desserts.

KOEHNE & BUNTING (1934) studied caries activity in a series of 300 children over 6 years of age. They give data about 109 boys and 60 girls observed for one to four and a half years.

In their investigation the dental condition had been recorded by several examiners and no radiographs were taken. Five symbols were used for designating the degree of caries. During the period covered by the investigation conservative treatment was given only in acute cases.

The dietary regime was characterised by the fact that the supply of calories, protein, calcium, phosphorus and certain vitamins was slightly less than optimal. The amount of sugar included in the food was also low (15 g. per individual per day, corresponding to 3 per cent of the supply of calories). The daily intake of starch in the form of potatoes, bread and other cereals was 250 g., which together constituted 45 per cent of the caloric supply. Sweets were forbidden and the children had a dessert only twice a week. On the other days the meals were finished off with fresh apples. Three meals a day were served at regular times.

Despite the inadequacy of the diet, caries activity was low and remained so even after improvement regarding the amout of protein, minerals and vitamins. Thus at the end of the trial 32 children were free from caries. Only 15 per cent of the children showed moderate to high caries activity some time during the study period. The authors ascribe the low activity of caries to the low level of the dietary sugar, the uniform and regular dietary habits and the consumption of raw fruit after the meals.

In an institutional study DRAIN & BOYD (1935) found caries activity low in 53 ten to fourteen year old children. They only assessed caries activity by judging the hardness of the floor of the cavity. The diet contained 20 g. refined sugar per individual per day. The children received nothing to eat between meals.

KING (1946) reported on 50 ten to fourteen year old children in an institution where they received an adequate diet containing only a small amount of sugar. Fifty per cent of the diet consisted of carbohydrates. The children received about 10 g. sweets per day. He did not report what kind of sweets the children received or at what time of the day the sweets were consumed. In the 33 children that had been at the institution for more than 3 years 4.5 per cent of the permanent teeth were decayed, the corresponding figure for the 17 children who had been there less than 3 years was 15.6 per cent.

CARIES ACTIVITY IN ASSOCIATION WITH REGULATED CARBOHYDRATE CONSUMPTION

Diabetics

BOYD *et al.* (1929) studied the teeth of 4 children who were placed on a dietary regimen (with 70 per cent of the calories in the form of fat, and omission of refined sugar), in 5 children, who were given an improved diet and who were allowed to eat sweets at meal times, and in 4 children with coeliac disease treated *inter alia* with a high sugar diet. They observed an "inactivation" of the tooth decay in these children, and no new cavities were recorded during the period of observation, which was less than 1 year. Common to all of these dietary regimes were the regularity of the meals and that the children received nothing at all to eat between the ordinary meals.

Long-term studies of caries activity in children with diabetes have been reported by BOYD and co-workers (BOYD & DRAIN 1928, BOYD 1940, BOYD 1943 a and b).

These studies were carried out on more than 200 diabetic children who were regularly reviewed at a paediatric department for regulation of the diet and insulin.

The children received more milk, eggs, meat, vegetables and fruit than most children do. Free sugar was omitted from the diet.

The studies covered a period of five and a half years, and the children's ages ranged from 14 months to 14 years. Caries activity was found to be low both in the deciduous and in the permanent teeth.

BOYD (1943) reported the caries activity in 26 boys and 29 girls after the shedding of the deciduous teeth. The average age of the children at the commencement of the study was 12.5 years. Each child was observed for 5 years on the average. The new cavities were recorded and the children received no conservative dental treatment as long as the investigation was in progress. The average annual caries activity recorded during the entire investigation was 0.86 new carious surface per girl and 0.49 surface per boy. BOYD had no control series of his own and therefore used KLEIN & PALMER's (1938) activity figure of 2.0 newly carious surfaces per individual per year for this age group. It should be pointed out that

BOYD's conclusion was that the diet of the diabetics included a fairly large amount of "protective foods". He himself did not say anything about the importance of the reduction in the amount of sugar consumed.

A similar study was also reported by TOVERUD *et al.* (1942). They stressed the relationship between the reduction of sugar in the diet and the improvement in the state of the teeth. Fifty-five children (average age 12 years) were admitted for short periods for dietary regulation. In 49 of the patients who had followed the dietary prescriptions for three and a half years and avoided the use of sugar and did not eat between meals, the caries activity ranged from 0.4 to 0.8 newly carious lesions per child per year.

Children's Homes

According to KOEHNE, BUNTING & MORRELL (1934), 9 of 13 children who received 100 g. sugar per day in the form of sweets had active caries. With the adequate basic diet only, i.e. a diet received by both groups, 9 of the 14 children had arrested caries. It is difficult to judge the data about caries activity in this investigation.

One of the best known and most frequently cited investigations of the relationship between carbohydrates and dental caries is that carried out by JAY, HADLEY, BUNTING & KOEHNE (1936), who studied the caries incidence in institutionalised children during experimental feeding with candy.

The investigation was performed on the same material as that described by KOEHNE & BUNTING (1934) and referred to above under sub-heading 1. The diet was thus poor in calories, it contained an inadequate amount of calcium and phosphorus, and was practically free from added sugar. Sweets were omitted and the calorie requirements were covered to 45 per cent by cereals and potatoes. The children lived in cottages and some of them went to a school outside the institution. The 51 children in two of these cottages received sweets (chocolate creams, fudge and hard candies) *ad libitum*. The rest of the children (128) were taken as controls.

Caries activity was assessed "clinically" and by determining the number of lactobacilli in the saliva. The number of new cavities

or the like is not given. They stated whether the experimental persons were clinically "inactive" or "active". The children were studied 12 months before the experiment proper and during 5 months' feeding with candy. A bootlegging system soon developed: some of the candy distributed among the children passed secretly into the hands of the controls. This, as pointed out by the authors themselves, reduced the value of the control series.

The caries activity during the preparatory period and during the experimental feeding with candy is summarised in Table 1.

TABLE 1

Caries activity and consumption of sweets
Based on data given by JAY *et al.* (1936)

Caries activity		Persons studied	
Preparatory period 12 mths.	Consumption of sweets 5 mths.	No.	%
inactive	inactive	25	51
inactive	active	19	39
active	active	2	4
active	inactive	3	6
	Total	49	
not included	active	2	
	Total	51	

As it is not possible to obtain an idea of the number of new cavities or the like per person per unit of time, the effect of candy feeding must be judged by a comparison of the percentage of patients in whom an increase in caries activity was recorded, i. e. the number of children in whom caries was inactive during the preparatory period, but became active during the experimental feeding (Table 1). As 2 of the children were not examined during the preparatory period, the number of experimental subjects was reduced to 49. Of these, 19 (39 per cent) turned caries-active, 3 subjects, who were caries-active during the preparatory period, became inactive during the experimental feeding of candy. The authors based their conclusions mainly on the increase in lactobacilli observed in association with the consumption of candy.

Although it is not intended here to discuss the value of the lactobacilli count as a test for caries activity (see KRASSE 1954), it might be mentioned that the 3 cases in which active caries became inactive during the experimental feeding showed an increase in the number of salivary lactobacilli, as did most of the other experimental subjects.

The conclusions suggested by the authors themselves were much more cautious than those by other writers referring to this study. JAY *et al.* thus conclude: "This study does not prove conclusively that the consumption of large amounts of candy will increase dental caries. It does point in that direction."

KING & CROLL (1939) also studied the effect of the consumption of sweets on caries. Eight institutionalised children, aged 12—15 years, received 57 g. toffee every evening for 12 weeks. In the beginning the children had altogether 16 cavities, as compared with 24 at the end of the experiment. This investigation was, however, too brief to permit valid conclusions.

KING (1946) studied the relationship between the consumption of sweets and dental caries in the inmates of an English children's home. He divided his 68 subjects into four groups, three of which received on the average 6.4 g. fruit drops consisting of 85 per cent sugar, and chocolate biscuits weighing 8.6 g. and consisting to one third of chocolate. The total sugar content of these biscuits was 26 per cent.

The sweets were distributed every evening after the children had had their last meal and brushed their teeth. In addition the children received a daily ration of about 10 g. of various sorts of sweets at different times of the day.

In one of the groups 22 children received one caramel per day for 6 months. In the beginning of the study these children had altogether only 2 carious teeth and no increase was noted during the experimental period.

The 17 children in another group received 1 sweet daily for 6 months, 2 sweets daily during the following 6 months and 1 chocolate biscuit per day during the subsequent 12 months. Thirteen children took part in the 2-year study. At the beginning of the study only 1 child in this group had caries (7 carious teeth),

the remainder were caries-free. No new cavities appeared during the study period.

The 13 children in the third group were caries-free at the beginning of the investigation and remained so for the following 18 months, during which they received 1 chocolate biscuit a day.

The control group, consisting of 16 children, 12 of whom took part in the entire study were caries-free in the beginning. In the course of these two years 1 cavity appeared in only 1 of the children.

In KING's investigation no increase in caries was observed in the milk teeth of institutionalised children. It is noteworthy that the majority of the children were free from caries both in the beginning and at the end of the experiment, despite the fact that they had received sweets every evening after they had cleaned their teeth.

MACK (1949) carried out an investigation at a children's home where both the dental condition and the diet were found to be good during a preparatory period. She afterwards studied the effect of certain dietary changes on the dental caries during what she termed the experimental period. Of the originally 263 boys, 234 were observed during both the preparatory and experimental periods.

The purpose of her investigation was to study the general condition and the frequency of caries,

1. when the diet was improved still more and,

2. when the supply of carbohydrates in the form of sweets was increased.

The ration of meat, vegetables including potatoes, citrus fruits, tomatoes and fruit juices was increased. Cereal products were slightly decreased. The vitamin A supply was high: 9500—10600 I. U. per child per day. As to sweets, the author writes: "In addition to the candy which the children purchased, and for which a record was kept, additional candy was supplied so that each child ingested an average approximately of one two-ounce bar of candy without nuts daily."

It is not easy to judge the results of this investigation, because a number of details are missing. The author thus states that the total carbohydrate consumption was 450 g. per child per day during the

preparatory period and 320 g. during the experimental perod, despite the fact that the author had increased the potato ration, and had the intention of following changes in the state of the teeth after "the addition of still further carbohydrate to the dietary, supplied in the form of candy". According to the tables, the consumption of refined sugar (including that contained in the sweets) for 10—12-year old children was 107 g. during the preparatory period and 115 g. during the experimental period. No figures on the sugar consumption are given for the entire group during the experimental period, but children over 12 years received 125 g. daily. Moreover, nothing is said about the ratio between the amount of candy consumed during the preparatory period, and the amount ingested during the experimental period. This is important, because control groups are lacking. Judging by the figures on the sugar consumption, the increase in candy eating must have been only slight.

In the course of the 2 years' experimental feeding with additional candy the frequency of dental caries rose from 0.195 to 0.272 DMF tooth per erupted tooth. The author calculated this to be an increase of 0.0032 DMF tooth per erupted tooth per month. Supposing that the children in this series had between 20 and 28 erupted teeth per child, the frequency expressed in this manner would correspond to an activity of between 0.77 and 1.08 new DMF teeth per child per year. KNUTSON & SCHOLZ (1950) found in a large series of school-children that the corresponding age group showed a value of about 1 new DMF tooth per child per year, which means that the activity in the series under discussion would not be remarkably low. It is not possible to evaluate the effect of the experimental feeding of candy with greater accuracy in this investigation, because the author had no controls, and comparison of the activity before and after experimental feeding in one and the same group cannot be made.

As to the cause of the "low" caries activity, which — according to MACK — might have been expected to be much higher in view of the large sugar consumption, the author writes:

"The large initial amount of sugar in the dietary, and the increase in sugar intake secured by providing sufficient candy bars, so that these together with what the children bought themselves totalled

one such two-ounce bar daily in addition to the sweets initially included in the dietary would be expected to cause a marked increase in the average DMF/n values. This, however, was not the case. The generally superior dietary, together with the superior dental care of the children and the further fact that the children were given their candy allotment after a meal and were encouraged to brush their teeth after eating it undoubtedly combined to give the results as found."

MACK's investigation may be briefly summarised as follows.

1. Institutionalised children received up to 125 g. sugar per individual per day for 2 years. Most of the sugar was incorporated in the food.

2. Some of the sugar was given in the form of sweets (57 g.) of unspecified composition.

3. The additional sweets were given immediately after meals, and the children were encouraged to clean their teeth immediately afterwards.

4. It it not possible to compare the caries activity recorded with a control group or with that existing during the preparatory period.

An interesting study of the relationship between carbohydrate intake and caries was carried out by BOYD *et al.* (1950).

Their series consisted of mentally deficient girls (median age 15 years). The state of the teeth was assessed with the use of probe and mirror and by X-ray. Caries activity was expressed as the number of new DMF surfaces per person per year. The oral hygiene of these girls was poor and only few of them had ever received dental treatment.

In their investigation 166 individuals were selected for special studies. During the first year of the investigation and during the first 6 months of the second year the children received the standard diet of the institution. Then 64 were selected for the trial, while the remaining 52 were used as controls. During the second half of the second year the subjects received a diet prepared without the addition of any refined sugar. The natural sugar content of the ingredients of the food was equal to about 105 g. per individual per day. During the first 6 months of the third year an extra amount

TABLE 2

Average number of newly affected tooth surfaces during each of three successive years for girls from diet and from control groups (BOYD 1950)

Year	New DMF tooth surfaces per annum		Critical Ratio, difference of means
	Diet Group	Controls	
1st:			
Mean	2.6	3.5	
S.E. mean	0.34	0.34	1.9
2nd:			
Mean	5.2	5.6	
S.E. mean	0.55	0.70	0.45
3rd:			
Mean	3.2	4.0	
S.E. mean	0.31	1.06	0.72

of 90—110 g. of refined sugar was used in the preparation of the food or occasionally eaten as candy, which the children ate before they left the table. The supply of calories consisted of 60 per cent carbohydrates. During this time the controls received the standard diet. The teeth of the entire series were examined on various occasions.

Statistical analysis showed no significant differences in caries activity between the two groups during any period of the investigation nor between one period and another of one and the same experimental group (Table 2). BOYD concluded that neither withdrawal of sugar from the diet nor the generous use of sugar has any effect on dental caries.

In the evaluation of this conclusion, however, it must be borne in mind

a) that the experimental period was short (6 months) and

b) that the sugar was ingested at meal times, mostly incorporated in the food.

Table 3 gives a survey of studies of the relationship between caries activity and regulated carbohydrate intake.

TABLE 3

Survey of investigations of caries activity and controlled carbohydrate consumption

Author	Year	Material	Observation time	Nr. of persons		Sugar consumption			Caries activity increased + decreased − unchanged	Remarks
				experimental	control	Sweets	Total sugar consumption	+ Increase − Decrease		
				4	—	—	?	—	—	Incompl. record. of caries activity
Boyd et al.	1929	Ped. clinic.	< 1 year	5	—	at meals	?	+	—	» » » » »
				4	—	—	?	+	—	» » » » »
Koehne et al.	1934	»	5—18 mths.	13	14	= 100 g. sugar daily	?	+	+	» » » » »
Jay et al.	1936	Children's home	5 mths.	51	128	ad lib.	?	+	+	Control group received sweets against regulations
King & Croll	1939	»	2 mths.	8	—	57 g. daily every evening	low	+	+	Observation time too short
Toverud et al.	1942	Diabetics	3 ½ years	55	—	forbidden	minimum	—	—	No control group
Boyd	1943	»	> 5 years	55	—	forbidden	»	—	—	» » »
King	1946	Children's home	2 years	52	16	6-13 g. daily every evening	low	+	unchanged	Resistant material?
Mack	1949	»	2 years	234	—	57 g. daily at meals	high	+	unchanged?	Sweets given also before exp.-period, quantity not stated. No control group
Boyd	1950	»	½ year	64	55	forbidden	minimum	—	unchanged	Observation time too short
»	1950	»	½ year	64	55	sometimes at meals	high	+	unchanged	» » » »

TENTATIVE TREATMENT OF CARIES BY REDUCTION OF CARBOHYDRATE INTAKE

HOWE *et al.* (1933) studied the effect of dietary restriction on caries activity in children 2—11 years old. In 104 subjects the consumption of milk, fruit and vegetables was increased, while the carbohydrate ration was decreased as much as possible. The children were allowed to eat sweets at meals only. Caries activity decreased from 3.51 to 0.73 new cavities per child per year. In 28 children whose diet was not restricted in this manner caries activity increased from 3.39 to 3.83 new cavities per child per year.

On the basis of studies in small series JAY, CROWLEY, HADLEY & BUNTING (1933) arrived at the conclusion that the correlation between the number of lactobacilli in the saliva and caries activity is so good that the former may be regarded as an expression of the latter. Therefore JAY afterwards tried in a number of series to influence the number of salivary lactobacilli and thereby caries activity by restricting the intake of carbohydrate to a varying degree. The value of all of these investigations is limited by the fact that the clinical caries activity was not determined by recording the number of new cavities.

However, BECKS and co-workers assessed the number of lactobacilli and the clinical caries activity in one and the same material (BECKS, JENSEN & MILLARR 1944, COLLINS, JENSEN & BECKS 1942, BECKS 1950). In some of the patients studied in their series caries activity exceeded 10 new cavities per person per year. In these cases sugar was omitted from the diet and starch intake kept at a minimum. In the course of the following year a striking decrease was observed in the caries activity (to 0—1 new cavity per person per year) and in the number of lactobacilli. This investigation on such a large series would have provided convincing evidence that sugar intake favours caries. The results are, however, impaired by the observations made in the control group with rampant caries (more than 10 cavities per year) and unrestricted diet during the second year (Table 4). In this series a striking decrease was also noticed in the caries activity (to 1—2 new cavities per year), while the number of lactobacilli persisted unchanged. In that part of the series in which the carbohydrate intake was

TABLE 4

Caries activity during the year following that in which more than 10 cavities per person were recorded

Compiled after BECKS (1950)

Study period	No. of patients	Conditions during 2nd year	Percentage distribution of the material according to number of new cavities during the 2nd year				
			0	1–2	3–5	6–9	>9
1938—1943	790	Reduction of carbohydrates	62.3	17.7	10.0	6.3	3.3
1943—1948	752	»	81.2	14.7	2.8	1.2	—
1943—1948	347	Unrestricted diet	2.3	88.7	8.0	0.9	—

unrestricted the reduction in caries activity was practically just as large as in the group *with* carbohydrate *restriction*. Therefore the actual effect of carbohydrate restriction in the experimental group could be expressed as a reduction of caries activity from 1—2 new cavities to 0—1 new cavity per person during the second year.

FORSHUFVUD *et al.* 1944 tried to decrease caries in school children by dietary regulation. The diet was regular and lacked variation and the children received nothing to eat between meals, and the sugar and sweets ration was reduced. Their study covered a 6-month period, during which the regression or progression of existent cavities was taken as a measure of caries activity. Any improvement or deterioration of the lesions was recorded in accordance with a specially devised scale. Information of the dietary habits was obtained by means of questionnaires.

According to the authors, considerable improvement was noted in 37 of the 39 children in the group with the adjusted diet as compared with 10 of the 28 whose diet was not adjusted. It should, however, be borne in mind that several of the children in the latter group may also have been influenced by the advice and prescriptions given to the former group.

DISCUSSION

1. *Caries activity in association with unregulated carbohydrate intake*

In two of the series referred to above and in which the children and adolescents were living under ordinary circumstances, KOEHNE *et al.* (1934) and COLLINS *et al.* (1942) found a relationship between high caries activity and high sugar intake. BRODSKY found no such relationship in his study of the effect of the consumption of sweets on caries. The assessment of the ingestion of carbohydrates in investigations of this type is based on information given by the subjects. Therefore caution should be exercised in the evaluation of the results.

In institutionalised children caries activity is regularly low, no matter whether or not the diet is optimal (KOEHNE & BUNTING 1934, COLLET 1935, SCHIØTZ 1936, MACK & URBACH 1949). The longer the period the individual spends at the institution the lower is the frequency of caries (KING 1946, BOYD & CHEYNE 1947). Characteristic of the diet at such institutions is the small amount of refined sugar used in the preparation of the food. In several of the investigations the amount of dietary starch was found to be fairly high. The diet was also regular and lacked variation and the children received nothing to eat between meals.

In the evaluation of any relationship between the consumption of carbohydrates and the activity of caries, it should be borne in mind that the validity of conclusions drawn from these investigations is limited because the mode of living of the subjects in the series under consideration included other factors such as the regularity of the diet and of the daily life in general.

2. *Caries activity in association with regulated carbohydrate intake*

It is this type of investigation that might be expected to give direct evidence for or against any accelerating effect of carbohydrates on dental caries. (Table 3.)

The investigations carried out by BOYD *et al.* (1929) and KOEHNE, BUNTING & MORRELL (1934) are less valuable because of incomplete registration or description of the caries activity. In

studies of diabetic children the authors had no control series, but showed the value of observation of the diet with regard to carbohydrate content and other factors (TOVERUD *et al.* 1942, BOYD 1943). In these studies, however, the possible effect of metabolic disorders due to the diabetes must be borne in mind.

Of first rank importance in the discussion of carbohydrate intake and caries are the investigations of the effect of

1. *the ingestion of 90—110 g. refined sugar, partly in the form of sweets, at meals for a period of 6 months* (BOYD 1950),

2. *the ingestion of 115 g. sucrose per day (including 57 g. sweets) at meals for a period of 2 years* (MACK 1949),

3. *the ingestion of 6 to 13 g. sweets at bed-time for a period of 2 years* (KING 1946) and

4. *the ingestion of sweets ad libitum for a period of 5 months* (JAY *et al.* 1936).

According to BOYD, the consumption of 110 g. refined sugar a day at meals does not increase caries. This investigation is one of the most valuable, but the validity of this conclusion is limited by the shortness of the trial.

It is difficult to evaluate the results presented by MACK (no primary data are given about the frequency of caries, nothing is said about the ratio between the amount of sweets consumed before and during the experimental feeding, and there was no control group). According to MACK, the ingestion of 57 g. sweets at meals is compatible with low caries activity, provided the teeth are brushed after the sweets have been eaten.

According to KING, the consumption of sweets or a piece of chocolate at bed-time after the child has cleaned his teeth has no effect on dental caries. In KING's series, however, the children received an additional ration of sweets only once a day and the susceptibility of his subjects to caries was probably less than usual. In a similar study in another series KING & CROLL (1939) found that caries tended to increase.

In the investigation reported by JAY and co-workers unrestricted consumption of sweets was followed by an increase in caries activity in 39 per cent of the subjects. The validity of their figures is, however, limited by the lack of a reliable control group.

In the 3 series in which increased consumption of sweets was

found not to accelerate caries activity (BOYD, MACK and KING) the sugar was consumed at meals in the form of sweets, in the form of sucrose incorporated in the food, or as sweets, the daily ration of which was eaten at a definite hour of the day. In the investigations in which the caries activity was found to be related to the carbohydrate intake, the consumption of sweets was apparently not limited to meal-times. Observations made in these investigations thus seem to infer that the effect of sugar products does not depend entirely on the quantity consumed, but also on the consistence of the products and on the frequency and the time of consumption.

3. Reduction of carbohydrate intake in the tentative therapy of caries.

These investigations are based on the assumption that caries activity persists at a constant level for a fairly long time if the caries-producing dietary factors are also constant. Several investigations, especially those of BOYD *et al.* (1950), and general clinical experience suggest that caries activity varies widely from one period to another in one and the same individual despite the absence of dietary and environmental changes. It is therefore not remarkable that a reduction in caries activity can be demonstrated in the absence of dietary changes if, like BECKS and co-workers, one selects an extreme variant of caries activity. Investigations of this type do, however, suggest that restriction of dietary carbohydrates is followed by a decrease in caries activity, even in series where caries is not rampant (HOWE *et al.* 1933).

SUMMARY

In the light of the investigations referred to above it is not easy to decide whether or not caries activity in man is related to the carbohydrate intake. The value of the observations made in some of the studies must be questioned.

In studies of this type it is of paramount importance to check whether and how closely regulations prescribed are complied with and to determine the accuracy of the methods for recording dental caries activity. However, these points have apparently received insufficient attention by earlier workers in this field.

The investigations referred to show as follows.

1. Caries activity is as a rule low in institutionalised children. No definite conclusions can be made concerning the cause of this low level. The diet is characterised by *regularity and lack of variation*, by the use of only a small amount of sugar in the preparation of the food and by absence of any food intake e. g. snacks and sweets between the ordinary meals.

2. The effect of increased sugar ration on dental caries seems not to be entirely due to the amount of sugar but also to other factors.

3. Reduction in the dietary sugar is followed by a reduction in activity of dental caries but not to the extent often supposed.

In the light of the investigations referred to above it is easy to understand why no unanimity has been attained regarding the relationship between carbohydrate intake and dental caries. The discrepancy of the results obtained in these studies also explains the sceptical attitude assumed by many objective workers in this field towards the value of encouraging large scale reduction of carbohydrate intake in anti-caries campaigns.

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