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THE VIPEHOLM DENTAL CARIES STUDY

The Effect of Different Levels of Carbohydrate Intake on Caries Activity in 436 Individuals Observed for Five Years [1]

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It is still too early to assume a definite attitude to the many theories about the etiology and pathogenesis of dental caries. Cumulative evidence strongly suggests that dental caries is related mainly to carbohydrate intake, especially to the amount of sugar consumed.

Indirect evidence produced in favour of this assumption appears overwhelming. Observations made in epidemiological, biochemical and bacteriological investigations and animal experiments argue strongly for the consumption of carbohydrate being a necessary requirement for the development of caries.

A question that then presents itself is whether the evidence produced by the investigations reported in the literature is not sufficient to decide this point one way or the other. Epidemiological studies have shown that caries activity decreases in the entire population of a country in times of war when sugar is rationed. The incidence of caries increases in primitive races as soon as they adopt diets resembling those of civilised peoples. These observations have sometimes been accepted as evidence that sugar favours the development of dental decay. A serious objection that

[1] This paper is a revised edition of a publication in Swedish in Svensk Tandläkare-Tidskrift vol. 45 Suppl. 1952. This revision was made necessary by later analysis of further data concerning the relationship between the consumption of chocolate and dental caries, which in turn necessitated modification of the Discussion. In addition, some sections, which will be the subjects of separate papers, have been abridged.

may be raised against this line of thought is that reduction in the consumption of sugar is not the only change in the mode of living during times of war, and increased sugar consumption is not the only change following in the wake of civilisation of natives races.

It is doubtful whether conclusions based on observations made in animals hold true for human beings. As to other studies such as lactobacilli counts of the saliva and acid production in the plaque, it is not always possible to say with certainty whether the point under discussion really is related to the pathogenesis of dental caries.

Long-term studies on human beings seem to be the only method capable of answering the question of causal relationship between carbohydrate intake and dental caries. The action or effect of the experimental variable on dental caries activity must therefore be assessed by continuous direct determination of the number of new carious lesions of the teeth per unit of time. This is the only satisfactory method available for measuring caries activity in a scientific investigation until an indirect method has been devised and found satisfactory, i. e. capable of reflecting clinical dental caries activity in detail.

In the evaluation of the relationship between dietary carbohydrates and dental caries certain types of sugar, are of greatest importance. The high consumption of refined sugar in certain countries in which the frequency of dental caries is also high again suggests the possible importance of sugar as a causal factor. The importance of bread and other high starch foodstuffs has not received any special attention in long-term studies on human beings.

The total consumption of sugar in Sweden with its population of 7,000,000 is about 300,000 tons per year i. e. round 45 kg. per person per year. The household consumption is about 60—70 per cent of this quantity. The rest was used mainly by foodstuff manufacturers.

Earlier clinical studies of dental caries have been surveyed and analysed by GUSTAFSSON (1954), who suggested that investigations that might be able to provide a definite information on any relationship between the amount of refined sugar in the diet and dental caries are:

1) Studies of dental caries activity in man associated with assessed and adjusted carbohydrate consumption.

2) Tentative therapy of caries by restricted carbohydrate consumption.

Only few investigations of this type are on record. In most of them the experimental period was short and the results are sometimes difficult to judge.

Thus, an overwhelming amount of experimental evidence is available in favour of sugar promoting dental caries, but clinical experimental studies hitherto performed give conflicting results. Clinical studies must therefore still be directed to fundamental questions.

THE PURPOSE OF THE PRESENT INVESTIGATION

A very important question in the study of carbohydrate intake and dental caries is: *Does an increase in carbohydrate (sugar) intake cause an increase in dental caries? If so, what factors related to consumption are of importance?*

Critical analysis of the earlier studies and results suggests that factors other than the *quantity* of carbohydrates (sugar) ingested are involved, e. g. type of sweetmeat or foodstuff in which sugar is incorporated, ingestion at or between meals and the type of basic diet. These factors may be many and their effect is hard to evaluate. Therefore, in investigations of this type it is necessary to have adequate control groups.

Another question of paramount importance is: *Does a decrease in carbohydrate (sugar) intake produce a decrease in dental caries activity?*

An important subordinate question in this connection is whether the activity falls towards nil if carbohydrates are restricted as much as possible. The answer to this question would indicate whether we must suppose the existence of caries, which is related to factors other than the dietary carbohydrates.

The purpose of the present investigation of the relationship between caries activity and carbohydrate intake was therefore to find answers to the following questions.

A. Whether and, if so, how caries activity, as studied under controlled conditions, is influenced

a) by the ingestion, *at meals*, of refined sugar with only a *slight tendency to be retained* in the mouth (non-sticky form),
b) by the ingestion, *at meals*, of sugar with a *strong tendency to be retained* in the mouth (sticky form, sugar-rich bread),
c) by the ingestion, *between meals*, of sugar with a *strong tendency to be retained* in the mouth (sticky form, sweets etc.).

B. Whether and, if so, how dental caries activity is influenced by the omission of a variable proved to be capable of increasing caries activity.

C. Will any new carious defects arise if the consumption of sugar is reduced as far as practically possible?

GENERAL CONSIDERATIONS ON THE PLANNING OF THE INVESTIGATION

In the clinical approach to the problems mentioned in the preceding section it was decided to choose an institution for mentally deficient, where the patients — on account of their mental disorders — might be expected to remain for a long time.

After a preliminary registration of the dental status, attention was directed to the question whether such persons could be regarded as suitable from a medical and an odontological point of view for an investigation of this type. The subjects were then examined dentally at regular intervals and at least once a year. On the basis of these examinations, numbered here as first to ninth, dental caries activity was assessed.

For a certain period all patients of the entire institution received one and the same basic diet. As judged by accepted standards, this basic diet was adequate in all respects except regarding calories. To the basic diet of every experimental group was added some supplement, which varied from one group to another. These supplements constituted the experimental variables. Every group consisted of patients from one or more independent departments.

The investigation, which is still in progress, began in 1945. The first year was a preliminary and adjustment period (Preparatory Period). For 18 months (1946—1947) various vitamins

and mineral substances were studied for their effect on caries in different groups. This part of the investigation will be referred to as the *Vitamin Study Period*. These studies have been reported earlier (1948). The caries activity in the series studied was found to be *low* and without any significant differences between the groups.

In the light of this observation it was assumed that the patients were highly resistant to dental caries, and the investigation of the relationship between carbohydrate intake and caries was planned accordingly. It was therefore considered that the investigation should include an initial stage during which the experimental conditions should represent extremes as far as the carbohydrate consumption is concerned. This period covered the years 1947 to 1949 and is referred to here as *Carbohydrate Study I*.

During Carbohydrate Study I the amount of refined sugar used in the preparation of the basic diet was kept to a minimum. However, in view of the natural sugar content of the foodstuffs, the diet was not "sugar-free". In some groups the subjects received nothing to eat between meals, in others they received a certain amount of sweets, which they were allowed to eat when they liked. The sweet ration varied from one group to another. In other groups the subjects received a supplement of refined sugar at meals, which brought the total sugar ration up to about twice as much as the daily consumption of sugar per head of the Swedish population. Some groups also received sugar-rich bread, while others received only the basic diet plus fat to bring up the caloric level.

When working out the experimental conditions for the 1949—1951 period attempts were made to set up a menu resembling that of an ordinary Swedish household as far as circumstances would permit. This part of the investigation is referred to below as *Carbohydrate Study II* and the conditions used may be briefly summarised as follows. The basic diet was roughly that of an ordinary Swedish family. The amount of sugar used per day in the preparation of the food corresponds roughly to the average daily household consumption per head of the Swedish population. It was forbidden to eat between meals except in those groups, where sweets were offered to the patients between meals in such amounts that the total consumption of refined sugar did not ex-

ceed the average Swedish consumption. One group received sugar dissolved in the beverages they drank at meals, while another group received only the basic diet plus fat to make up for the calories. Finally some patients received sugar-rich bread instead of the ordinary bread of the basic diet.

The experimental conditions chosen were thus such that both during Carbohydrate Study I and II four essentially different types of groups were represented, so that the relationship between carbohydrate intake and caries could be studied from the following points of view:

1) Basic diet without additional carbohydrates but with supplementary fat to bring up the caloric level. Observations made in this group elucidate the relationship between the basic diet and dental caries activity. (*Control Group.*)

2) Basic diet with additional sugar in solution (not sticky form at meals). The amount of sucrose is somewhat larger than in any of the other groups. Observations made in this group elucidate the relationship between the total sugar intake and dental caries activity. (*Sucrose Group.*)

3) Basic diet plus addition of sugar in bread (sticky form) consumed at meals. Observations made in this group elucidate the relationship between dental caries activity and the retention of sugar consumed in low concentration at meals. (*Bread Group.*)

4) Basic diet plus addition of sugar in the form of sweets (sticky form) consumed between meals. Observations made in this group elucidate the relationship between caries activity and sugar retention, between meals, from preparations containing sugar in high concentration. (*Chocolate, Caramel, 8-toffee, 24-toffee Groups.*)

MATERIAL

The Vipeholm Hospital is an institution for mentally deficient. The institution receives patients from all parts of Sweden, so that the selection is geographically representative of the entire country.

The hospital is situated in a large park just outside of Lund. For purposes of administration the hospital is divided into 12 departments. These departments are accommodated in 6 buildings with one ward in each of the two floors. Every department is

closed, so that the inmates are not allowed outside except under supervision. During the daytime the patients are under continuous observation of well trained, experienced personnel. Therefore it was not difficult to check how the dietary regime was followed. The personnel consists of 300 persons.

The fluorine content of the water

Drinking water is supplied from the water-works of the city of Lund. It consists of a mixture of surface- and well water. The drinking water was analysed on several occasions during the experimental period. As measured by 8 determinations made since 1945, the fluorine content is 0.4 p. p. m. (ranging from 0.7 to 0.2 p. p. m.). On 2 occasions the hardness of the water was found to be 63 and 116 mg.Ca/litre.

THE PATIENTS

At the end of Carbohydrate Study II, in June 1951, there were 964 patients at the institution. Of these, the dental status of 663 (506 males and 157 females) was noted. To be accepted for the investigation the patient had to fill the following requirements:

1. The patient should not object to dental examination.
2. The patient should show no signs of active tuberculosis or other disease requiring dietary measures.
3. The patient should have a minimum of 10 teeth.

Most of the patients spend the whole of their lives at the hospital. They have a feeling of security there and do not want to leave it. In view hereof one might expect the series to be practically constant and that most of the 633 patients examined in 1946 would still be at the same ward 5 years later. However, only two thirds, i. e. 436 patients, were in the same ward and thereby in one and the same dietary group throughout the Vitamin Study, and the Carbohydrate Studies I and II. This is due to the transfer of patients from one department to another and to deaths as well as exceptionally to tentative releases.

For reasons given later, is was thought justified to include in the present account only these 436 patients — the constant mat-

TABLE 1

Age distribution of the main material 1946—1951

Group		Number of pat.	Born				Average age	
			1910 or before	1911—1920	1921—1930	1931 or later	1946	1951
Control Group		60	24	25	9	2	34.9	39.9
Sucrose Group		57	26	19	8	4	34.7	39.7
Bread Group	male	41	12	15	14	—	30.4	35.4
	female	42	8	17	15	2	28.0	33.0
Chocolate Group		47	12	18	12	5	29.1	34.1
Caramel Group		62	32	19	11	—	35.6	40.6
8-toffee Group		40	9	10	14	7	26.3	31.3
24-toffee Group	male	48	16	15	15	2	31.0	36.0
	female	39	12	10	15	2	31.1	36.1
Total		436	151	148	113	24	31.9	36.9
	male	355	131	121	83	20	32.2	37.2
	female	81	20	27	30	4	30.5	35.5

erial. Thus patients entering a group after August 1946 or leaving it before June 1951 were not included in the analysis.[1] Therefore, unless otherwise stated, all data given below refer to these patients, who have been termed the *main material* 1946—1951.

The average age of these patients was 31.9 years (males 32.2; females 30.5, Table 1). The commonest types of mental disease in the material were idiocy and imbecility. In many cases a hereditary factor was obvious. There were also a number of cases of epilepsy, some in the dement stage and some in combination with oligophrenia.

In the evaluation of the degree of oligophrenia it was often not possible to use ordinary methods for estimating the degree of underdevelopment.

FRÖDERBERG (1948) devised a method for evaluating the intelligence of a patient according to reactions to certain types of

[1] In the Chocolate Group the total number of patients was included in an extended analysis.

stimulation. With the use of this method six different degrees of oligophrenia could be recognised.

Group 0, which consists of the lowest degree of development, comprises patients who in some respects differ widely from normals. They react poorly to extrinsic stimuli and must as a rule be helped at meals. Only rarely were such patients accepted in the present series.

In groups 1—3 the patients show a tendency to imitation and try to speak.

The groups in which the patients most resemble normals are 4—6. In these groups the patients could do light, simple work and could give correct answers to simple questions.

Oligophrenic deficiency of the severity seen in the present series is often associated with certain peculiar habits which may influence the state of the teeth. (Table 2.)

An observation of interest was that in only 40 per cent of the subjects in the present series was paraffin stimulated saliva available.

The ability of the patients to perform their toilet by themselves, to sit at table and eat without help varied widely from one patient to another, and the personnel often had to help them. Only some of the least defective cleaned their teeth. Of the entire series, only 82 subjects brushed their teeth regularly. The better oral hygiene in the female bread group is explained by the fact that the nurses in that department brushed the patients' teeth every morning.

Difficulties have always been encountered in the conservative dental treatment of these patients. Some of them have, however, received such treatment by dentists outside the hospital. In view of the mental condition etc. of the patients, dental treatment had formerly usually consisted of extraction, while most of the cavities had been left untreated. Thus in the beginning of the investigation only 625 (5.6 per cent) of the 11,238 cavities had been filled. At the end of the Carbohydrate Study the number of untreated cavities had increased to 13,363. Since 1950 the patients have received more systematic dental treatment which thus consists mainly of filling cavities that had existed before the commancement of the investigation.

TABLE 2

Oral hygiene etc. in the main material

Group	Nr. of patients	Number of patients[1]							
		Brush teeth regularly	Stim. saliva possible	Chew tobacco	Need help at table	Regurgi-tate	Grind teeth	Swallow food without chewing	Put stones etc. in mouth
Control Group	60	9	20	4	6	0	2	5	0
Sucrose Group	57	2	21	11	4	2	3	3	4
Bread Group male	41	2	21	4	1	4	9	3	6
female	42	38	19	0	7	0	2	0	2
Chocolate Group	47	1	13	0	1	1	0	0	0
Caramel Group	62	10	20	4	0	1	0	1	2
8-toffee Group	40	0	20	2	9	5	2	3	3
24-toffee Group male	48	1	20	2	1	0	1	3	1
female	39	19	18	0	7	0	2	2	6
Total	436	82	172	27	36	13	21	20	24

[1] Some patients appear in more than one column.

METHODS

Records were made of the number of decayed teeth, the surfaces involved, the number of teeth extracted, not erupted or retained. Plaster models of the bite were also made for recording malocclusions of the teeth. The condition of the periodontium was also noted at the beginning of the study.

1. Recording of Caries

DIAGNOSIS AND CLASSIFICATION OF CARIOUS LESIONS

In the present investigation the following types of dental lesions were accepted as carious:

A. PRIMARY CARIES

1. *Such macroscopic* defects of the enamel, dentine and cementum as did not show characteristics of hypoplasia or erosion. The properties of the bottom of the cavity or its colour and contents were not considered in deciding whether or not the lesion should be classed as dental caries. If the floor of the cavity was hard, a note of this was, however, made in the record.

2. "*Caries without defect*" (Cwd). Visible, decalcified spots of enamel that had lost their normal translucence and assumed a chalk-like consistence (precaries).

3. *Pit and fissure caries* was also said to be present when the probe was "caught".

4. *Roentgen caries* (Rtg-caries). Well defined decalcified areas of the proximal surfaces in the x-ray film, which could not be verified as cavities on inspection with mirror and probe.

B. SECONDARY CARIES

Caries adjacent fillings was, as usual, classed as secondary caries. This type of caries was not included in the statistical analysis in the present investigation.

The Moulage System

The lesions thus observed were classed according to the Scandinavian Moulage System, (Fig. 1 a—d) devised in accordance with suggestions made by WESTIN (1940), DAHLBERG (1940) and

LINDSTRÖM (1940). The system has been described in detail by WESTIN & WOLD (1943), RÖNNHOLM, MARKÉN & ARVILL (1951), and also used by SELLMAN (1945) and BÖÖK & GRAHNÉN (1952).

The way in which this method was applied in the present investigation was described earlier by LUNDQVIST, BONOW & GRAHNÉN (1948).

According to this method, a cavity is compared with respect to position, depth and extent with models of teeth with cavities, each of which has been made on the basis of a large number of observations of all types of caries lesions. Every type of caries is represented by a series of models containing cavities of varying size and depth. Every lesion has its own size and type number. For example a cavity in the distal surface of a premolar or molar included in the Moulage System is designated 11. If this cavity increases in size, it is classed as 12, 13, 14 etc. In the following the Moulage number is given with an M as index, *e.g.* M 1, M 31 etc. With this system, then, it is possible to describe

1) the position, type and size of any cavity at a given time,
2) the number of cavities occurring between two consecutive examinations,
3) any increase in the size of the cavities recorded earlier.

The method is superior to simply recording whether or not a tooth or dental surface is decayed. This is especially the case in investigations like the present one, in which the changes were to be followed for a number of years. In such studies the state of the teeth on one occasion should be described as accurately as possible, so that any progress might be detected at a later examination. It will later be apparent how useful the method proved for overcoming difficulties encountered in the evaluation and recording of caries activity in the present investigation.

Photographic Recording

The most objective methods available for recording dental caries are, of course, those using photography. It was, however, not possible to apply such a method in the present investigation of such a large material. A specially devised method of intra-oral

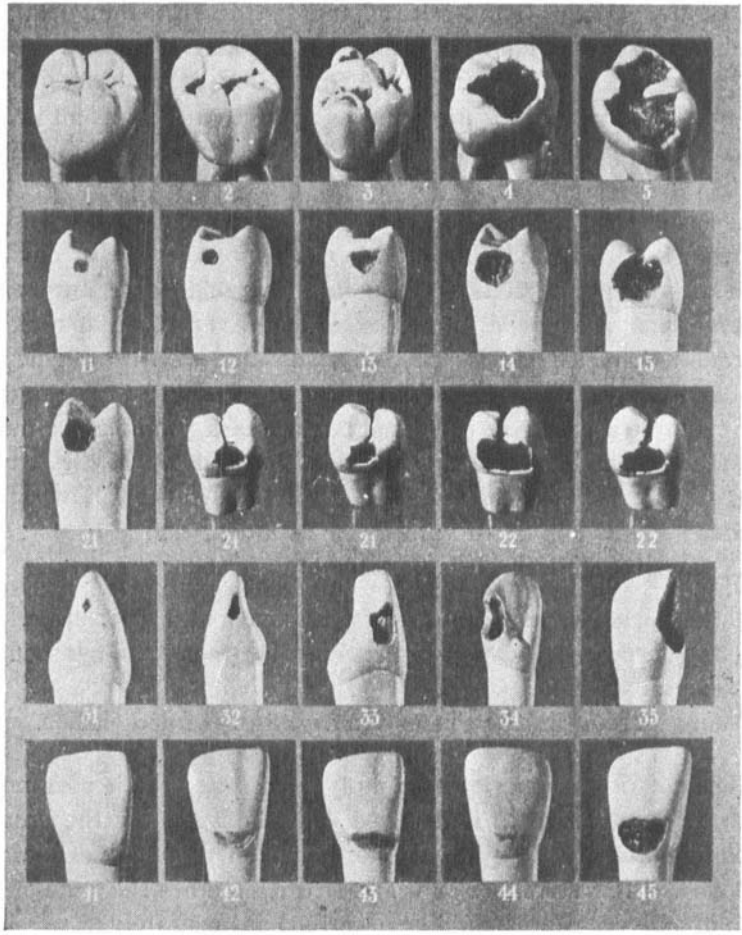


Fig. 1 a. Moulage System Series 1.

photography (GUSTAFSSON & LUNDQVIST, 1953) was, however, employed for the recording of certain types of new lesions. Figs. 2 and 3 thus show changes of the type Cwd and M 1 photographed intra-orally.

DENTAL EXAMINATION

Before the patient was sent from the ward to the dental department the teeth were brushed by the personnel and then again by the examiner when the patient was in the chair. The mouth was after-

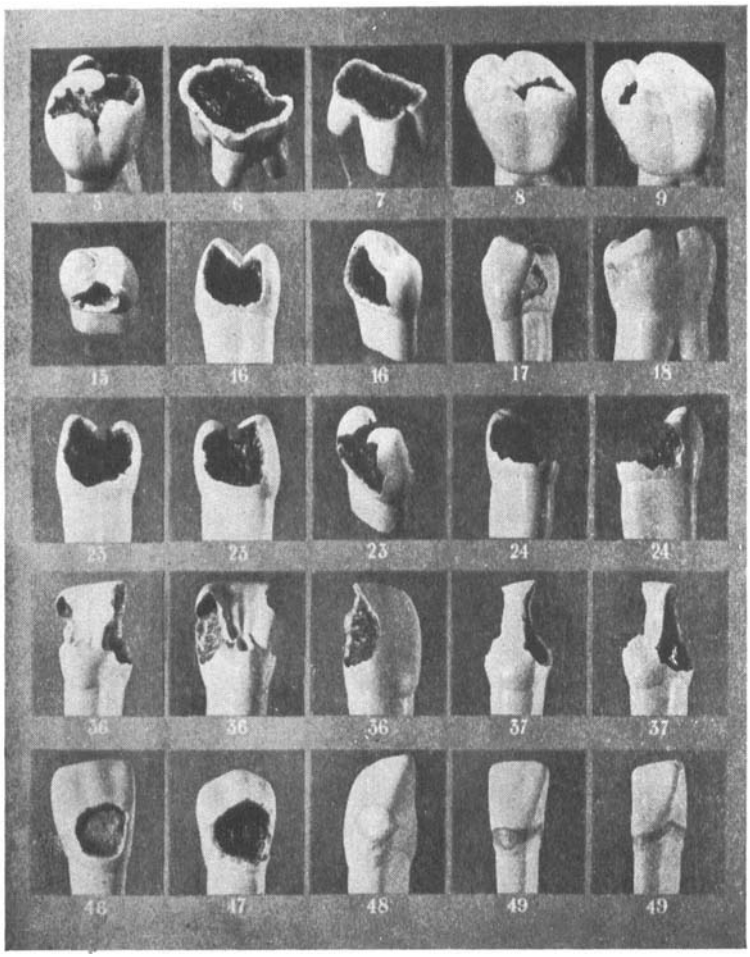


Fig. 1 b. Moulage System Series 2.

wards rinsed with a water spray and dried with the air syringe. The teeth were then examined, tooth by tooth and surface by surface, with the mirror and probe, generous use being made of the compressed air to remove the remains of any loose debris and saliva. Curved, sharp probes of the type Maillefer Inox 13 and 14 were used. The source of illumination consisted of a Dentatus spot light, type VLA. At the examination the dentist had at his disposal a bitewing-status of 5 films taken a few days beforehand. All the

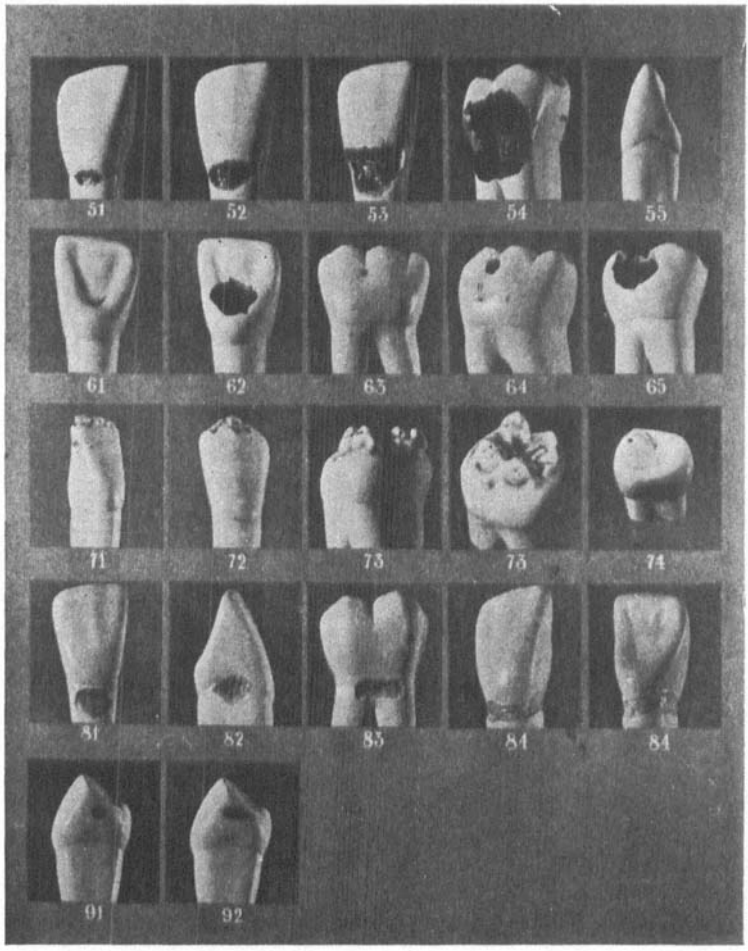


Fig. 1 c. Moulage System Series 3.

findings were dictated to a secretary who recorded them in the dental cards of a loose-leaf register.

If the examiner did not observe a cavity that had been recorded at a preceding examination, the secretary immediately reported the fact to the examiner, who then re-inspected the surface under consideration and the lesion was duly noted. However, if the examiner was unable to find a defect in a surface reported earlier as decayed, the surface was still recorded as carious and was marked

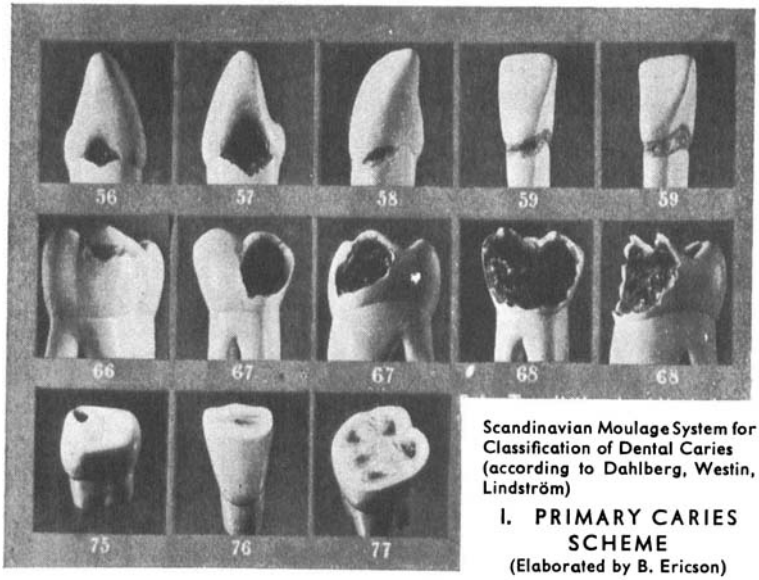


Fig. 1 d. Moulage System Series 4.

with a red K in the register. It was necessary to make this correction in order to be sure that cavities that were registered for a certain period as new really were new and did not represent doubtful registrations re-appearing after an interval of varying length during which they were not regarded as cavities. This problem is discussed in detail in a later section (page 255).

Dental Records

In the beginning the data about the extent of the caries defects were entered in a record at every examination. Therefore in the analysis of the material 2 sheets or more had to be compared. Owing to the size of the record sheets it was both difficult and time-consuming to follow the changes in the state of the individual surfaces from one examination to another without making mistakes.

Therefore a new system was tried during Carbohydrate Study II. This consisted of a loose-leaf register: the dental record of each patient consisted of 32 tooth cards, the leaves (tooth cards and summarising cards) inserted between covers so that the foot of the

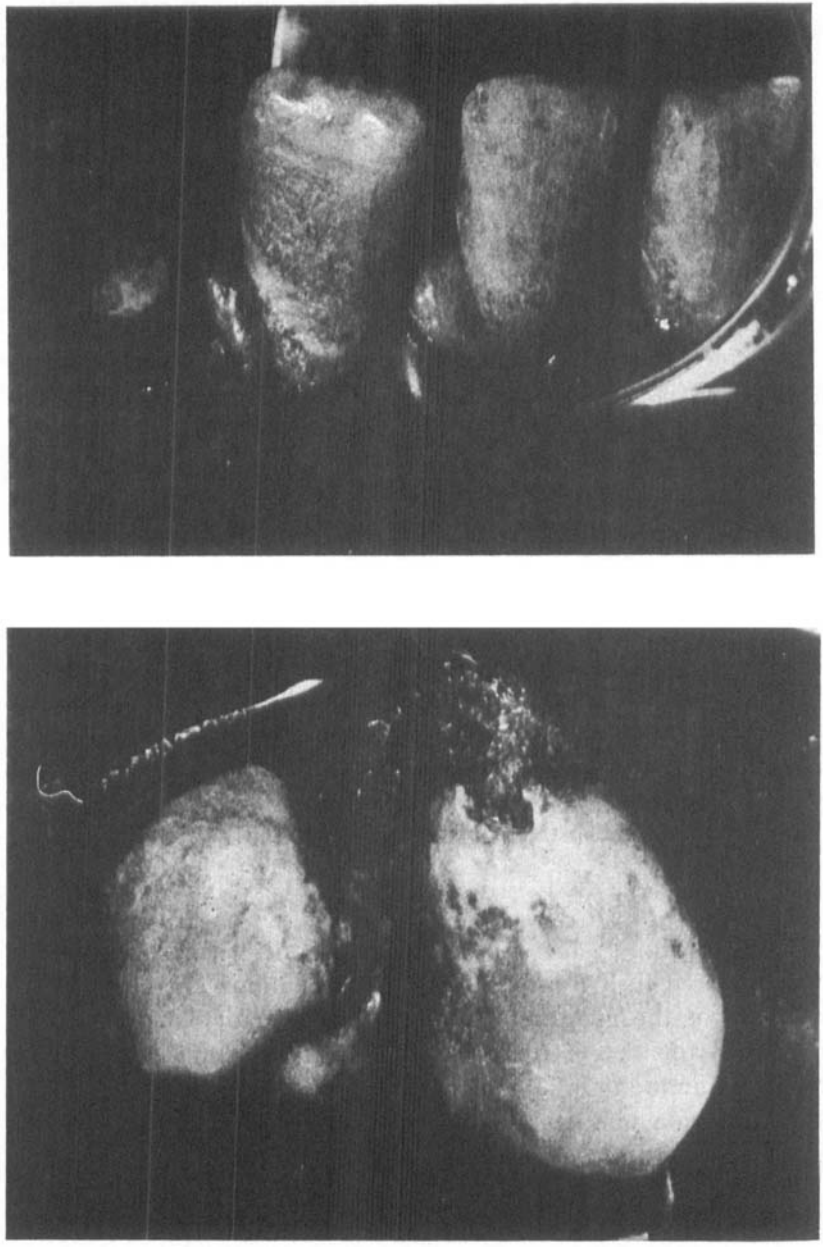


Fig. 2 a and b. Caries without defect (Cwd) intra-orally photographed. In Fig. 2 b the change has partly developed into a cavity of the type M 51.

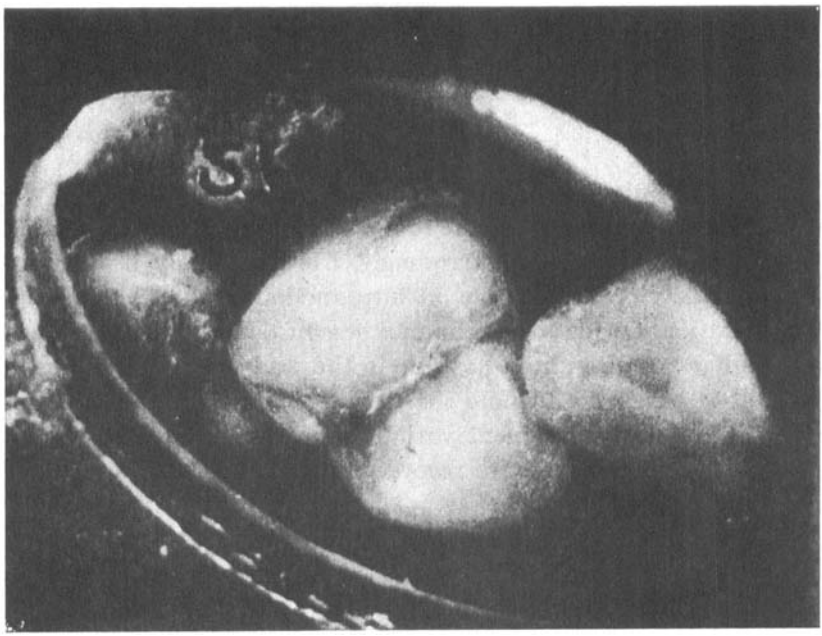


Fig. 3. Initial fissure caries (M 1) intra-orally photographed in mirror.

card with the tooth number was always visible. The tooth card contained vertical columns for each examination, which was given a number, and horizontal columns for each tooth surface (Fig. 4). For the mesial, distal and facial surface there are two lines. In the lower one those cavities are entered in which the cementum is engaged. The carious lesions were entered here according to the Moulage numbers of the surfaces involved or, if caries without defect or roentgen caries was demonstrable the designations Cwd or Rtg.

Any increase in the number of carious surfaces from one examination to another was noted in the row in the visible part of the tooth card as was also the number of intact and decayed surfaces. Here a note was also made if the tooth was extracted or retained. If the tooth was intact, the visible part of the card was blank.

In order to obtain necessary data for assessing caries activity and frequency, 4 summarising cards were allotted to each patient. The first of these included the patient's name and date of birth,

hospital record number and department. As a rule it was possible to read the desired data in the visible part of the card.

TREATMENT OF THE PRIMARY MATERIAL FOR STATISTICAL PURPOSES

In the investigation of a factor of possible importance in the causation of a given disease the role played by such a factor should be evaluated as morbidity frequency, i. e. how many healthy individuals develop the disease on introduction of the factor under consideration. Owing to the commonness of dental caries, this procedure has not often been possible in the study of dental caries in man. It is necessary to note the extent of caries in the bite and study it for any subsequent variation. In caries investigations 3 possibilities are available for recording the dental status on a given occasion.

1. Number of cavities (untreated or filled).
2. Number of damaged surfaces[1] (decayed or filled as well as surfaces of missing teeth).
3. Number of damaged teeth (decayed or filled and missing teeth).

In recording of the *state of the teeth or caries frequency* the absolute figure or any form of index based on the above-mentioned units or measures may be used for individual persons and for groups. A difficulty inherent in method 2 is the evaluation of extracted teeth or teeth with crowns. In most investigations an extracted tooth is said to represent 3 decayed surfaces. WESTIN & WOLD (1943) introduced the so-called 3—2 method, i. e. an extracted molar or premolar was said to represent 3 decayed surfaces and an incisor and cuspid 2.

BODECKER (1939) gives the number of decayed surfaces of the 180 surfaces he distinguished by his own classification or of the 148 anatomical surfaces (Bodecker's index).

WESTIN based his classification on the assumption that in the correct evaluation of caries frequency consideration should be given to the difference between the individual surfaces regarding their susceptibility to decay. Because of the difference between the lingual surfaces and others with respect to retention, and as the

[1] Mesial, occlusal, distal, facial (buccal) and lingual surfaces.

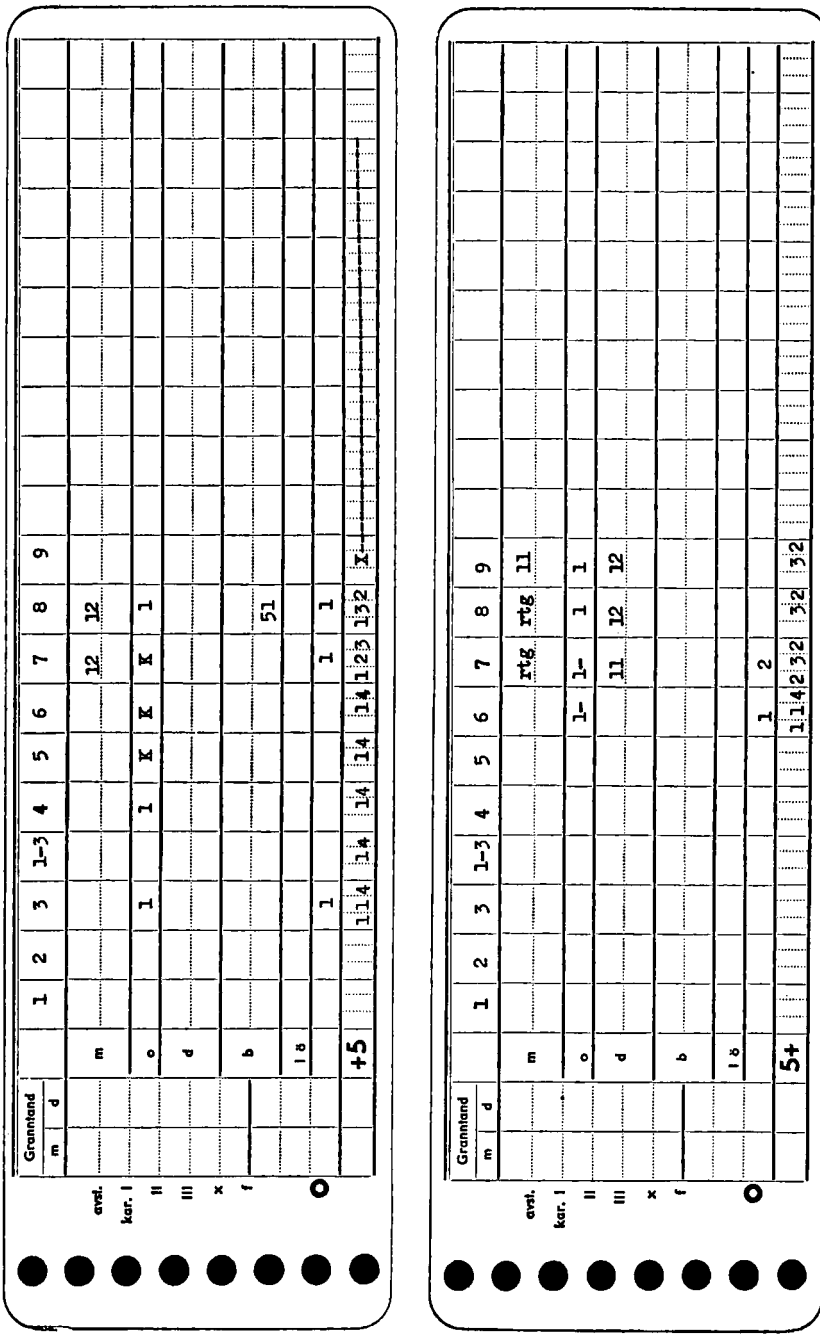


Fig. 4. Example of dental cards in the loose-leaf system. Examinations 1—9registered according to the Moulage System

third molars differ from the rest in susceptibility to caries, e. g. on account of irregular eruption, WESTIN excluded these surfaces from his classification and calculation. This reduced the number of surfaces of relevant interest to 100 (148 surfaces minus 4×5 surfaces per third molar and 28 lingual surfaces). In the present investigation certain calculations were made of the lesions occurring in these 100 surfaces, which are hereinafter referred to as *Westin's index surfaces.*

Broadly speaking, *caries activity* may be conceived as the rate at which the teeth are destroyed by caries. The term thus includes all new primary and secondary carious lesions as well as intact surfaces interfered with in the treatment of dental caries and by the enlargement of existent cavities.

In the evaluation of caries activity in investigations of the etiology and pathogenesis of caries, primary defects are of special importance.

The most suitable way of assessing caries activity is therefore to use the number of new cavities appearing per unit of time. A difficulty attending this type of recording is the registration of two cavities in one and the same surface. Sometimes it is impossible to decide with certainty whether a new cavity in an earlier carious fissure system really is a new cavity or simply an extension of a lesion already recorded. This also applies to cavities in the facial surfaces. These difficulties can be more or less circumvented by measuring the caries activity by the number of new decayed surfaces per person per unit of time.

According to the DMF method, caries activity is measured by determining the difference between the DMF-values at the end and at the beginning of the study period and dividing the value found by the time. A disadvantage of this method is, however, that surfaces and teeth can be damaged by factors other than caries. This is particularly the case with elderly people in whom diseases other than caries are capable of causing larger losses of surfaces than is caries.

It is therefore of paramount importance to determine which surfaces are caries-free and which are decayed at a given examination, and at the following examination, which of these caries-free surfaces have in the meantime become decayed.

In this way caries activity is expressed as the mortality rate of the surfaces. This surface mortality may be expressed as the numerical value per person per year and as the mean value of a group of persons. In the calculation of the mean value for a group, however, it must be supposed that the number of intact surfaces in the individuals of the groups compared are roughly equal. The influence of such individual variation can however, be avoided by giving the surface mortality during the study period per 100 originally caries-free surfaces. By taking into account only changes in the number of previously intact surfaces it is possible to avoid the source of error accompanying the assessment of the statistical value of missing teeth, which has also been suggested by WESTIN & WOLD (1943) and SELLMAN (1945).

It is, however clear that an objective analysis of caries activity requires classification of the individual surfaces according to their susceptibility to caries, it being known that some teeth vary widely from one another in this respect and surfaces still more so (LEIGH, 1923). Extreme variants are the occlusal surfaces of the first molars of the lower jaw and the lingual surfaces of the incisors and canines of the lower jaw. The risk of certain surfaces developing caries may, however, increase with advancing decay of neighbouring teeth, the presence or occurrence of other dental diseases, conservative treatment, crowns and bridges etc. Thus, proximal surfaces usually show a high caries-risk, which decreases considerably if the neighbouring teeth are extracted.

The evaluation of caries activity by this method requires that the entire series be examined, tooth by tooth and surface by surface, and any changes found be systematically recorded. These requirements were filled in the present investigation in which a card was assigned to every tooth and punched according to a special code and the data thus registered were analysed by the Hollerith method.

Data obtained from the Primary Material

The dental caries activity found in the various groups and described below is expressed as the number of new carious surfaces per unit of time observed in

1. Westin's 100 index surfaces, or
2. the 148 surfaces of the 32 teeth, or
3. the 148 surfaces of the 32 teeth with the exception of lesions difficult to judge (Cwd, Rtg and the earliest stages of caries in the fissure system, M 1).

Statistical analysis of caries activity is based on Westin's index surfaces, because the values refer to surfaces less different with regard to susceptibility to caries.

It is, however, obvious that it is important in biochemical and bacteriological studies to know whether a person or group is caries active or not. In such investigations the activity must be calculated on the basis of all types of lesions in all surfaces.

The exclusions listed under point 3) were made because of the difference of opinion between the examiners in the classification of a surface as carious or non-carious when the lesions were Cwd, M 1 and Rtg. The calculations were based on "major cavities", and the cavities were only looked upon as new if they were of the type M 2, M 11, M 51, M 41—43, regardless of the fact whether lesions of the type M 1, Cwd or Rtg-caries had been observed at the same site at the preceding examination.

No account will be given of the caries activity of the individual teeth, but, in order to elucidate certain relevant problems, the following calculations were also made:

a) activity in incisors and cuspids as compared with that in premolars and molars,[1]
b) activity in occlusal, proximal, facial and lingual surfaces of previously intact teeth,
c) the frequency of cementum caries.

In these special calculations of the distribution and site of new cavities the third molars were not considered.

No analysis was made of secondary caries or of enlargements of cavities except for the enlargement of certain types of lesions (Cwd, M 1, Rtg) in those groups in which the caries activity was highest.

[1] In the following the terms incisors (inc.) and molars (mol.) denote incisors+cuspids respectively premolars+molars.

The caries frequency in the different groups was calculated as the number of DMF teeth per person. With the aid of the DMF curves it was also possible to compare the present series with those of earlier investigations regarding the state of the teeth at the beginning and at the end of the study period. Here, too, the third molars were excluded.

In order to calculate the activity of caries in these different ways it was necessary to collect extensive data for every patient.

After due codification the data were analysed, usually by the Hollerith punch card system.

Discrepant Recordings

When checking the data for statistical analysis it was observed (QUENSEL, 1948) that cavities recorded in the first or second examination were sometimes missed at the second or third. These registrations had been performed without the examiner knowing what findings had been made on the previous occasion. Therefore, at the fourth examination the examiner dictated the number and site of cavities to the secretary who had the records before her and who checked the findings with the entries made at previous registrations. She reported any cavities that had been previously noted but now missed. In this way all entries made at previous examinations were checked and corrected (QUENSEL, 1948).

However, it was found at still later examinations that cavities sometimes appeared at the same site and with the same Moulage number as before on some surfaces for which correction had been made at the fourth examination. The dental records of the entire series were again checked in 1949 for discrepant recordings. It was found that cavities found in the earlier part of the investigation had fairly often been missed later. The seriousness of this source of error must receive attention.

By repeated examinations of the same patient some inconsistent recordings must probably be expected (Table 3). All variants from 1 to 5 will be referred to here as discrepancies. In certain cases such as 1 and 2 the variation is surely due to recording errors, but it is questionable whether this assumption will hold good for types 3—5.

This variation may be a serious source of error in studies based on differences in the number of newly carious surfaces recorded at conse-

TABLE 3

Examples of theoretically possible discrepant recordings

Variant	Examination								
	1	2	3	4	5	6	7	8	9
1	Cav.	—	—	—	—	—	—	—	—
2	Cav.	Cav.	Cav.	—	Cav.	Cav.	Cav.	Cav.	Cav.
3	Cav.	Cav.	Cav.	—	—	Cav.	Cav.	Cav.	Cav.
4	—	Cav.	—	—	—	Cav.	Cav.	Cav.	Cav.
5	—	—	—	—	Cav.	—	—	—	—

cutive examinations, when e. g. cavities detected at the second but missed at the third, fourth and fifth are recorded as new cavities at the sixth examination. In view of what was said on page 252, only those cavities appearing in surfaces found intact at all the previous examinations should be classed as new.

Correction for Discrepancies

The method used will be best understood from a few examples (Table 4).

In patient C 7 five cavities had been registered at two of the first, second or third examinations, but the surfaces had been considered non-carious at the fourth examination. In patient C 10 one cavity had been excluded (mes.). One cavity (dist.) had been recorded as new at the third examination and was again recorded at the fourth. It was then missed at the fifth and sixth and recorded again at the seventh, at which it was classed as *new*. In a case like this, it may with certainty be assumed that the cavity recorded at the seventh examination was *not* new. This also applies to the cavities excluded in patients C 7 and C 10 at the fourth examination but which later "re-appeared" at the same site and with the same Moulage number.

At the fifth, sixth and seventh examinations of these patients, then, there were 6, perhaps 7, "new" cavities which were in reality old cavities that had been missed at some of the previous examinations. In view of the findings made at later examinations, one is tempted to believe that too many cavities had been excluded by the correction made during the fourth examination. The cavities were observed at two independent examinations and each time they were given the same Moulage number, which strongly suggests that the cavities really existed. Every dental surface recorded at any single examination as decayed was therefore also afterwards considered as carious (Table 4). This infers that the number of surfaces recorded as intact at the fourth and subsequent examinations was fictitiously low. This in turn also means that the number of new cavities recorded was, if anything, too low. Thus the caries activity

figures deduced from the records will be slightly too low throughout, but this is no disadvantage, as it will only strengthen the reliability of any differences found.

As mentioned, the correction was entered as a capital red K in the tooth records. In patients C 7 and C 10, for example, this means that the number of new cavities recorded as such at the sixth and seventh examination was smaller than it would have been if the correction made at the fourth examination had been allowed to stand (Table 4).

In an investigation of this type it is of interest to know not only whether a cavity has developed but also *when*. As far as proximal cavities are concerned, such information is usually obtainable from the X-ray films. In some cases later knowledge of the presence of a definite cavity facilitates a more reliable interpretation of small differences in the density of the enamel shadow which would not by themselves be sufficient to class a surface as carious. Therefore the X-ray films of all of the proximal cavities were reviewed. If earlier changes could be demonstrated at the site of the cavities, the entries in the tooth records were corrected in the manner exemplified for patients C 20 and C 24 in Table 4.

Frequency of Discrepancies

At inspection of the tooth records for discrepant recordings in 1949, altogether 1,125 surfaces had been recorded as decayed in at least one of the first 7 examinations in the Caramel Group (which included a slightly larger number of patients than that of the Caramel Group of the main material 1946—1951). Of these cavities, 797 had never been missed after discovery. The remaining 328 surfaces had at one examination or other been missed. Of these, 140 were found to be caries-free and 188 decayed at the seventh examination.

In 106 of these 328 cases the cavity had been missed at one examination only. When a recorded cavity had afterwards been missed more than once, the cavity was classed in 71 cases as "new" in subsequent recordings.

At the seventh examination and before correction, 153 of the surfaces in the Caramel Group had been classed as newly carious. Of these, 19 cavities (12.4 per cent) were of the type: cavity, missed cavity, "new" cavity. The true number of newly involved surfaces after the correction was thus 134.

The frequencies given above are based on the total number of discrepancies including those observed at the seventh examination. It was thought of interest to know how the number of these surfaces marked with a red K, varied from one examination to another. Table 5 shows that most of these discrepancies are referable to the first three examinations. The number of surfaces for which the recordings required correction was low (2—3 per cent) in comparison with the total number examined.

TABLE 4

Examples of the effect of correction of discrepancies on the number of new carious surfaces noted

Pat. Nr.	Tooth	Surface	Moulage number recorded																	
			According to correction at fourth examination									According to successive correction								
			1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
C 7	8—	o	—	1	1	—	—	—	**1**	1	1	—	**1**	1	K	K	K	1	1	1
	4+	o	—	1	1	—	**1**	1	1	1	1	—	**1**	1	K	1	1	1	1	1
	+4	o	—	1	1	—	**1**	1	1	1	1	—	**1**	1	K	1	1	1	1	1
	6—	b	—	**63**	*63*	63	63	—	—	—	—	—	**63**	K	63	63	K	K	K	K
		d	91	91	—	—	—	**16**	16	16	16	91	91	K	K	K	16	16	16	16
	—4	o	1	1	—	—	—	—	**1**	1	1	1	1	K	K	K	K	1	1	1
C 10	1—	m	—	—	55	—	—	—	**56**	56	56	—	—	**55**	K	K	K	56	56	56
		d	—	—	**56**	56	—	—	**56**	56	56	—	—	**56**	56	K	K	56	56	56
C 20	1+	m	—	—	—	—	—	**31**	33	33	35	—	**Rtg**	*Rtg*	*Rtg*	*Rtg*	31	33	33	35
C 24	+5	o	1	1	1	1	1	1	—	—	X	1	1	K	1	1	1	K	K	X
		d	—	—	—	—	**13**	13	16	16	X	—	—	**Rtg**	*Rtg*	13	13	16	16	X

1, 2 etc. — recordings rejected at fourth examination
Italics — corrections inserted at fourth examination
Rtg — recordings inserted at re-examination of the radiographs
Bold print indicates new cavities

K designates a surface in which a cavity has been demonstrated at an earlier examination but overlooked at later examinations or found doubtful

TABLE 5

Relative frequency of corrections (K) for discrepancies in recording. The Caramel Group of the main material

	Examination Nr.							
	2	3	4	5	6	7	8	9
Number of new K	91	166	36	16	17	7	9	26
Number of K noted earlier		55	136	146	139	118	85	74
Total K	91	221	172	162	156	125	94	100
Number of intact surfaces			5411	5330	5230	5020	4698	4567
K in per cent of intact surfaces			3.2	3.0	3.0	2.5	2.0	2.2

It was interesting to note that the discrepancies were commonest for cavities of type M 91 and M 92 ("arrested caries") neither of which, however, were classed as new lesions in the present study of caries activity. Then came M 1 with 20.5 per cent of the total number of discrepancies, roentgen caries with 13.7 per cent and caries without defect with 5.0 per cent. However, these frequencies tell us only little, because the types of cavities under consideration are the most common. Although an account is given of only one patient group, in which caries activity was high, the distribution of discrepancies was found to be roughly the same in the others.

Discrepant recordings of the kind described above have probably often been observed in long-term studies of caries (BOYD, 1950), although it is seldom mentioned in the literature.

In a series of the present type, i. e. in which it is difficult to examine the patient, the frequency of discrepant recordings must be fairly high. The effect of this source of error has, however, been essentially eliminated by the correction performed. This correction, which was done in part long after the examination, would not have been possible if the recording had not been made by the Moulage System.

It should, however, be stressed that these discrepancies need not

be ascribable entirely to missed cavities. They may be an expression of a true variation in the course of the disease shown by morphologic changes of the carious lesions, which though slight, may be of considerable biologic importance. This directs one's thoughts to the "healing" and to the arrest of caries.

ACCURACY OF RECORDING METHOD

This point received special attention by QUENSEL *et al.* (1954) here only the size of the error of the method will be accounted for.

In a series of persons with low caries activity (at most 3 new carious surfaces per year) the error of a single observation is of the magnitude of 1 carious surface. The standard error of the mean caries activity, as judged by observations made in 40—50 persons will be in the range of 0.2 new carious surface per person per year.

If the activity is still higher (4—6 new carious surfaces per person per year) the error of a single observation will be 2 new carious surfaces. The standard error of the mean of 40—50 persons will be about 0.5 new carious surface per person per year.

2. The Periodontium and Tooth Position

The state of the periodontium was also recorded at the beginning of the study. In the analysis of these data, which has not yet been performed, attention must be directed to the accuracy of the method. The frequency of gingivitis and periodontitis was fairly high. This might be partly ascribable to the poor oral hygiene. As the average age of the series was fairly high, the changes were sometimes advanced and led to the loss of teeth. Of the surfaces lost in this way during the 1946—1951 period, 7.9 per cent were due to periodontitis.

In order to record malocclusions impressions were taken and models were made in plaster of Paris. These models were then studied in order to get an idea of frequency and types of anomalies. This study showed that the groups did not differ essentially from one another regarding the anomalies under consideration.

3. Plan of the Investigation

The Vipeholm dental caries investigation proper consists to date of 4 consecutive studies (the Preparatory Period, the Vitamin Study and the Carbohydrate Studies I and II). During each of these study periods the subjects in one group were compared with those in another. This type of comparison will be referred to as *inter-group comparison.* But the subjects belonging to each of these groups and living under conditions varying from one experimental period to another were also compared. The advantage of this procedure is that the comparisons are made throughout in the same patients and the effect of individual variation on the statistical analysis diminished. This type of comparison will be referred to as *intra-group comparison.*

During each of these four study periods the subjects were repeatedly examined for carious lesions, which were then recorded for the calculation of caries activity. It was originally intended to carry out the individual trial for equal periods, i.e. 1 year or for multiples of such a period; this would facilitate the appraisal of caries activity, which is best expressed as the number of new cavities per person per year. As the interval between any two consecutive study periods was never more than about a month, the lesions recorded at the end of one study period were taken as the starting values of the text. (The interval of 1 month between the study periods was necessary for carrying out preliminary analyses of the observations made and for planning final details of the procedure to be followed during the next study period.)

The studies covered the following periods (see also Fig. 5):

Preparatory Period	March 1945—Jan. 1946
Vitamin Study Period	Jan. 1946—July 1947
Carbohydrate Study Period I	July 1947—July 1949
Carbohydrate Study Period II	July 1949—July 1951

DENTAL EXAMINATIONS

The entire material was first dentally examined in as short a time as possible (main registration). In addition, some groups were examined at shorter intervals for special purposes (supplementary registration). (See Fig. 5.)

At the first three examinations the examiners had no reference to the patients' dental cards. In order to diminish the risk of missing any earlier defects, from the fourth examination on the examiners had before them the dental cards containing records of earlier findings.

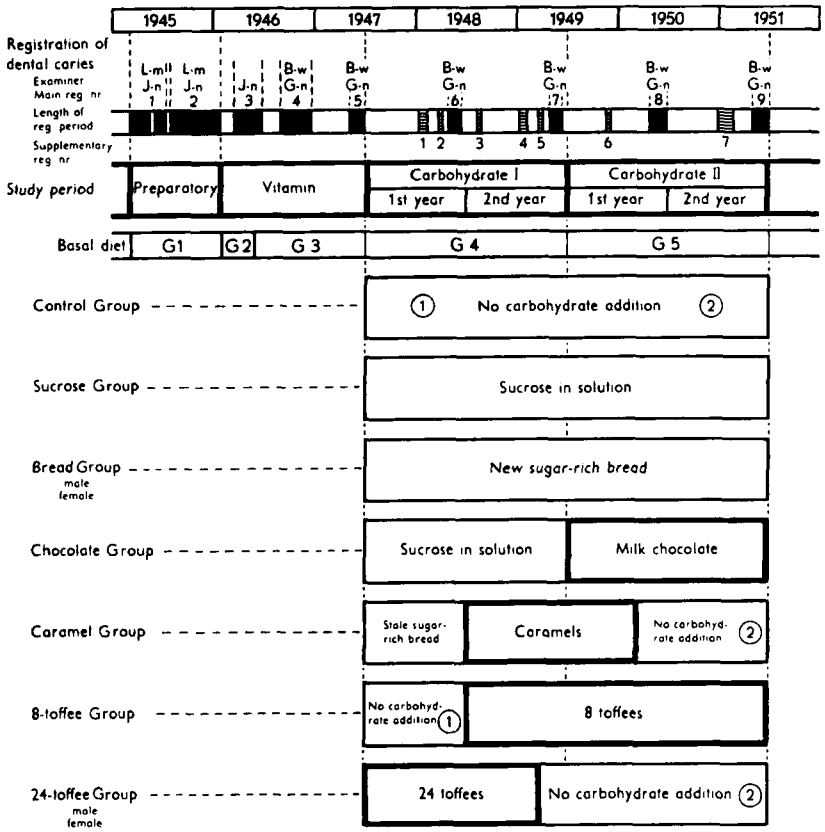
All the main dental recordings were performed by two dentists (Bonow and Grahnén) except the first three, which were carried out by two others (Lindholm and Jacobsson). In supplementary recordings three dentists participated (Bonow, Grahnén and Krasse).

As the first three examinations were performed in a different way (without knowledge of earlier cavities) from those carried out later, when the examiner had the subject's dental card before him, and as all of the main examinations from the fourth on were done by the same examiners, *only observations made at the fourth and subsequent examinations will be considered here.* As the fourth examination was carried out in the middle of the Vitamin Study Period, only those observations made during the latter half of that period i. e. 9 months instead of 18 will be accounted for. Therefore, in order to calculate the number of new carious lesions per year, the figures found should, by rights, have been multiplied by 1.3. However, in view of the magnitude of the error of the method, which is independent of the length of the study period, it was decided to refrain from such correction, because it might cause undue changes in the distribution of the patients with respect to caries activity.

DESCRIPTION OF THE GROUPS

Every department had its own initials and numbers before the time of the present investigation. In this presentation, however, the departments will not be referred to by these designations but by descriptive names (see Fig. 5 and Table 6). Two departments, for example, received a dietary addition of a special type of bread throughout the investigation and were therefore termed the Bread Groups. In certain cases, the subjects were first taken as an inactive control group and afterwards received an experimental variable (chocolate) that caused an increase in caries activity. As the main point of interest in this group was the reaction ob-

MAIN DIAGRAM
of the Vipeholm Dental Caries Study



1 150 g. margarine as caloric compensation.
2 40 „ „ „ „ »

Fig. 5.

served during the latter period, it was named the Chocolate Group, despite the fact that it was originally (during Carbohydrate Study Period I) a kind of control group. Another reason why this type of nomenclature was chosen was that the relationship between caries activity and the experimental variable is based mainly on intra-group comparison. The hospital designations and the descriptive names of the various groups are summarised in Table 6.

BASIC DIETS AND DIETARY SUPPLEMENTS

The Preparatory Period

March 1945—January 1946. That year the diet (G 1) consisted of the ordinary hospital diet.

The Vitamin Study

The basic diet G 2 for the period 15.1.1946 to 1.6.1946 contained 2800 calories per person per day. This diet was replaced on 1.6.1946 by diet G 3, which was a slight modification of diet G 2 and which was continued until the end of the Vitamin Study Period in 1947. The nutritional values of the various diets are summarised in Table 7.

The main purpose of the vitamin trial was to find out whether inbalance of the amounts of vitamins ingested was capable of producing any changes in caries activity. The basic diet therefore contained an adequate amount of all nutritional constituents and the supplements were usually given as an extra daily dose. Thus one group received an excess amount of vitamin A, another of vitamin C, etc. Some groups received supplements of all the vitamins to compensate the imbalance of the amounts of vitamins. Supplementary calcium and fluorine were also studied for any caries inhibiting effect. One group received calcium as the lactate, one group received a daily dose of 1 mg. fluorine in the form of a sodium fluoride tablet. Another group received 1 mg. fluorine in the form of bone meal that was spread on the bread. The control groups consisted of two wards in which the subjects received the basic diet only. The various groups and the dietary supplements are summarised in Table 6.

CARBOHYDRATE INTAKE DURING THE VITAMIN STUDY PERIOD

Carbohydrates were supplied mainly in the form of potatoes (500 g. per day) and white, soft bread (200 g. per day). The daily amount of refined sugar used in the preparation of the basic diet was 60 g. per person. The daily carbohydrate intake per person was thus 350 g., the total sugar content of which was 90 g. (Table 8). The subjects received nothing between the meals.

TABLE 6. General survey of the study

Unless otherwise stated all dietary supplements were served at meals

Group	Number of patients	Department	Vitamin Study Basic diet G_3: 3000 kcal [1]) 1946–1947	Carbohydrate Study I (CH I) Basic diet G4: 1800 kcal [3]) 1st year (CH I: 1) 1947–1948	Carbohydrate Study I (CH I) Basic diet G4: 1800 kcal [3]) 2nd year (CH I: 2) 1948–1949	Carbohydrate Study II (CH II) Basic diet G5: 2760 kcal 1st year (CH II: 1) 1949–1950	Carbohydrate Study II (CH II) Basic diet G5: 2760 kcal 2nd year (CH II: 2) 1950–1951	Sugar consumption during the Carbohydrate Study: Sugar in less sticky form	Sugar consumption during the Carbohydrate Study: Sugar at meals	Sugar consumption during the Carbohydrate Study: Sugar in sticky form	Sugar consumption during the Carbohydrate Study: Sugar also between meals
Control Group	60	A_{3-4} D_{1-2}	Ca A+C+D; Ca	**No supplementary carbohydrates** Calorie compensation 150 g margarine + [2])		40 g margarine					
Sucrose Group	57	C_{3-4}	1 mg F (tablet, swallowed whole)	**Sucrose in solution** 300 g + [2])		75 g					
Bread Group male	41	D_{3-4}	A	**New high-sugar bread 345 g** at one meal		substitutes basic diet bread					
female	42	K_{3-4}	—								
Chocolate Group	47	B_{1-2}	D	**Sucrose in solution** 300 g + [2])		**Milk chocolate** 65 g in 4 portions between meals					
Caramel Group	62	B_{3-4}	C	**Stale, high-sugar bread 345 g** at one meal	**22 caramels** 155 g between meals + 200 g sugar in sol. + [2])	155 g in 4 portions between meals (10 % red. of basic diet)	**No suppl. carbohydr.** Calorie compensation 40 g margarine				
8-toffee Group	40	A_{1-2}	—	**No suppl. carbohydr.** Calorie compensation 150 g margarine + [2])	**8 toffees** 60 g between meals + 250 g sucrose in sol. + [2])	60 g in 4 portions between meals + 25 g sucrose in sol.					
24-toffee Group male	48	C_{1-2}	1 mg F (bone meal)	**24 toffees** 180 g between meals + 150 g sucrose in sol. + [2])		**No suppl. carbohydr.** Calorie compensation 40 g margarine					
female	39	K_{1-2}	A+C+D; Ca								

[1] The supplements during the Vitamin Study have been given in ordinary symbols. Vit. A = 8000 I.U.; C = 100 mg; D = 2000 I.U.; 0.8 g Ca as calcium lactate. [2] One tablet daily containing: 1 mg vit B_1; 0.6 mg vit. B_2; 8 mg niacine and 8 mg Fe. [3] Daily supplement of rose hip powder corresponding to 20 mg vit. C.

TABLE 7

Nutritional value of basic diets G3, G4 and G5
(per person per day)

		Vitamin Study	Carbohydrate Study		Nutritional standard in Sweden 1940 [2]
			I	II	
		G3	G4 [1]	G5	
Calories	kcal	3000	1800	2700	3791
Fat	g	125	98	88	148
Carbohydrates	g	349	130	366	483 [3]
Proteins	g	93	85	87	90
Calcium Ca	g	0.9	0.9	0.9	1.1
Phosphorus P	g	1.6	1.4	1.7	1.6
Iron Fe	mg	12.6	9.9	14.5	15
Vitamin A	I.U.	2700	3200	2900	3300
Vitamin B_1	mg	1.2	0.9	1.6	1.5
Vitamin C	mg	43	45	63	73

[1] During CH I one tablet daily containing: 1 mg vit. B_1; 0.6 mg vit. B_2; 8 mg niacine and 8 mg Fe. Rose hip powder corresponding to 20 mg vit. C.
[2] ABRAMSON (1946) page 125.
[3] > 20 per cent as refined sucrose.

Carbohydrate Study Periods

The purpose of these studies was to assess the effect of the oral retention of sugar on caries activity. In order to find out whether such retention is capable of accelerating caries, large amounts of sucrose (twice the total Swedish consumption) were employed during Carbohydrate Study I. During Carbohydrate Study II the amount of sucrose was roughly the same as the average total Swedish consumption. With the exception of these quantitative discrepancies the principles in the planning of the Carbohydrate Studies I and II were essentially the same.

BASIC DIETS

The basic diet G 4 [1] during Carbohydrate Study I had a caloric value of 1800 kcal and contained all the nutritional substances generally believed to be necessary for the diet to be adequate (Table 7). The amount of sucrose used in the preparation of the

[1] Worked out by State Institute for Public Health under the supervision of Professor E. ABRAMSON and Professor E. BRUNIUS.

TABLE 8. *Carbohydrate ration in the different types of diet (g per person per day)*

Conditions		Starch + dextrin		Sugar								Total carbohydrates		
				Mono- and disaccharides in foodstuffs		Added sucrose			Total sugar					
Basic diet	Supplements	At meals	Btw. meals	At meals	Btw. meals	At meals	Btw. meals	Total	At meals	Btw. meals	Total	At meals	Btw. meals	Total
G 3	No suppl. carbohydrates	260	—	30	—	60	—	60	90	—	90	350	—	350
G 4	No suppl. carbohydrates (150 g margarine)	100	—	30	—	—	—	—	30	—	30	130	—	130
	300 g sucrose in sol.	100	—	30	—	300	—	300	330	—	330	430	—	430
	345 g high-sugar bread at one meal	250	—	30	—	50[1]	—	50	80[1]	—	80	330	—	330
	22 caramels + 200 g sucrose in sol.	100	30	30	40	200	30	230	230	70	300	330	100	430
	8 toffees + 250 g sucrose in sol.	100	10	30	10	250	30	280	280	40	320	380	50	430
	24 toffees + 150 g sucrose in sol.	100	40	30	40	150	80	230	180	120	300	280	160	440
G 5	No suppl. carbohydrates (40 g margarine)	260	—	50	—	70	—	70	110	—	110	370	—	370
	75 g sucrose in sol.	260	—	50	—	140	—	140	190	—	190	440	—	440
	345 g high-sugar bread (subst. basic diet bread)	270	—	50	—	110[1]	—	110	160[1]	—	160	430	—	430
	65 g milk chocolate	260	—	50	10	70	20	90	110	30	140	370	30	400
	22 caramels	230	30	40	40	60	30	90	100	70	170	330	100	430
	8 toffees + 25 g sucrose in sol.	260	10	50	10	90	30	120	140	40	180	390	50	440

[1] 50 g sucrose in sticky form.

food was reduced as far as possible (1 g. per person per day), inter alia by employing saccharine instead of sugar in the preparation of the food.

The basic diet was on the whole poor in carbohydrates owing to the low sugar- and starch content of the constituents. The most important sources of carbohydrates were the bread ration (80 g. white bread per day) and the potato ration (250 g. per day). In order to get a constant level of vitamins A and D, milk powder was used instead of milk in the preparation of the food. The beverages drunk at meals consisted of a weak malt drink, coffee or cocoa. This diet differed from an ordinary Swedish menu in that part of the mineral and vitamin requirements were filled either by a tablet given once a day in all groups except the bread group or by a ration of dry powdered hips that was sprinkled on the food (Table 7).

The basic diet G 5 during Carbohydrate Study II was roughly representative of Swedish standards.

The composition of the basic diet and the amount of some of its constituents are given in Table 7.

The daily caloric value of the basic diet was 2700 and the daily carbohydrate intake, 370 g., roughly the same as that given during the Vitamin Study.

The total consumption of sugar was about the same as during the Vitamin Study, or 110 g. per day. The other main sources of carbohydrates were bread (245 g.) and potatoes (370 g.). Basic diet G 5 contained much larger quantities of these foodstuffs than diet G 4.

During this period milk was used (not milk powder) and no supplementary vitamins were given.

TYPES OF DIETARY REGIMES

Experimental variables were introduced by supplementary foodstuffs (see below) with a caloric value of 1200 during Carbohydrate Study I and 300 during Study II. In this manner each of the groups was placed on a dietary regime with at total caloric value of 3,000, which included different components to be studied for their effect on caries activity (see Fig. 5, Tables 6 and 8).

A. *Diet with only slight retention tendency of the sugar*

Basic Diet. No supplementary carbohydrates

A caloric intake of 3,000 kcal per day was secured by the addition of 150 g. non-vitaminised margarine during Carbohydrate Study I and 40 g. margarine during Carbohydrate Study II. The margarine was spread on the bread, but part of it had also to be added to the food during Carbohydrate Study I.

Basic Diet + sugar in solution

During Carbohydrate Study I a daily ration of 300 g. sugar was given partly as an addition to the beverages drunk at meals and partly to the food after it had been prepared. It was intended to add the entire ration to the drinks only, but this proved hardly possible.

During Carbohydrate Study II a 50 per cent solution of sucrose was prepared in the central kitchen. Such quantities of this solution were then added to the beverages consumed at meals that every subject received 75 g. supplementary sugar per day. This guaranteed that the supplementary sugar was really given in solution during this period.

B. *Diet with a pronounced retention tendency of the sugar*

a. *Sugar in sticky form at meals*

Basic Diet + new bread with high sugar content

Each subject received 345 g. of bread containing 50 g. of refined sugar. The composition is given in Tables 9 and 10. Bread of this type is widely consumed in Sweden in the afternoon with coffee. During Carbohydrate Study I the subjects received this bread once a day with coffee in the afternoon. Most of the patients ate the bread first and drank their coffee afterwards. In order to secure a high degree of "stickiness" the bread was served very fresh.

During Carbohydrate Study II all bread in the basic diet was replaced by the sweet type, which was thus served at *all* meals.

TABLE 9

Composition of additional sweets and bread during carbohydrate studies

Calculated on the basis of the ingredients

	Protein %	Fat %	Carbohydrate %	Ca %	P %
Toffee	—	2.2	87.6	—	—
Caramel	8.4	13.3	67.2	0.23	0.19
Milk chocolate	9.1	35.7	50.0	0.27	0.21
High-sugar bread	5.9	12.7	57.4	0.01	0.05

Average weight of toffee 7.18 g.
„ „ „ caramel 7.11 g.

Basic Diet+stale bread with high sugar content

During Carbohydrate Study I bread of the sweet type was stored for at least 24 hours, after which it was served once a day to the afternoon coffee. No stale bread was used during Carbohydrate Study II.

b. *Sugar in sticky form between meals*

Basic Diet+pieces of chocolate

Chocolate was given only during Carbohydrate Study II and ordinary commercial milk chocolate was used. The composition

TABLE 10

Carbohydrates of additional sweets and bread

	Calculated on the basis of the ingredients						Analysis (average)
	Starch + Dextrine %	Sucrose %	Lactose %	Maltose %	Monosaccharides %	Total sugar (as monosaccharides) %	Total sugar (as monosaccharides)
Toffee	21.9	44.4	—	12.2	9.1	68.6	70
Caramel	19.9	19.0	9.3	10.9	8.1	49.3	51
Milk chocolate	3.5	35.7	10.8	—	—	48.8	48
High-sugar bread	42.6	14.5	—	—	—	15.2	13

of the chocolate is given in Tables 9 and 10.The chocolate ration (65 g.) corresponds to 30 g. sugar.

Basic Diet+caramels (max. 22)

These caramels were of the same type as those sold in shops. The quantities placed at our disposal by the manufacturers had been taken directly from ordinary stock. The composition of these caramels is given in Tables 9 and 10. The amount given (about 160 g.) corresponds to 100 g. carbohydrate per person per day, of which 70 g. consists of different sugars. Furthermore, in order that the total carbohydrate supplement would be the same as that in the Sucrose Group (Table 8) every person received 200 g. sugar in solution per day.

During Carbohydrate Study II the amount of sugar in the caramels corresponds to the 75 g. given in the Sucrose Group. Therefore no additional sucrose in solution was given during this period. An increase in body weight was soon noted for the patients, for which reason the daily ration of the basic diet was decreased by 10 per cent.

Basic Diet+toffees (max. 8)

As it was desired to study the effect of sticky *sugar* in as pure form as possible, the binders and other ingredients used in the manufacture of ordinary toffee and sweets were omitted. The toffees were prepared especially for the investigation, and their composition is given in Tables 9 and 10. These toffees therefore differed somewhat from the ordinary types of Swedish sweets, but they resembled English toffees.

The 8 toffees (about 60 g.) correspond to 50 g. carbohydrates, of which 40 g. were various sugars. In order to bring up the total carbohydrate supplement to the same level as in the Sucrose Group 250 g. of sugar in solution were given during Carbohydrate Study I. During Carbohydrate Study II 25 g. sucrose in solution were given for similar reasons.

Basic Diet+toffees (max. 24)

This group represents, like the Caramel Group, a practically unrestricted consumption of sweets. The toffees were of the same type as those used for the 8-toffee Group.

The amount of sweets given (about 180 g. per day) corresponded to about 160 g. carbohydrate per person per day, of which 120 g. consisted of sugars. An additional ration of 150 g. sucrose in solution was given for the same reasons as described above.

This regime with practically unrestricted consumption of toffees was used only during Carbohydrate Study I.

DAILY ROUTINE

During Carbohydrate Study I the subjects received the sweets after meals, one half was served after breakfast, the other half after lunch. During Carbohydrate Study II the sweets were given in 4 portions. Many of the patients ate their entire ration as soon as they got it. Many of them ate two or three sweets at a time, some even swallowed them without chewing and some ate no sweets at all. The patients themselves decided how much of their ration they wanted to eat, and therefore the actual consumption varied widely. This point will be reverted to in connection with the presentation of the results. (Cf. the survey-tables for the different groups.)

The daily routine during Carbohydrate Study II was the same as that in the earlier periods except regarding the distribution of sweets:

Awakened	6.30 a. m.
Breakfast	7.30
Distribution of 1/4 of daily ration of sweets	9.30
Distribution of 1/4 of daily ration of sweets	10.30
Dinner	11.30
Distribution of 1/4 of daily ration of sweets	1.30 p. m.
Distribution of 1/4 of daily ration of sweets	2.30
Coffee	3.15
Supper	5.30
Bed-time	6.00

CONTROL OF EXPERIMENTAL CONDITIONS

None of the patients in the Vipeholm investigation were requested or encouraged to eat more of the sweet additions than they desired. It was therefore necessary to check how much of the

supplements really was consumed. This was done in the following ways:

1. Any changes in the general condition of the patient and changes in appetite or amounts of supplements consumed were noted in special forms issued to every department and returned to the Station at the end of the month.

2. Dietary supplements given in the wards were supplied by the central store and kitchen, where an account was kept of all supplies issued.

3. All waste and food returned from the departments was weighed from time to time and studied in order to find out whether the calorie supply was too high or whether the dietary supplement appealed to the taste of the patients.

4. Individuals selected at random were occasionally observed regarding the amount of the ration they consumed.

5. At the main dental examinations the personnel in charge was also questioned about how much of the dietary supplement the patient generally ate.

4. Control of the General Condition

The patients were under the daily observation of departmental physicians, who co-operated with the Station. During the Vitamin Studies and Carbohydrate Study I, a special physician was employed for the purpose of controlling the general condition of the patients. The methods used have been described by FRÖDERBERG (1952). In addition, a large number of laboratory tests were performed (SWENANDER LANKE, 1952; survey: HÖJER & MAUNSBACH, 1954). The purpose of these laboratory tests was to check any extra-oral effects of the experimental conditions.

RESULTS AND DISCUSSION

Survey

The results are summarised in the main tables recording the caries activity on Westin's 100 index surfaces (Table 11), caries activity for all surfaces (Table 12) and caries development calculated on the basis of the number of DMF teeth (Table 13 and Fig. 6, page 284).

As the risk of caries is more uniform for Westin's index surfaces, all statistical analyses were based on the values noted for caries activity observed in these surfaces. Tables 11 and 12 show that the activity figures calculated on Westin's index surfaces and on all 148 surfaces run parallel, though with the natural difference that the former are slightly lower than the latter. Tables 11 and 12 also show that in the present material a large number of intact surfaces per unit of time were lost for reasons other than primary caries, e. g. involvement of neighbouring surfaces by existing cavities, fractures, extractions and periodontitis. It would therefore have been misleading if caries activity had been estimated only by calculating it from the difference between two determinations of the number of surfaces lost. The total surface losses distributed among the causes are accounted for in Table 12.

As a background to the following statistical analysis of every group of patients, it might be convenient to give a general survey of the results.

General Condition

Reports of the general condition of the patients during the investigations described here have been presented by FRÖDERBERG (1952) and SWENANDER LANKE (1952). It was shown, *inter alia*, that the morbidity of tuberculosis markedly decreased during the investigation. The mortality also showed a tendency to decrease. Bodyweight showed a slow but definite increase in the entire material (Table 14), and was most marked during Carbohydrate Study II.

The Vitamin Study

At the beginning of the Vitamin Study Period accounted for here, the patients had on the average 15 DMF teeth (Table 13). The number of intact surfaces (Westin's index surfaces) ranged from 53 to 68 per person in the various departments. These values for the frequency of caries showed that the state of the teeth at the beginning of the investigation was better in this material than in the population as a whole. According to WESTIN & WOLD (1943), military conscripts aged 20 had 18.44 carious teeth per individual and a Westin's caries index of 0.37.

During the Vitamin Study, when the patients received a diet relatively low in sugar and no additional sugar between meals, the average caries activity was 0.34 new carious surfaces per patient per year, calculated on Westin's index surfaces (Table 15). This average is, however, somewhat too low (see page 262), because the period was shorter than one year.

A statistical analysis of caries activity gave the following results. Comparisons of the occurrence of new caries in the various departments showed an χ^2-value of 7.13 (8 degrees of freedom), which corresponds to a probability of $P > 50$ per cent for the differences between the departments being ascribable to chance. The results obtained by the analysis of variance are given in Tables 15 and 16. Even by this analysis, the differences between the departments appear to be due to chance.

The analysis thus showed no difference in caries activity between the different groups of patients during the Vitamin Study. Tables 11 and 12, however, show that the average number of new cavities per group of patients per period varied considerably. The average for all departments was 0.34 new carious surfaces per person per year. The means for the different departments varied between 0.15 and 0.50.

Even occasional cases of relatively many new carious surfaces per person per year are sufficient to increase the mean, often by 0.1 unit. An extreme case was found, for example, in the Caramel Group, where one individual with 13 new carious surfaces increased the mean for that group from 0.28 units to 0.48 units.

Summing up, then, the variation of 0.30 in the averages of new carious surfaces per person per year was not remarkable. This is

TABLE 11. *Number of new carious surfaces per Westin's*

Group	Period	Conditions		Nr. of pers.
		Basic diet	Additions	
Control Group	Vit.	G 3	Vit. A, C, D; Ca	60
	CH I: 1	G 4	150 g margarine	
	: 2	G 4	150 » »	
	CH II: 1	G 5	40 » »	
	: 2	G 5	40 » »	
Sucrose Group	Vit.	G 3	1 mg F in tablet	57
	CH I: 1	G 4	300 g sucrose in sol.	
	: 2	G 4	300 » » » »	
	CH II: 1	G 5	75 » » » »	
	: 2	G 5	75 » » » »	
Bread Group	Vit.	G 3	Vit. A	41
	CH I: 1	G 4	345 g new high-sugar bread at one meal	
male	: 2	G 4	345 » » » » » » »	
	CH II: 1	G 5	345 » » » » » all meals	
	: 2	G 5	345 » » » » » » »	
	Vit.	G 3		42
	CH I: 1	G 4	345 g new high-sugar bread at one meal	
female	: 2	G 4	345 » » » » » » »	
	CH II: 1	G 5	345 » » » » » all meals	
	: 2	G 5	345 » » » » » » »	
Chocolate Group	Vit.	G 3	Vit. D	47
	CH I: 1	G 4	300 g sucrose in sol.	
	: 2	G 4	300 » » » »	
	CH II: 1	G 5	65 » milk chocolate	
	: 2	G 5	65 » » »	
Caramel Group	Vit.	G 3	Vit. C	62
	CH I: 1	G 4	345 g stale high-sugar bread at one meal	
	: 2	G 4	22 caramels + 200 g sucrose in sol.	
	CH II: 1	G 5	22 caramels	
	: 2	G 5	40 g margarine	
8-toffee Group	Vit.	G 3		40
	CH I: 1	G 4	150 g margarine	
	: 2	G 4	8 toffees + 250 g sucrose in sol.	
	CH II: 1	G 5	8 » + 25 » » » »	
	: 2	G 5	8 » + 25 » » » »	
24-toffee Group	Vit.	G 3	1 mg F (bone meal)	48
	CH I: 1	G 4	24 toffees + 150 g sucrose in sol.	
male	: 2	G 4	24 » + 150 » » » »	
	CH II: 1	G 5	40 g margarine	
	: 2	G 5	40 » »	
	Vit.	G 3	Vit. A, C, D; Ca	39
	CH I: 1	G 4	24 toffees + 150 g sucrose in sol.	
female	: 2	G 4	24 » + 150 » » » »	
	CH II: 1	G 5	40 g margarine	
	: 2	G 5	40 » »	

index-surfaces in the main material 1946—1951

Initially intact surfaces	New carious surfaces per period			Distribution of persons according to new carious surfaces per period						
per person	total	per person	per 100 initially intact surfaces	0	1	2	3	4—6	7—9	10 or more
59.5	9	0.15	0.25	52	7	1				
59.1	7	0.12	0.20	53	7					
58.6	4	0.07	0.11	57	2	1				
58.0	34	0.57	0.98	44	10	2	2	1	1	
56.4	26	0.43	0.77	48	7	1	2	1	1	
57.3	21	0.37	0.64	42	11	2	2			
56.8	25	0.44	0.77	39	12	5	1			
56.0	44	0.77	1.38	42	9	2		2	1	1
54.8	40	0.70	1.28	42	7	5	1	1		1
53.4	44	0.77	1.45	46	3	4	2	1		1
56.9	15	0.37	0.64	30	9	1		1		
56.2	7	0.17	0.30	36	4		1			
55.6	18	0.44	0.79	31	8		1		1	
54.8	25	0.61	1.11	32	3	4		1	1	
53.3	82	2.00	3.75	20	9	4	1	2	2	3
61.0	10	0.24	0.39	32	10					
60.4	20	0.48	0.79	31	5	3	3			
59.9	13	0.31	0.52	31	9	2				
59.5	22	0.52	0.88	32	5	3	1		1	
58.7	41	0.98	1.66	29	6	2	3		1	1
53.1	19	0.40	0.76	35	6	5	1			
52.7	9	0.19	0.36	39	7	1				
52.2	11	0.23	0.45	39	5	3				
51.3	52	1.11	2.16	26	11	4	2	2	2	
49.7	58	1.23	2.48	21	12	8	1	3	2	
59.9	30	0.48	0.81	49	7	5				1
58.9	21	0.34	0.58	49	7	4	2			
57.8	119	1.92	3.32	22	15	8	8	5	1	3
55.0	187	3.02	5.48	19	10	7	3	12	9	2
50.9	41	0.66	1.30	39	12	8		3		
68.1	20	0.50	0.73	28	8	2	1	1		
68.4	32	0.80	1.17	24	10	2	3		1	
67.7	121	3.03	4.47	12	11	3	2	8	2	2
64.7	111	2.78	4.29	14	7	4	5	3	5	2
60.3	143	3.58	5.93	9	7	6	3	9	1	5
61.2	16	0.33	0.54	39	4	3	2			
60.3	187	3.90	6.47	18	9	2	3	8		8
55.7	199	4.15	7.44	18	8	1	4	4	4	9
50.5	10	0.21	0.41	40	6	2				
49.4	19	0.40	0.80	33	11	4				
62.7	9	0.23	0.37	33	4	1	1			
62.2	239	6.13	9.85	8	8	2	1	6	5	9
55.5	252	6.46	11.64	1	4	4	5	8	5	12
47.9	11	0.28	0.59	32	5		2			
46.6	15	0.38	0.83	30	4	4	1			

TABLE 12

Surface losses per period according to cause. Calculated on the 148 surfaces in the main material 1946—1951

Group	Period	Number of persons	Initially intact surfaces per person	Intact surfaces lost								
				Total		By primary caries			By enlargement of existing cavities	By extractions and loss of teeth because of		
										Caries	Periodontitis	Other causes[1]
				Number	Per pers.	Number	Per pers.	% of total losses	Number	Number	Number	Number
Control Group	Vit.	60	85.3	49	0.82	10	0.17	20.4	31	3	—	5
	CH I: 1		84.8	65	1.08	9	0.15	13.9	19	—	4	33
	: 2		84.3	41	0.68	8	0.13	19.5	9	4	12	8
	CH II: 1		83.8	145	2.42	36	0.60	24.8	59	—	11	39
	: 2		81.7	100	1.67	28	0.47	28.0	57	8	4	3
Sucrose Group	Vit.	57	81.8	41	0.72	25	0.44	61.0	16	—	—	—
	CH I: 1		81.4	64	1.12	28	0.49	43.8	20	1	3	12
	: 2		80.9	102	1.79	55	0.96	53.9	22	5	6	14
	CH II: 1		79.2	119	2.09	48	0.84	40.3	59	1	11	—
	: 2		77.6	138	2.42	47	0.82	34.1	79	—	4	8
Bread Group	Vit.	41	85.0	54	1.32	23	0.56	42.6	12	4	—	15
	CH I: 1		84.0	70	1.71	12	0.29	17.1	21	3	4	30
male	: 2		82.7	55	1.34	24	0.59	43.6	12	—	4	15
	CH II: 1		81.5	89	2.17	29	0.71	32.6	23	7	24	6
	: 2		79.6	186	4.54	95	2.32	51.1	54	—	27	10
	Vit.	42	88.4	39	0.93	14	0.33	35.9	19	2	4	—
	CH I: 1		87.6	47	1.12	22	0.52	46.8	11	10	4	—
female	: 2		87.3	60	1.43	16	0.38	26.7	32	3	—	9
	CH II: 1		86.5	98	2.33	27	0.64	27.6	62	2	—	7
	: 2		85.5	113	2.69	50	1.19	44.3	31	7	12	13

Chocolate Group	Vit.	47	79.0	49	1.04	21	0.45	42.9	22	6	—	—
	CH I: 1		78.7	45	0.96	11	0.23	24.4	29	3	2	—
	: 2		78.7	71	1.51	17	0.36	23.9	33	7	12	2
	CH II: 1		77.8	113	2.40	61	1.30	54.0	41	10	1	—
	: 2		75.8	127	2.70	66	1.40	52.0	50	11	—	—
Caramel Group	Vit.	62	87.3	81	1.31	31	0.50	38.3	21	—	14	15
	CH I: 1		86.0	105	1.69	26	0.42	24.8	59	6	11	3
	: 2		84.4	215	3.47	134	2.16	62.3	62	2	10	7
	CH II: 1		81.0	342	5.52	220	3.55	64.3	81	11	18	12
	: 2		75.8	151	2.44	50	0.81	33.1	71	17	11	2
8-toffee Group	Vit.	40	96.9	51	1.28	22	0.55	43.1	15	6	4	4
	CH I: 1		97.3	103	2.58	35	0.88	34.0	50	—	—	18
	: 2		95.9	209	5.23	131	3.28	62.7	46	—	21	11
	CH II: 1		92.3	273	6.83	128	3.20	46.9	112	9	14	10
	: 2		87.4	322	8.05	162	4.05	50.3	85	10	54	11
24-toffee Group	Vit.	48	88.1	58	1.21	18	0.38	31.0	13	7	4	16
	CH I: 1		87.1	254	5.29	206	4.29	81.1	20	3	13	12
male	: 2		82.5	312	6.50	220	4.58	70.5	38	8	29	17
	CH II: 1		76.6	103	2.15	16	0.33	15.5	48	14	21	4
	: 2		74.8	201	4.19	24	0.50	11.9	45	79	41	12
	Vit.	39	89.1	32	0.82	9	0.23	28.1	5	3	10	5
	CH I: 1		88.5	308	7.90	269	6.90	87.3	30	3	2	4
female	: 2		81.1	369	9.46	289	7.41	78.3	58	7	10	5
	CH II: 1		72.1	102	2.62	14	0.36	13.7	51	16	14	7
	: 2		69.9	82	2.11	17	0.44	20.7	45	8	4	8
		436		5753		2803		M=48.7	1778	306	454	412

[1] Teeth lost between examinations mainly due to periodontitis.

TABLE 13

Caries frequency in the main material 1946—1951

DMF teeth per person at the main registrations

Group	Nr. of pers.	Vitamin Study		Carbohydrate Study I		Carbohydrate Study II	
				1st year	2nd year	1st year	2nd year
Control Group	60	15.3	15.4	15.5	15.6	16.0	16.3
Sucrose Group	57	16.4	16.4	16.7	17.3	17.6	17.8
Bread Group							
male	41	17.1	17.4	17.6	17.9	18.2	19.2
female	42	14.5	14.6	15.0	15.3	15.5	16.0
Chocolate Group	47	17.7	17.9	18.0	18.1	18.7	19.3
Caramel Group	62	15.5	15.5	15.9	16.9	18.4	18.6
8-toffee Group	40	11.7	12.0	12.3	13.8	15.4	17.1
24-toffee Group							
male	48	15.1	15.4	18.2	19.8	19.9	20.3
female	39	14.1	14.3	18.5	21.1	21.1	21.3

TABLE 14

Average weight (kg.) for the main material 1946—1951

Group	Nr. of pers.	Vitamin Study		Carbohydrate Study I		Carbohydrate Study II	
				1st year	2nd year	1st year	2nd year
Control Group	60	57.6	58.6	58.5	60.2	62.1	62.2
Sucrose Group	57	59.2	58.9	60.1	59.4	61.7	62.2
Bread Group							
male	41	64.8	65.7	67.3	69.8	71.2	74.3
female	42			59.2	58.7	61.5	60.6
Chocolate Group	47	59.2	59.4	61.7	61.5	63.9	65.8
Caramel Group	62	59.4	59.3	61.3	61.9	61.8	61.4
8-toffee Group	40	49.2	47.7	48.5	51.5	53.2	53.4
24-toffee Group							
male	48	57.3	59.3	59.8	59.6	63.7	63.0
female	39			58.1	56.0	57.9	56.8

TABLE 15

Distribution of new carious surfaces during the Vitamin Study. Westin's index-surfaces

Number of new carious surfaces	Number of persons
0	340
1	66
2	20
3	7
4	1
5	1
—	—
13	1
Total: patients	436
» carious surfaces	149
Mean	0.34
Standard deviation	0.91

in conformity with the results obtained on analysis of the error of the method (QUENSEL *et al.* 1954).

The distribution of the patients with regard to caries activity during the Vitamin Study was obviously skew. Thus a very large number, 78 per cent, of the patients had no new carious surfaces per year.

Carbohydrate Study I

The caries activity was high in groups which received sugar in sticky form between meals. In the Control, Sucrose and Bread Groups the activity was still low and of the same order as during the Vitamin Study.

TABLE 16

Statistical analysis of caries activity in the various groups during the Vitamin Study. Westin's index-surfaces. Analysis of variance

	Sum of squares	Degrees of freedom	Variance
Total	360	435	0.828
Within classes	354	427	0.829
Between classes	5.642	8	0.705

Especially remarkable was the development in the Control Group and the later 8-toffee Group, i. e. the groups that received the basic diet plus 150 grams of margarine. During this period, the activity was low in the group with the older patient material, with a mean value of 0.12 and 0.07 new carious surfaces per person. The younger group had 0.80 new carious surfaces per person. Thus, the activity did not drop to nil, despite the fact that the patients had received a diet as sugar-free as was practically possible and a large additional fat ration.

Although the patients in the Sucrose Group received 300 grams of sugar per day, caries activity did not distinctly increase in that group, or in the later Chocolate Group, which, during Carbohydrate Study I, had lived under the same conditions. In the 24-toffee Group, 8-toffee Group, and Caramel Group an increase was observed in the mean caries activity. This increase started immediately after introduction of the experimental conditions. When initial stages are not recorded as caries, there will be a retardation in the increase in dental caries activity: it will be much higher during the second year than during the first.

Carbohydrate Study II

During this period, caries activity in the Control and Sucrose Groups was on the whole on the same level as during the Vitamin Study and Carbohydrate Study I. In the Bread Groups there was a certain increase during the second year of the period.

In the 24-toffee Group, the activity returned to the same low level as during the Vitamin Study in connection with the withdrawal of the addition (and its replacement with fat). This also applies to the Caramel Group, for which the change occurred during Carbohydrate Study II.

The 8-toffee Group persisted at roughly the same activity level as during Carbohydrate Study I. In the Chocolate Group there was a moderate increase in caries activity on the introduction of the chocolate.

In some groups the activity figures recorded are high in relation to the starting values. However, in most cases they are lower than the caries activity demonstrable in school children (cf. GUSTAFSSON & WIBOM 1952).

Caries Frequency as Calculated on the Basis of DMF Teeth

The frequency of caries, based on the number of DMF teeth, is summarised in Fig. 6. The slope of the curve for this number for every patient group shows the caries activity, with the reservation that not all of the teeth were lost because of caries.

For the groups and for the times during which sugar was given with the meals, the DMF curves showed a slope, at different levels, of about 20 degrees in the scale used (exception: the Bread Group, second year of Carbohydrate Study II). Even though this slope is due partly (<10 per cent, see Table 12) to periodontitis, it is thus remarkable that the caries activity in the material was about 0.3 new DMF teeth per person per year on the whole independently of the experimental variables used when sugar was given only in a form with a slight tendency to be retained in the oral cavity.

A different and larger angle, and thereby higher caries activity, was noted when the sugar was given between meals in a form with a strong tendency to be retained. The curves recovered their usual slope as soon as the consumption of sweets between meals was stopped, as was the case in the 24-toffee Group and the Caramel Group.

Observations made in the male Bread Group during the second year of the Carbohydrate Study II were also remarkable. The slope for the DMF curve was now the same as that for the Caramel Group and greater than for the Chocolate Group, both of which had received sugar between meals. The female group studied under the same conditions showed only a tendency to a change in the slope of the curve.

Intra-Group Comparisons

The account given above can only convey a general impression of the results obtained: it tells us nothing about which changes should be attributed to the experimental variables and which changes should be ascribed to chance. Elucidation of this point requires a statistical analysis of the data.

The purpose of the statistical analysis presented was to answer the main problems of the investigation on the basis of caries activity data for the groups as entities. Where changes have been esta-

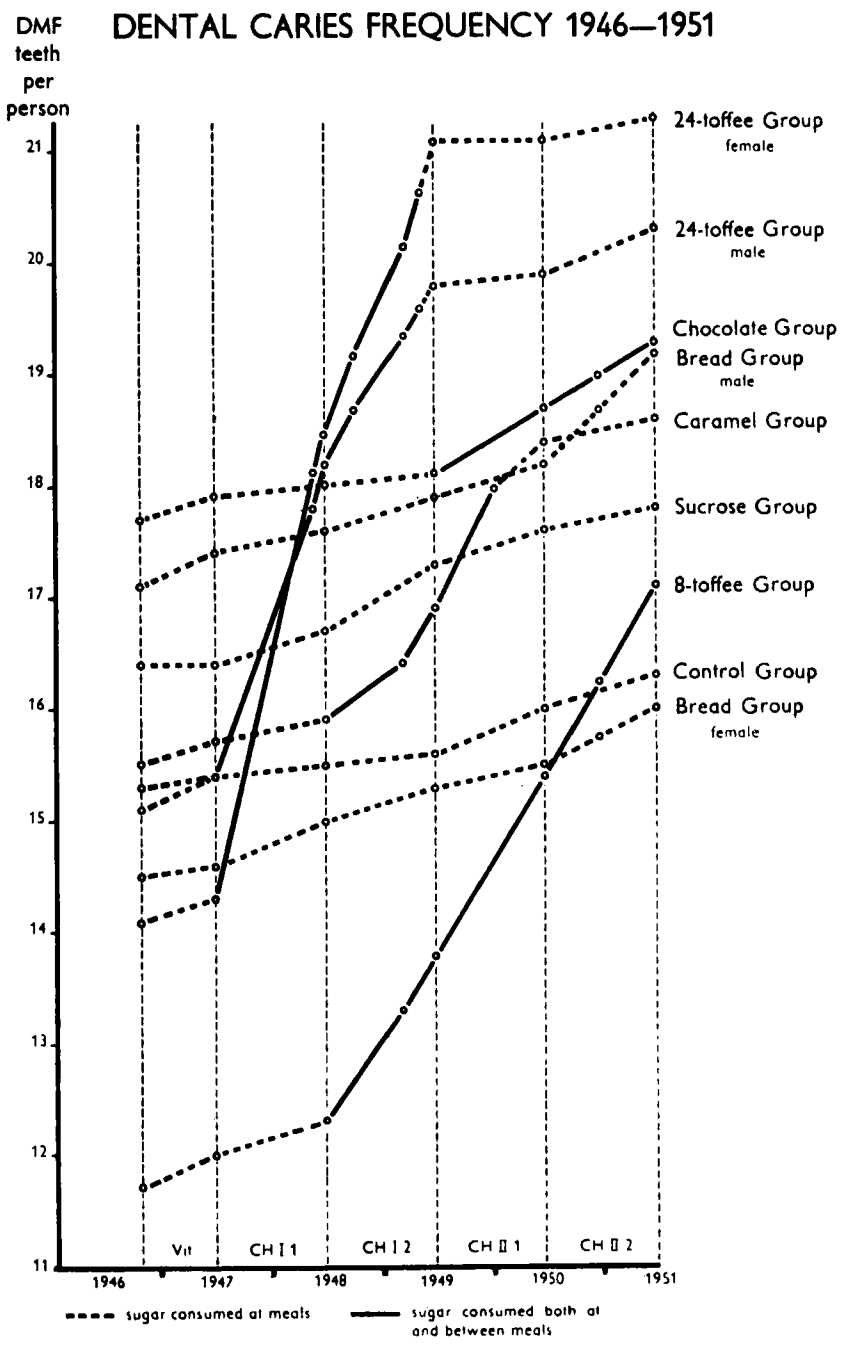

DENTAL CARIES FREQUENCY 1946—1951
DMF teeth per person
21
20
19
18
17
16
15
14
13
12
11
1946
1947
1948
1949
1950
1951
Vit
CH I 1
CH I 2
CH II 1
CH II 2
24-toffee Group female
24-toffee Group male
Chocolate Group
Bread Group male
Caramel Group
Sucrose Group
8-toffee Group
Control Group
Bread Group female
sugar consumed at meals
sugar consumed both at and between meals

Fig. 6.

blished it is planned to consider in detail activity in relation to age and dental status. Such studies cannot, however, be carried out until data have been obtained from the years following the experimental periods.

Analysis of the Data Obtained

The variation in caries activity can be analysed by the standard procedure of comparing the differences between means and their standard errors or by the analysis of variance.

If the individual observations made during a given period are grouped in classes according to the number of new carious surfaces per person per year (e. g. 0 and 1—3 and 4 or more new carious surfaces) the distribution of the patients among these classes will be very asymmetric, most patients in the present series being assignable to the class with 0 new carious surface (Table 11), but also a few cases with a large number of new carious surfaces.

Statistical analysis using the standard deviation and standard error of the mean is possible in these small groups of patients only if the distribution of the data is roughly that of the normal frequency curve, a condition that was by no means filled by the present series because of the abnormally skew distribution.

The differences in susceptibility to caries under uniform conditions (dietary, environmental) are ascribable to differences in resistance to caries, which in turn varies with age, previous caries, number of intact surfaces and a number of unknown factors. Individual differences in disposition to caries might markedly influence the mean values found for caries activity in the groups under consideration. A single individual might thus account for just as much of the numerical value of the mean, as all the other members of the group together.

The effect of these fluctuations in resistance can be compensated in the analysis by a suitable classification of the data and by making comparisons in the same group of patients during different experimental conditions. The latter is possible in such a long-term study as the present and is referred to as *intra-group comparison.* Comparisons between different groups of pa-

tients are termed *inter-group comparison.* The present investigation showed wide individual variation in caries activity under uniform conditions, this therefore increased the importance of intra-group studies.

The present material was classed as follows:

1. Patients in whom no new carious surface appeared within a given period.
2. Patients in whom 1—3 new carious surfaces were observed within a given period.
3. Patients in whom 4 or more carious surfaces appeared within a given period.

This classification reduces the effect of individual patients with a very large number of new carious surfaces. In addition, in order to avoid classes too small for statistical analysis, groups 2 and 3 were sometimes taken together as a single group; this reduced the analysis to a study of the material for the presence or absence of new carious surfaces.

Every group of patients was studied for 5 periods. For each of these periods there was thus a distribution according to the appearance of 0 and 1—3 and 4 or more new carious surfaces per person per year. The statistical analysis of the difference between these distributions was carried out in the following way. All 5 distributions were first compared simultaneously by the χ^2-test. The distributions were then taken as two groups and the new distributions thereby obtained were compared. The original distributions in each of the two subgroups were also compared.

In this way we obtained for each experimental group a longitudinal comparison giving:

1. A total χ^2-value based on differences between all periods.
2. A χ^2-value showing the differences between, for example, periods during the Vitamin Study and the Carbohydrate Study I, on the one hand, and Carbohydrate Study II, on the other.
3. Two χ^2-values for differences between distributions within these two groups of periods.

The χ^2-values given under points 2 and 3 should together roughly equal that given under point 1.

In the present investigation the analysis was complicated by the fact that two or more distributions were not based on completely different series, but on distributions of the same groups of persons during two or more different observation periods. The caries activity, as expressed by the number of new carious surfaces for each person for a given observation time must be more or less influenced by chance. But it is also dependent to no small degree on the resistance of the single individual throughout all study periods, independently of changes in the experimental conditions.

This relationship between the distributions of the same group of patients infers that the validity of any difference found on intra-group comparison is greater than that obtained from the χ^2-values and the corresponding values of probability (P), QUENSEL (1952).

In the following the results obtained in each group are summarised diagrammatically and in tabular form. Unless otherwise stated, figures given for the consumption of sugar etc. are to be understood as consumption per person per day. Caries activity figures are given as the average number of new lesions per person per given period (1 year). How the experimental conditions were filled by the groups that received additional sugar between meals and by the Bread Groups during Carbohydrate Study II are accounted for in the tables.

The tables also show losses of intact surfaces calculated on the basis of all surfaces. Here the losses have been grouped according to the cause: primary caries, loss of teeth or extension of cavities. This last mentioned cause includes the surfaces lost by the extension of an existent cavity onto a hitherto intact surface by enlargement or by conservative treatment or by fracture in connection with undermining caries.

The upper part of the diagrams indicates caries activity, as represented by the mean values. A comparison can be made between the changes in these and in the relative distributions of the patients with respect to caries activity, which are represented by the columns at the bottom of the diagram. The caries activity is also represented by the means that would have been obtained if lesions of

the type "caries without defect", roentgen caries and the initial stages of pit and fissure caries had not been included at the recording of dental caries. This also conveys an idea of the relationship between the frequency of these initial and the definite dental caries lesions.

In the statistical analysis the distributions for the various periods are grouped. In order to facilitate the description the periods 1—5 are termed 1=Vitamin Study, 2=Carbohydrate Study I, 1 year, 3=Carbohydrate Study I, 2 year and so on.

CONTROL GROUP

This group consisted of a large department and a few patients from another department. The group was made up of altogether 60 men with an average age of 34.9 years at the commencement of the study period in 1946.

During the Vitamin Study both departments received supplementary calcium and the small department received additional vitamins A, C and D (Table 17). The purpose of Carbohydrate Study I was to study the effect of reduced carbohydrate consumption on caries activity when this consumption was reduced by simultaneous

1) elimination of practically all refined sugar from the diet,

2) maximum restriction of foodstuffs naturally containing sugar, and

3) reduction of the carbohydrate ration to about half of that of ordinary Swedish standard.

These restrictions rendered the diet calorie-poor (basic diet G 4 1,800 kcal). The patients therefore received an additional ration of 150 g. margarine per day to bring up the caloric level. A reduction in caries activity can thus be attributed either to the reduction in carbohydrate consumption or to the increased fat ration (total 225 g.). This eludicates the difficulty in investigations of this type with marked carbohydrate restriction, which must be compensated by calories from some other source. This additional fat ration makes it doubtful whether this group can be considered a true control group during Carbohydrate Study I. This group is, however, classed as a control group in accordance with what was

said on page 262 because it merits this name as a basis for the conclusions drawn from the observations made in Carbohydrate Study II.

The carbohydrate-poor, fat-rich diet has been shown to cause very mild ketonuria (SWENANDER LANKE, 1952). This stresses still more the special position of this group during Carbohydrate Study I.

During Carbohydrate Study II the patients in this study group received ordinary Swedish food (basic diet G 5 2,700 kcal.) with supplementary margarine (40 g.) to bring up the caloric level. While the fat ration during Carbohydrate Study I was also used in the preparation of the food the margarine was served during Carbohydrate Study II by simply spreading it a little thicker on the bread. The total daily fat ration was 120 g., thus slightly less than what may be regarded as Swedish standard, i. e. 148 g. (Table 7). In this group the change in the conditions from Carbohydrate Study I to Carbohydrate Study II thus implied that

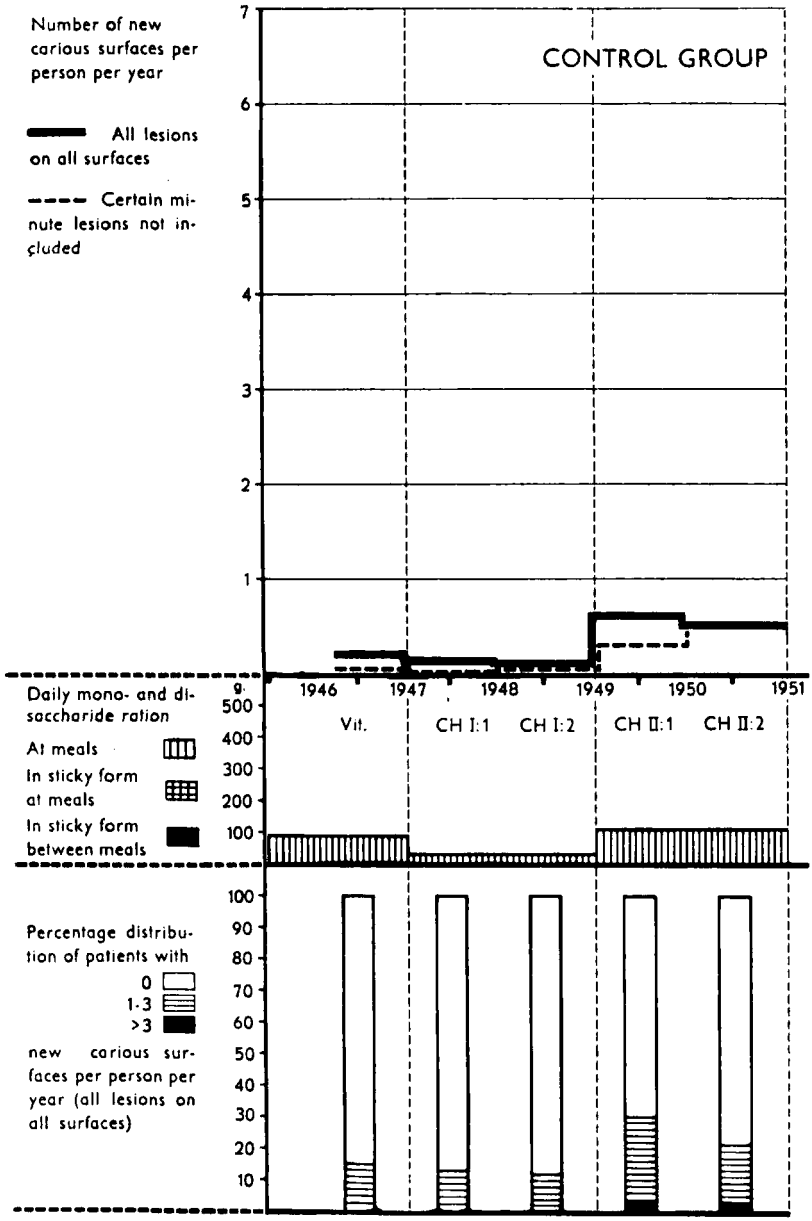
1) the margarine addition was decreased from 150 g. to 40 g.,

2) the total carbohydrate ration was increased from 130 g. to 370 g., partly by the increase in the bread and potato ration and partly by increasing the total sugar consumption from 30 g. to 110 g. In this group all food between meals was forbidden.

Caries Activity

The changes in the experimental conditions were accompanied by only slight changes in the average caries activity, which was low throughout all the 5 years (Fig. 7). Thus, caries activity was very low during the second year of the period with the carbohydrate-poor, fat-rich diet. Only 8 new surfaces were involved and then only by small lesions (see Moulage illustrations, Figs. 1 a—d, 2 and 3, page 244—249):

Cavity type:	Number of surfaces:
Rtg-caries	1
M 1	3
M 31	1
M 44	1
M 51	1
M 63	1



Conditions: Vit. G 3+Vit. A, C, D; Ca
CH I: 1 G 4+150 g margarine
: 2 G 4+150 ,, ,,
CH II: 1 G 5+ 40 ,, ,,
: 2 G 5+ 40 ,, ,,

Fig. 7.

TABLE 17

Survey of the results in the Control Group (60 patients)

		Vitamin Study	Carbohydrate Study I		Carbohydrate Study II	
			1st year	2nd year	1st year	2nd year
		Vit. A+C+D; Ca	No supplementary carbohydrates Calorie compensation 150 g margarine		40 g margarine	
Surface losses per person per period	*Primary caries*					
	Per Westin's index-surfaces	0.15	0.12	0.07	0.57	0.43
	Per 148 surfaces	0.17	0.15	0.13	0.60	0.47
	Ibid. but Cwd., Rtg., MI excl.	0.08	0.05	0.07	0.30	0.47
	Primary caries according to distribution of lesions[1]					
	Mandib. mol.	0.05	—	0.03	0.13	0.11
	Mandib. inc.	0.07	0.03	—	0.07	0.15
	Maxill. mol.	—	0.05	0.03	0.18	0.06
	Maxill. inc.	0.03	0.03	0.02	0.18	0.10
	Previously intact teeth	0.08	0.08	0.03	0.22	0.30
	Cementum caries	—	0.02	—	0.12	0.18
	Total surface losses per 148 surfaces					
	Primary caries	0.17	0.15	0.13	0.60	0.47
	Enlargements	0.52	0.32	0.15	0.98	0.95
	Loss of teeth					
	periodontitis	—	0.07	0.20	0.18	0.07
	other causes	0.13	0.55	0.20	0.65	0.18
	Total:	0.82	1.08	0.68	2.42	1.67

[1] Third molars not included.

TABLE 18

Statistical analysis of the changes in caries activity in the Control Group. Westin's index-surfaces

Classes: 0 and ≥ 1 new carious surface per person per period

Comparison	χ^2-value	Degrees of freedom	Probability (P) of the changes being due to chance only
All periods with one another	12.68	4	$5\% > P > 1\%$
The first three periods in relation to the last two	9.86	1	$1\% > P > 0{,}1\%$
The first three periods and the last two in relation to one another separately	2.82	3	$P > 50\%$

The number of surfaces lost by cavities involving neighbouring surfaces was one of the lowest recorded (Table 12) during the entire investigation.

During Carbohydrate Study II caries activity increased and cases with more than 3 new carious surfaces began to occur.

Statistical Analysis

As to the number of new carious surfaces, the series was only divided into two classes — subjects with and without new carious surfaces. Statistical analysis (χ^2-test) showed a probable difference between any of the periods (Table 18). Comparison of the distribution of the first three periods taken together and the last two periods, likewise taken together, also showed a significant difference, a difference thus attributable to the change from Carbohydrate Study I to II.

On the other hand, the first three periods did not differ from one another, nor did the last two.

This difference between Carbohydrate Study I and II was, however, referable entirely to changes observed in the small department (19 patients), no changes being demonstrable in the large department with its 41 patients. The difference observed between the first three periods and the last two periods in the small department showed an χ^2-value of the same magnitude as for the whole group.

Discussion

In this group of patients low-carbohydrate, high-fat diet depressed caries activity to practically nil. It is therefore remarkable that no such depression was noted in the 8-toffee Group, who were on the same low-carbohydrate, high-fat diet during the first year of Carbohydrate Study I (Fig. 13 and Tables 36 and 37). This difference is discussed on page 324).

During Carbohydrate Study II caries activity was higher than during Carbohydrate Study I. Nothing definite can be said about the cause of this increase in caries, because several of the experimental conditions (increase in sugar, bread and potato consumption) were changed at the same time in order to secure conditions

similar to Swedish standards, i. e. conditions desired for Carbohydrate Study II.

The increase in caries activity in this group can also be attributed to a possible return to the original level on withdrawal of supplementary fat with any retarding effect it might have on dental caries. That a high-fat diet is capable of retarding caries in animals has been shown by ROSEBURY & KARSHAN (1939 a and b) and SCHWEIGERT *et al.* (1946). It might then be objected that a decrease in caries should have been recordable in association with the introduction of supplementary fat. But no such decrease was noted. It must, however, be mentioned that the figures recorded for caries activity during the Vitamin Studies were fictitiously low, because the observation time was then less than one year (cf page 262). This may have masked any difference in caries activity between the Vitamin Study and Carbohydrate Study I.

Summary

A group of 60 males with an average age of 34.9 years received a carbohydrate-poor, high-fat diet practically free from refined sugar. Slight ketonuria was noted in some of the patients. Caries activity was depressed to practically nil.

After two years this diet was replaced by an ordinary diet with a ration, at meals, of refined sugar corresponding to what may be regarded as the average Swedish household consumption in 1948. This change of diet was accompanied by a small but statistically significant change in caries activity. This change may depend either on the withdrawal of the addition of fat or to increased carbohydrate consumption. During all of the periods the patients received nothing to eat between meals.

THE SUCROSE GROUP

The group consisted of one department with 57 males. The average age of this group in 1946 was 34.7 years.

During the Vitamin Study they received a daily dose of 1 mg. fluorine as NaF in a tablet which they swallowed without chewing (Table 19). During Carbohydrate Study I the patients received an addition of 300 g. sucrose in solution. It was originally intended

to mix this sugar in beverages. However, the ration proved too large for this procedure: therefore, part of it was added to other liquid and semi-liquid food-stuffs. During Carbohydrate Study II the extra sugar ration was 75 g. The entire ration was dissolved in the beverages served at meals.

When changing over from the Vitamin Study to the Carbohydrate Study, the total carbohydrate ration was increased by the addition of sugar (Table 8), while the consumption of starch and dextrin was decreased (from 260 g. to 100 g.). The total carbohydrate consumption during Carbohydrate Study II was almost the same as during Carbohydrate Study I, but starch and dextrins were increased from 100 g. to 260 g., while the ration of sugars was decreased from 330 g. to 190 g. The sucrose consumption was equal to the average total consumption in Sweden. During all of the periods, the patients received nothing to eat between the meals.

Caries Activity

Caries activity was low throughout all the five years (Table 19 and Fig. 8). During the second year of Carbohydrate Study I the mean caries activity showed a slight tendency to increase. This increase may be partly attributed to the fact that some patients showed 3 or more new cavities (Fig. 8, Table 11). Twenty-seven (47 per cent) persons showed no new carious surfaces during either of the Carbohydrate Study Periods.

Statistical Analysis

Statistical analysis by the χ^2-test (Table 20) showed no difference between the study periods concerning the ratio between the number of patients with and without caries. During the last three periods, however, some of the patients showed more than three new carious surfaces per period, an activity never seen during the first two periods. The first two periods were compared with the last three (Table 21). The probability of the 8 patients with four new carious surfaces or more falling within *one* group of periods being due to chance is less than 2 per cent.

The analysis suggests certain true differences in the distributions which become apparent between the second and third periods, *i. e.* the first and second year of Carbohydrate Study I, during which the experimental conditions were the same.

Discussion

In the search for any relationship between this change in caries activity and the experimental conditions a point deserving special attention is that during Carbohydrate Study I part of the extra sugar ration was mixed with fluid and semi-fluid food, and its tendency to be retained in the mouth thereby increased. During Carbohydrate Study I the Chocolate Group (47 patients) were on the same diet as the Sucrose Group (se main diagram, page 263). No increase in caries activity was seen in the Chocolate Group either.

This observation is also important, because otherwise the low caries activity recorded in the Sucrose Group might have been interpreted as an effect of the addition of fluorine, which was administered during the last 18 months before Carbohydrate Study I was started. It is, however, hardly likely that this addition of fluorine, which moreover had no local effect, should exert any influence on a series of patients with such a high mean age.

If the distribution of the patients with regard to caries activity in the Chocolate Group and the Sucrose Group be taken together for the Vitamin Study and for Carbohydrate Study I, during which latter period the experimental conditions were the same for both, it will provide a wider basis for judging whether any difference in caries activity occurred in connection with the addition of 300 g. sucrose (Table 22). Statistical analysis by the χ^2-test of these combined distributions of 104 patients did not show any real difference in caries activity during the three first years of the study.

So far the present analysis shows, that on consumption of 300 g. sucrose at meals mainly in the beverages there were no other changes in caries activity than those due to chance only. It ought to be stressed, however, that this 300 g. was consumed as part of a diet, which was poor in carbohydrates and differing from Swedish standards.

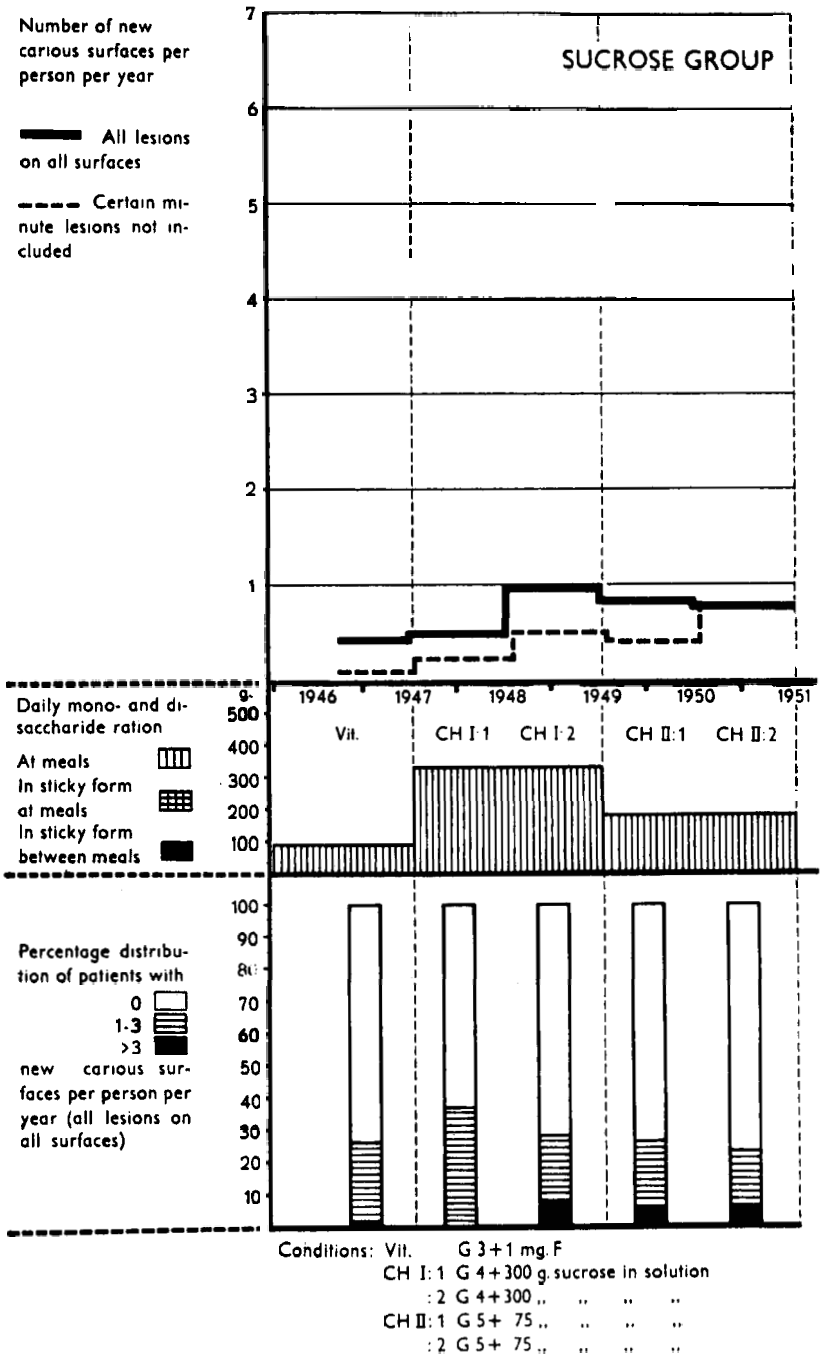

Number of new carious surfaces per person per year
All lesions on all surfaces
Certain minute lesions not included
SUCROSE GROUP
7
6
5
4
3
2
1
1946
1947
1948
1949
1950
1951
Vit.
CH I:1
CH I:2
CH II:1
CH II:2
Daily mono- and disaccharide ration
g.
500
400
300
200
100
At meals
In sticky form at meals
In sticky form between meals
Percentage distribution of patients with
0
1-3
>3
new carious surfaces per person per year (all lesions on all surfaces)
100
90
80
70
60
50
40
30
20
10
Conditions: Vit. G 3+1 mg. F
CH I: 1 G 4+300 g. sucrose in solution
: 2 G 4+300 ,, ,, ,, ,,
CH II: 1 G 5+ 75 ,, ,, ,, ,,
: 2 G 5+ 75 ,, ,, ,, ,,

Fig. 8.

TABLE 19

Survey of the results in the Sucrose Group (57 patients)

		Vitamin Study	Carbohydr. Study I		Carbohydr. Study II	
			1st year	2nd year	1st year	2nd year
		1 mg F (tablet, swallowed whole)	Sucrose in solution 300 g		Sucrose in solution 75 g	
Surface losses per person per period	*Primary caries*					
	Per Westin's index-surfaces	0.37	0.44	0.77	0.70	0.77
	Per 148 surfaces	0.44	0.49	0.96	0.84	0.82
	Ibid. but Cwd., Rtg., MI excl.	0.11	0.25	0.49	0.47	0.79
	Primary caries according to distribution of lesions[1]					
	Mandib. mol.	0.17	0.09	0.26	0.22	0.16
	Mandib. inc.	0.02	0.07	0.26	0.16	0.09
	Maxill. mol.	0.12	0.17	0.18	0.22	0.17
	Maxill. inc.	0.03	0.12	0.19	0.16	0.37
	Previously intact teeth	0.19	0.28	0.54	0.37	0.37
	Cementum caries	0.05	0.11	0.07	0.11	0.07
	Total surface losses per 148 surfaces					
	Primary caries	0.44	0.49	0.96	0.84	0.82
	Enlargements	0.28	0.35	0.39	1.04	1.39
	Loss of teeth					
	periodontitis	—	0,05	0.11	0.19	0.07
	other causes	—	0.23	0.34	0.02	0.14
	Total:	0.72	1.12	1.79	2.09	2.42

[1] Third molars not included.

TABLE 20

Statistical analysis of the changes in caries activity in the Sucrose Group. Westin's index-surfaces

Classes: 0 and $\geqq 1$ new carious surface per person per period

Comparison	χ^2-value	Degrees of freedom	Probability (P) of the changes being due to chance only
All periods with one another	2.35	4	$P > 50\,\%$
The first three periods in relation to the last two	1.20	1	$50\,\% > P > 10\,\%$
The first three periods with one another	0.40	2	$P > 50\,\%$
The last two periods with one another	0.90	1	$50\,\% > P > 10\,\%$

TABLE 21

Comparison of the caries activity in the Sucrose Group before and after the increase during Carbohydrate Study I

Period	Distribution of patients according to the number of new carious surfaces		
	0	1–3	4 or more
1 + 2	81	33	0
3 + 4 + 5	130	33	8
Total	211	66	8

Summary

A group of 57 male patients with an average age of 34.7 years, who had for 1 1/2 years been on an ordinary Swedish diet and who had received 1 mg. fluorine daily in the form of a tablet, were placed on a diet in which the major part of the carbohydrate ration was consumed in the form of refined sugar mainly in solution at meals, the amount of sugar representing about twice the average total Swedish consumption. After a further two years the distribution, but not the quantity, of the carbohydrates was again changed in such a manner that the amount of refined sugar consumed at meals was slightly more than the average Swedish consumption. During these study periods all consumption of food between meals was forbidden.

These changes in the distribution of the carbohydrates produced no statistically significant changes in caries activity.

TABLE 22

Statistical analysis of the changes in caries activity in the Sucrose and Chocolate Groups taken together during Carbohydrate Study I (104 persons). Westin's index-surfaces

Classes: 0 and $\geqq 1$ new carious surface per person per period

Comparison	χ^2-value	Degrees of freedom	Probability (P) of the changes being due to chance only
The first three periods with one another	0.45	2	$P > 50\ \%$

BREAD GROUPS

Forty-one men and forty-two women with an average age of 30.4 and 28.0 years, respectively, at the start of the study had the same dietary regimen during Carbohydrate Study I and II. The supplement consisted of 345 g. sweet bread which contained 50 g. refined sugar. During Carbohydrate Study I the patients received this type of bread with their afternoon coffee, and most of them ate the bread before they drank their coffee. During Carbohydrate Study II this bread was served daily at all four meals and replaced the bread ration of the basic diet. During all the study periods consumption of food between meals was forbidden.

Caries Activity

The average caries activity during Carbohydrate Study I was about the same as during the Vitamin Study Period (Tables 23, 25, Figs. 9 and 10). During the second year of Carbohydrate Study II the males showed a distinct increase in caries activity, even in the number of definite cavities. The same tendency, though less pronounced, was also seen in the female group. The change in the male group was also evident from the change in the distribution of the patients according to caries activity as shown in Table 11 and in the columns in the right hand bottom corner of Fig. 9.

Statistical Analysis

The χ^2-analysis (Table 24) showed that the increase in caries activity in the male group during the 2nd year of the Carbohydrate Study II can only be attributed to chance with a probability of less than 5 per cent. However, as far as caries activity in the females is concerned, no differences were found between the various periods, except those due to chance (Table 26).

Discussion

It is remarkable that the increase of dental caries activity does not occur until the second year of the Carbohydrate Study II *i. e.* more than one year after the experimental conditions (consumption of the sweet bread at all meals) had been altered. Further the two groups differed regarding the results despite the same dietary conditions. However, the female group differed in two important

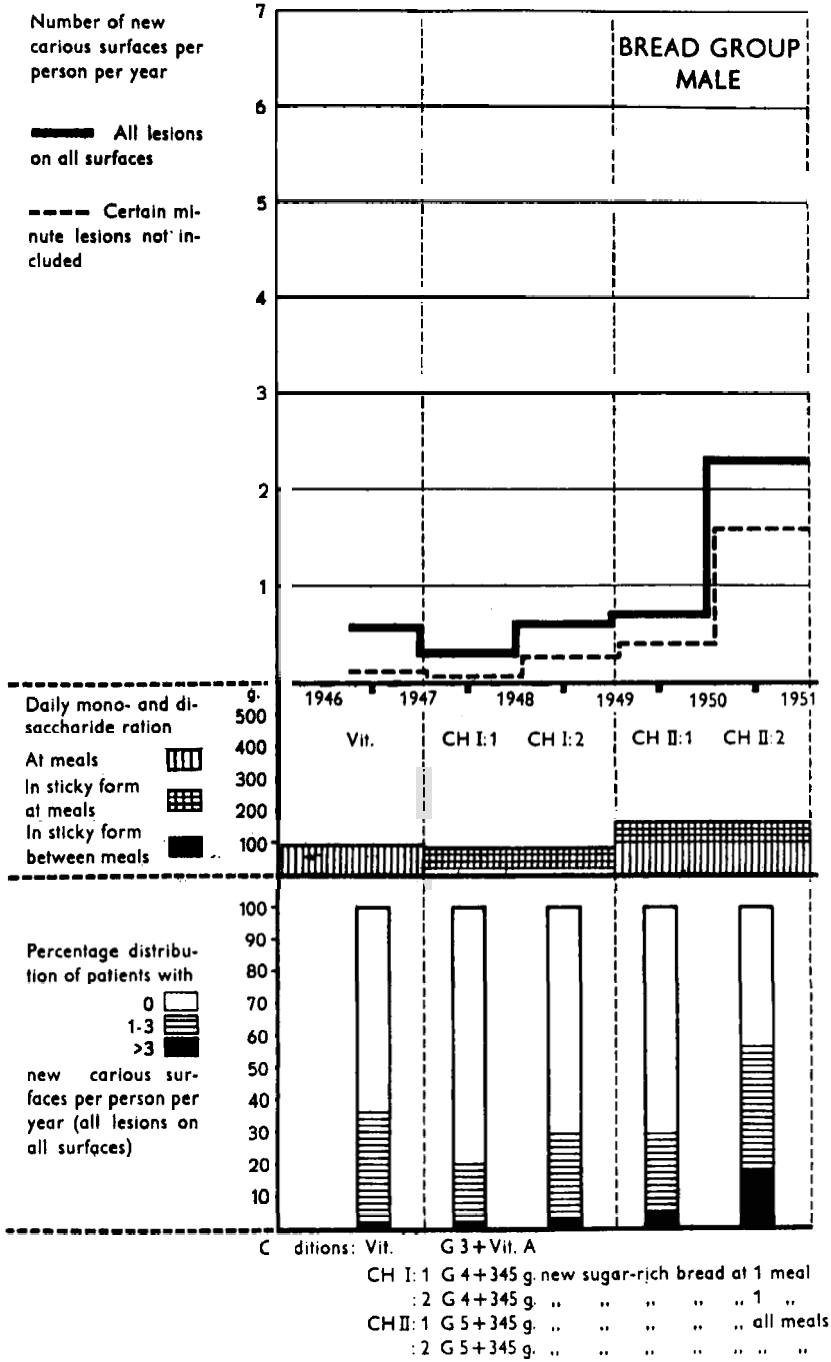

Number of new carious surfaces per person per year
All lesions on all surfaces
Certain minute lesions not included
BREAD GROUP
MALE
7
6
5
4
3
2
1
1946
1947
1948
1949
1950
1951
Daily mono- and disaccharide ration
g.
500
400
300
200
100
At meals
In sticky form at meals
In sticky form between meals
Vit.
CH I:1
CH I:2
CH II:1
CH II:2
Percentage distribution of patients with
0
1-3
>3
new carious surfaces per person per year (all lesions on all surfaces)
100
90
80
70
60
50
40
30
20
10
Conditions: Vit. G 3+Vit. A
CH I: 1 G 4+345 g. new sugar-rich bread at 1 meal
: 2 G 4+345 g. ,, ,, ,, ,, ,, 1 ,,
CH II: 1 G 5+345 g. ,, ,, ,, ,, ,, all meals
: 2 G 5+345 g. ,, ,, ,, ,, ,, ,, ,,

Fig. 9.

TABLE 23

Survey of the results in the Bread Group (male, 41 patients)

		Vitamin Study	Carbohydr. Study I		Carbohydr. Study II	
			1st year	2nd year	1st year	2nd year
		Vit. A	New high-sugar bread 345 g at one meal		substitutes basic diet bread	
	Number of patients who consumed					
	> the supplement				—	—
	= „ „				38	41
	< „ „				3	—
	0 „ „				—	—
Surface losses per person per period	*Primary caries*					
	Per Westin's index-surfaces	0.37	0.17	0.44	0.61	2.00
	Per 148 surfaces	0.56	0.29	0.59	0.71	2.32
	Ibid. but Cwd., Rtg., MI excl.	0.10	0.07	0.27	0.41	1.61
	Primary caries according to distribution of lesions[1]					
	Mandib. mol.	0.17	0.10	0.22	0.15	0.46
	Mandib. inc.	0.02	0.02	0.12	0.05	0.46
	Maxill. mol.	0.12	0.05	0.12	0.17	0.56
	Maxill. inc.	0.05	—	—	0.27	0.56
	Previously intact teeth	0.22	0.10	0.27	0.34	0.98
	Cementum caries	—	—	0.02	0.12	0.49
	Total surface losses per 148 surfaces					
	Primary caries	0.56	0.29	0.59	0.71	2.32
	Enlargements	0.29	0.51	0.29	0.56	1.32
	Loss of teeth					
	periodontitis	–	0.10	0.10	0.59	0.66
	other causes	0.47	0.80	0.37	0.32	0.24
	Total:	1.32	1.71	1.34	2.17	4.54

[1] Third molars not included.

respects from the male group with regard to the fulfilment of the experimental conditions. First, practically all of the males ate their entire ration of sweet bread during Carbohydrate Study II, while about one third of the females consumed less than their

TABLE 24

Statistical analysis of the changes in caries activity in the male Bread Group. Westin's index-surfaces

Comparison	χ^2-value	Degrees of freedom	Probability (P) of the changes being due to chance only
All periods with one another	23.89	8	$1\% > P > 0.1\%$
The first three periods in relation to the last two	10.48	2	$1\% > P > 0.1\%$
The first three periods with one another	3.39	4	$P > 50\%$
The last two periods with one another	7.88	2	$5\% > P > 1\%$
The first four periods in relation to the last	20.58	2	$0.1\% > P$

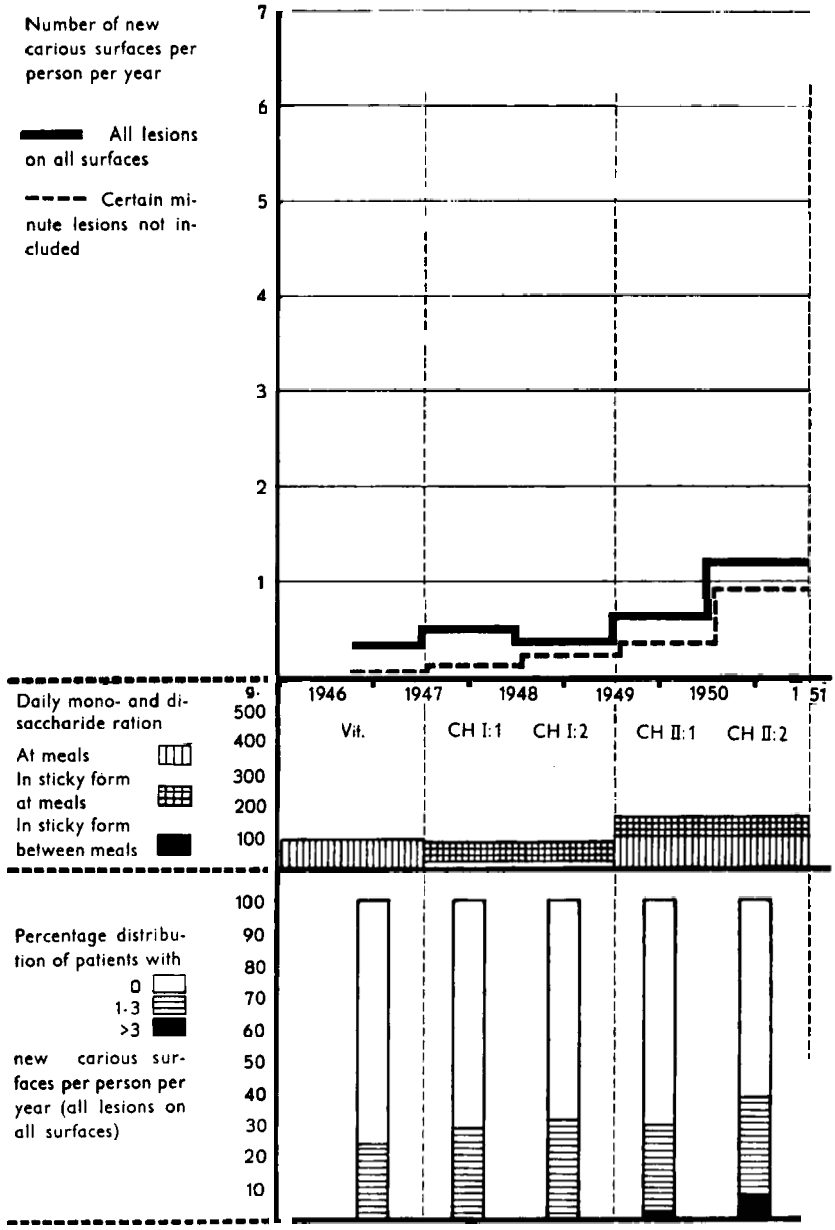
ration (Tables 23 and 25). Secondly, oral hygiene was much better in the female group. Of the 42 females, 38 had their teeth brushed regularly, as compared with only 2 of the 41 males.

Summary

A group of patients consisting of 41 males and 42 females with an average age of 30.4 and 28.0 years, respectively, received sweet bread at one meal every day for 2 years: the consumption of this bread did not produce a demonstrable increase in caries activity. During the following 2 years the same sort of sweet bread was served at all meals (breakfast, dinner, afternoon coffee and supper). During the second year of this 2-year period an increase was observed in the mean caries activity. The increase recorded was statistically significant for the males, but not for the females. The female group differed from the male group in that their oral hygiene was better and secondly they did not eat so much of their ration. Consumption of food between meals was forbidden.

THE CHOCOLATE GROUP

Forty-seven male patients with an average age of 29.1 years at the commencement of the study received an extra daily ration of 300 g. refined sugar in solution at meals during the Carbohydrate Study I i.e. the same as the Sucrose Group. At the beginning of Carbohydrate Study II the total amount of sugar served at meals



Conditions: Vit. G 3
CH I: 1 G 4+345 g. new sugar-rich bread at 1 meal
: 2 G 4+345 g. ,, ,, ,, ,, ,, 1 ,,
CH II: 1 G 5+345 g. ,, ,, ,, ,, ,, all meals
: 2 G 5+345 g. ,, ,, ,, ,, ,, ,, ,,

Fig. 10.

TABLE 25

Survey of the results in the Bread Group (female, 42 patients)

		Vitamin study	Carbohydr. Study I		Carbohydr. Study II	
			1st year	2nd year	1st year	2nd year
		—	New high-sugar bread 345 g at one meal		substitutes basic diet bread	
	Number of patients who consumed					
	> the supplement				—	—
	= „ „				26	29
	< „ „				16	13
	0 „ „				—	—
Surface losses per person per period	*Primary caries*					
	Per Westin's index-surfaces	0.24	0.48	0.31	0.52	0.98
	Per 148 surfaces	0.33	0.52	0.38	0.64	1.19
	Ibid. but Cwd., Rtg., MI excl.	0.07	0.12	0.26	0.36	0.95
	Primary caries according to distribution of lesions[1]					
	Mandib. mol.	0.05	0.17	0.05	0.19	0.33
	Mandib. inc.	—	0.10	0.02	0.05	0.12
	Maxill. mol.	0.16	0.17	0.19	0.19	0.31
	Maxill. inc.	0.02	0.05	0.05	0.10	0.24
	Previously intact teeth	0.17	0.33	0.24	0.33	0.22
	Cementum caries	—	0.02	0.04	0.07	0.07
	Total surface losses per 148 surfaces					
	Primary caries	0.33	0.52	0.38	0.64	1.19
	Enlargements	0.45	0.26	0.76	1.48	0.74
	Loss of teeth					
	periodontitis	0.10	0.10	—	—	0.29
	other causes	0.05	0.24	0.28	0.22	0.48
	Total:	0.93	1.12	1.43	2.33	2.69

[1] Third molars not included.

TABLE 26

Statistical analysis of the changes in the caries activity in the female Bread Group. Westin's index-surfaces

Comparison	χ^2-value	Degrees of freedom	Probability (P) of the changes being due to chance only
All periods with one another	5.83	8	P > 50 %

was reduced from 330 g. to 110 g. From the start of the Carbohydrate Study II the patients received 30 g. sugar between meals as 65 g. milk chocolate. This chocolate ration was served as 4 portions between the meals. The total carbohydrate consumption was almost the same during both study periods.

Caries Activity

The mean caries activity, as calculated on the basis of Westin's index surfaces and all surfaces was low during Carbohydrate Study I. The mean increased with the consumption of chocolate. This was also reflected by the distribution of the patients according to caries activity. Thus there was an increase in the number of patients with 3 or more new carious surfaces and a decrease in the number of those with no new carious surfaces. It is clear from Fig. 11 and Table 27 that the lesions occurring on introduction of the chocolate ration, were mainly of the initial types.

Statistical Analysis and Discussion

The χ^2-analysis (Table 28) of the various periods showed that there was a significant increase in caries activity during at least one of the 5 years. Further analysis showed that the difference was mainly attributable to the change in conditions between Carbohydrate Study I and II when chocolate was introduced. There was, however, an increase in caries activity also in the Control Group at the commencement of the Carbohydrate Study II which was attributed to the increase in carbohydrate consumption when the conditions were altered to resemble ordinary Swedish standards. This merited closer analysis of the activity and data in both the Control Group and the Chocolate Group in order to judge whether the greater increase in the Chocolate Group was related to a difference, in the caries tendency of the patients or to the difference in the conditions.

COMPARATIVE ANALYSIS OF THE CHANGES IN THE CHOCOLATE AND CONTROL GROUPS

As the patients have by now been studied for a further year (1951—1952) with unchanged consumption of sugar and for a subsequent year (1952—1953) since the withdrawal of chocolate,

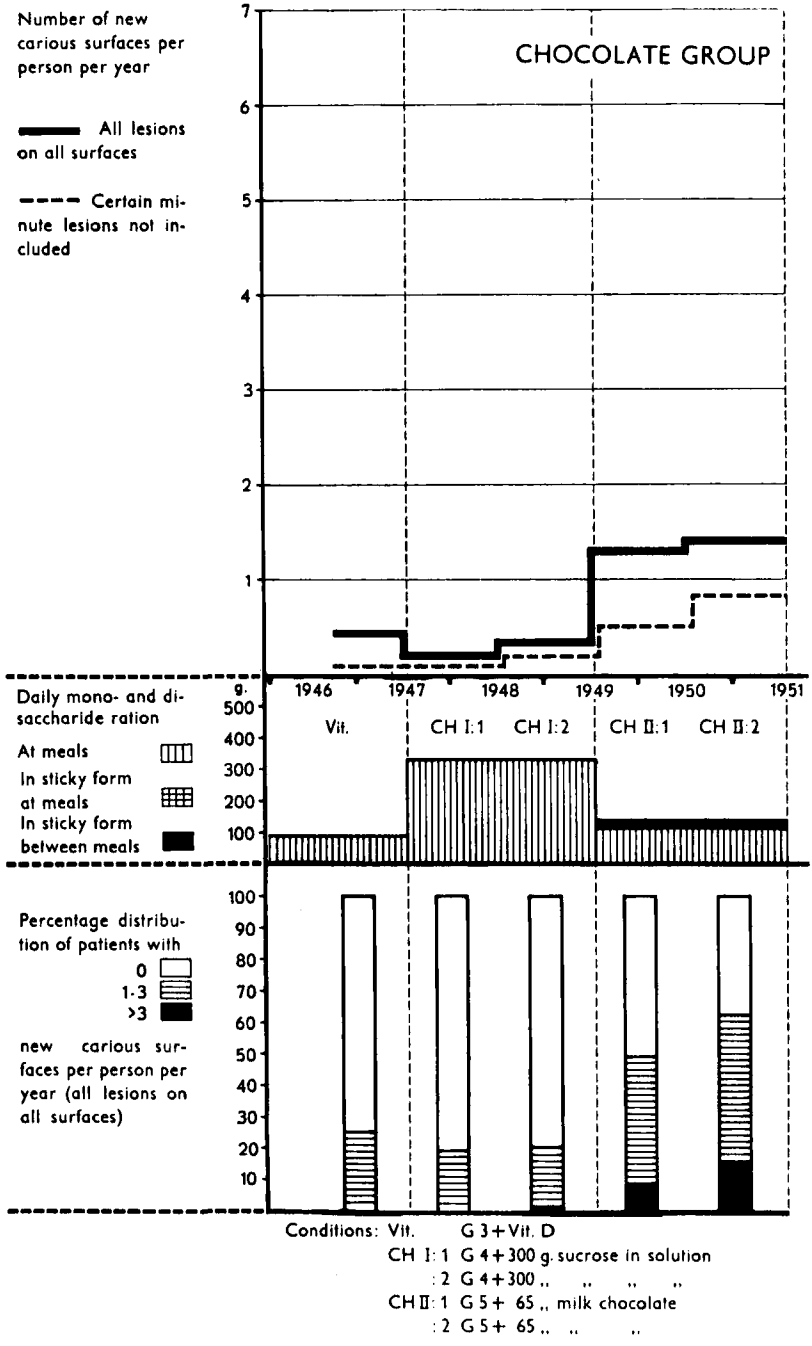

Number of new carious surfaces per person per year
All lesions on all surfaces
Certain minute lesions not included
CHOCOLATE GROUP
7
6
5
4
3
2
1
Daily mono- and disaccharide ration
At meals
In sticky form at meals
In sticky form between meals
g.
500
400
300
200
100
1946
1947
1948
1949
1950
1951
Vit.
CH I:1
CH I:2
CH II:1
CH II:2
Percentage distribution of patients with
0
1-3
>3
new carious surfaces per person per year (all lesions on all surfaces)
100
90
80
70
60
50
40
30
20
10
Conditions: Vit. G 3+Vit. D
CH I: 1 G 4+300 g. sucrose in solution
: 2 G 4+300 ,, ,, ,, ,,
CH II: 1 G 5+ 65 ,, milk chocolate
: 2 G 5+ 65 ,, ,, ,,

Fig. 11.

TABLE 27

Survey of the results in the Chocolate Group. (47 patients)

		Vitamin Study	Carbohydr. Study I		Carbohydr. Study II	
			1st year	2nd year	1st year	2nd year
		Vit. D	Sucrose in solution 300 g		Milk chocolate 65 g in 4 portions between meals	
	Number of patients who consumed					
	> the supplement				—	—
	= „ „				46	47
	< „ „				1	—
	0 „ „				—	—
Surface losses per person per period	*Primary caries*					
	Per Westin's index-surfaces	0.40	0.19	0.23	1.11	1.23
	Per 148 surfaces	0.45	0.23	0.36	1.30	1.40
	Ibid. but Cwd., Rtg., MI excl.	0.13	0.13	0.19	0.51	0.83
	Primary caries according to distribution of lesions[1]					
	Mandib. mol.	0.02	0.09	0.11	0.55	0.25
	Mandib. inc.	0.04	0.06	—	0.17	0.11
	Maxill. mol.	0.21	0.09	0.09	0.28	0.45
	Maxill. inc.	0.04	—	0.06	0.15	0.43
	Previously intact teeth	0.19	0.13	0.09	0.68	0.53
	Cementum caries	0.02	—	0.04	0.06	0.21
	Total surface losses per 148 surfaces					
	Primary caries	0.45	0.23	0.36	1.30	1.40
	Enlargements	0.47	0.62	0.70	0.87	1.06
	Loss of teeth					
	periodontitis	—	0.04	0.26	0.02	—
	other causes	0.13	0.06	0.19	0.21	0.23
	Total:	1.04	0.96	1.51	2.40	2.70

[1] Third molars not included.

the data obtained throw still further light on the effect of the consumption of chocolate on caries activity (Table 29). A more detailed analysis was made of the data obtained in this group. The caries activity recorded during the three years with chocolate con-

TABLE 28

Statistical analysis of the changes in caries activity in the Chocolate Group. Main material. Westin's index-surfaces

Comparison	χ^2-value	Degrees of freedom	Probability (P) of the changes being due to chance only
All periods with one another	31.94	8	0.1 % > P
The first three periods in relation to the last two	29.70	2	0.1 % > P
The first three periods with one another	1.42	2	P > 50 %
The last two periods with one another	1.06	2	P > 50 %

sumption was correlated with the ages of the persons and the caries activity noted during the year before the chocolate study was started, below called the pre-chocolate period. The years during which chocolate was consumed, have been called the experimental period. This applies both to the Control and Chocolate Groups.

Because of individual differences in disposition to caries, so far data have been given only for persons who partook in the entire investigation. In the analysis below, the data refer to all persons who partook in at least one of the study years and who filled the requirements given in the section "Material". This procedure was considered justified, because here the individual differences in disposition to caries was compensated in a different way. As a result of this re-grouping of the material the figures below differ, though slightly, from those given in the preceding section. However, persons for whom data were available only for the pre-chocolate period were not included.

Table 30 gives the average number of new carious surfaces per person per year and the relative number of persons who showed no new carious surfaces during the observation period.

CHANGES IN THE CONTROL GROUP

During the pre-chocolate period the caries activity in the Control Group was low, but then increased during the following four years to an average of 0.65 new carious surface per person per year. The

TABLE 29

Survey of the studies in the Chocolate and Control Groups
Total material 1948—1953

Period	Code of the periods in the extended analysis	Diet		Sugar consumption g per person per day					
		Chocolate Group	Control Group	At meals		Between meals		Total	
				Chocol.	Contr.	Chocol.	Contr.	Chocol.	Contr.
Carbohydr. Study I 2nd year	Pre-chocolate period = Pre	G_4 + 300 g sugar in solution	G_4 without carbohydrate additions	330	30	—	—	330	30
Carbohydr. Study II 1st year	Experimental period I	G_5 + 65 g milk chocolate	G_5 without carbohydrate additions	110	110	30	—	140	110
2nd year	» » II	»	»	110	110	30	—	140	110
3rd year	» » III	»	»	110	110	30	—	140	110
4th year	Post-chocolate period = Post	G_5 without carbohydrate additions	»	110	110	—	—	110	110

TABLE 30

Caries activity in the Chocolate and Control Groups
Total material 1948—1953

Period[1]	Number of persons		Average number of new carious surfaces per person per year[2]		Percentage of persons with no new carious surfaces	
	Chocolate Group	Control Group	Chocolate Group	Control Group	Chocolate Group	Control Group
Pre	54	72	0.46	0.12	70	89
I	65	82	1.58	0.57	45	70
II	74	77	1.54	0.60	41	75
III	61	66	1.20	0.83	57	67
Post	59	64	0.78	0.64	69	70

[1] Abbreviations for periods: see Table 29.
[2] Per 148 surfaces.

variation in the figures for the last four years was in line with the fact that the experimental conditions were on the whole constant during the time studied here, *except for the pre-chocolate period.*

Table 31 gives a more detailed survey of the changes. Those persons for whom data were available for two successive years were grouped according to caries activity in each period. Each person was assigned to one of the following three activity classes:

A=no new carious surfaces during the period.
B= 1—2 new carious surfaces during the period.
C=3 or more new carious surfaces during the period.

Thus $3\times3=9$ combinations of caries activity classes were distinguished for two years.

On comparison of the pre-chocolate period and the experimental year I in the Control Group it will be apparent that of 72 persons, 52 belonged to the same activity class during both observation periods (AA, BB and CC). Of the other twenty, 16 were graded up from lower to higher activity classes (AB, AC, BC), and 4 were graded down. With random fluctuations only, the last two figures probably counterbalance one another. The disproportion between the number graded up and the number graded down denotes a significant change in caries activity from the pre-chocolate period

TABLE 31

Distribution of the patients according to the number of new carious surfaces during each of two consecutive years Total material 1948—1953

Combination of activity classes[2]	Chocolate Group				Control Group			
	Consecutive years[1]				Consecutive years[1]			
	Pre I	I II	II III	III Post	Pre I	I II	II III	III Post
A A	20	14	15	25	49	47	41	30
A B	13	11	6	2	12	3	4	3
A C	5	3	1	1	3		4	2
B A	7	7	15	7	4	9	1	6
B B	4	10	8	5	3	8	7	4
B C	4	7	2	1	1	3	3	1
C A	1	3	4	3	—	1	1	5
C B	—	6	2	3	—	—	—	4
C C	—	2	6	2	—	3	3	1
Total	54	63	59	49	72	74	64	56
Unchanged	24	26	29	32	52	58	51	35
+	22	21	9	4	16	6	11	6
—	8	16	21	13	4	10	2	15

[1] Abbreviations for periods: see Table 29.

[2] A: No new carious surfaces
B: 1—2 new carious surfaces
C: 3 or more new carious surfaces.

Combination B C: Activity class B during the first, activity class C during the second of the two consecutive years.

to experimental year I. No difference in caries activity was found between experimental years I and II. From experimental year II to III there occurred a change in the Control Group, in that 11 persons were graded up to a higher activity class and only 2 were graded down. This suggests a probable difference. Between experimental year III and the post-chocolate period the activity again diminished.

In the Control Group then an increase in caries activity was recorded from the pre-chocolate period to the experimental period and among the experimental years, experimental year III might

for some unknown reason be characterised by a somewhat lower caries activity than experimental years I and II and the post-chocolate period.

COMPARISON BETWEEN THE CHOCOLATE GROUP AND THE CONTROL GROUP DURING THE PRE- AND POST-CHOCOLATE PERIODS

During the pre-chocolate period and possibly also during the post-chocolate period the Chocolate Group showed a higher caries activity than did the Control Group. During the pre-chocolate period, however, the diet was not the same for both groups, the diet of the Chocolate Group containing more sugar (300 g. sucrose in solution added) than that of the Control Group.

CARIES ACTIVITY IN THE CHOCOLATE GROUP DURING THE EXPERIMENTAL PERIODS

As is apparent from the figures given above, the caries activity in the Chocolate Group increased from the pre-chocolate period to the experimental period I. Table 30 shows that the number of new carious surfaces increased from 0.46 per person to 1.58, while the number of caries inactive persons fell from 70 per cent to 45 per cent. According to Table 31, only 24 of the 54 persons remained in the same activity class, while 22 were graded up and 8 were graded down. The disproportion between these figures was in accordance with the definite difference in the experimental conditions.

As far as the Chocolate Group is concerned, no changes other than those due to chance, occurred between periods I and II. Between periods II and III there was a decrease (during which time an increase was noted for the caries activity of the Control Group). From a statistical point of view, this decrease suggests the occurrence of a probable difference, despite the absence of any changes in dietary conditions. Table 31 shows that 9 persons were graded up into a higher activity class and 21 were graded down.

A decrease was demonstrated between experimental period III and the post-chocolate period, so that the figures for the Chocolate Group were then on the same level as those for the Control Group.

Only 4 persons were graded up, but 13 were graded down, which suggests a probable difference. On closer analysis, not accounted for here, of the activity data of the experimental periods in relation to those for the pre- and post-chocolate periods, the Chocolate Group was found to differ significantly from the Control Group.

Statistically significant differences imply that the random factors, any over- or under-registration of caries and any transient fluctuation in the caries activity of the individuals, could not by themselves have produced the differences observed. But the differences might possibly have been ascribable to differences in disposition to caries in combination with any differences due to chance. As a certain difference in caries activity (after elimination of differences in age) was found between the Chocolate Group and the Control Group during the pre-chocolate period, it might be suggested that the difference found during the experimental periods was due to the persons in the Chocolate Groups really having had a greater disposition to caries than those in the Control Group. This difference would then, however, have been masked by random deviations during the pre- and post-chocolate periods.

In order to check any influence of any such objection on the results, the caries activity during the experimental periods must be studied against the background of the observed caries activity during the pre-chocolate period.

A more detailed analysis can be made on the basis of data given in Table 32, where the material is divided into two age groups, those born before respectively after 1920. In each of the age groups the patients are divided according to the presence or absence of caries activity during the pre-chocolate period. Only those persons were now included that were observed during all three experimental periods. If the caries activity in the Chocolate Group and the Control Group had been equal in all four subgroups i. e. those with and without caries in each of the age classes the distribution, according to caries activity, of the patients belonging to the Chocolate Group would have been:

Activity class no new carious surfaces: expected number 16.1 persons, observed number 8;

Activity class 1—5 new carious surfaces: expected number 17.4 persons, observed number 23;

TABLE 32

Distribution according to total caries activity during chocolate consumption.

The material is grouped by age and caries activity during the pre-chocolate period. Patients partaking in the study during the periods Pre and I—III

Group etc.		Number of patients grouped according to number of new carious surfaces during periods I—III				Total numbers of new carious surfaces during periods	
		Total	0	1—5	6—	Pre	I—III
Chocolate Group	Y —	14	1	7	6	0	86
	Y +	8	—	4	4	14	50
	O —	16	7	8	1	0	21
	O +	5	0	4	1	6	18
Total		43	8	23	12	20	175
Control Group	Y —	8	7	—	1	0	10
	Y +	3	2	1	—	3	3
	O —	40	24	13	3	0	62
	O +	5	2	2	1	6	23
Total		56	35	16	5	9	98

Y = younger, born in 1920 or later
O = olderly, born in 1919 or earlier
— = inactive during the pre-chocolate period
\+ = active during the pre-chocolate period.

TABLE 33

Caries activity during consumption of chocolate Total material 1948—1953

(Number of new carious surfaces per person per year)

Age Group	Chocolate Group	Control Group
Below 30 years	1.98	0.67
Above 30 years	0.77	0.65

Activity class 6 or more new carious surfaces: expected number 9.5, observed number 12.

These differences are too great to be ascribed to chance alone. The difference between the expected number and the number observed in the inactive class was 8.1 with a standard error of 2.2 units.

A possibly greater disposition to caries in the Chocolate Group under otherwise equal conditions can thus not have been the cause of the differences between the Control Group and the Chocolate Group during the actual experimental period, because now all comparisons took into account earlier manifest caries activity.

The increase in caries activity in the Chocolate Group during the three experimental years must thus be ascribed to the consumption of chocolate. The effect varied with the age of the patients and was only very slight in the higher age classes but distinct in the lower age classes (Table 33). Whether this difference is due to a general increase in caries resistance with age or whether only certain teeth or surfaces are involved by caries during the consumption of chocolate, and whether these teeth or surfaces are seldom intact in higher age classes, requires further investigation.

PARALLEL STUDY OF THE RELATIONSHIP BETWEEN THE CONSUMPTION OF CHOCOLATE AND CARIES ACTIVITY

A parallel study was carried out on the personnel at Vipeholm Hospital. The study covered the period from Febr. 1, 1946 to Aug. 30, 1947.

The series consisted of altogether 108 male and female volunteers with an average age of 34 years. The teeth were examined and the changes noted were recorded in exactly the same way as that used in the main investigation. The persons were examined on 5 occasions.

The series was divided into four groups:

Ordinary diet plus wheat bread
„ „ „ Swedish hard rye bread
„ „ „ wheat bread+chocolate
„ „ „ Swedish hard rye bread+chocolate

Those belonging to the chocolate groups received a bar of milk chocolate (54 g.) daily, which they were allowed to eat when they liked during the day. Most of the persons reported that they ate their ration in small portions between meals.

In this connection it should, however, be stressed that chocolate was practically unavailable in the shops at that time and it is quite possible that part of the chocolate ration was consumed by other family members not partaking in the study. As in other similar investigations in non-institutionalised material it was not possible to control the conditions in an objectively satisfactory manner, especially as the experimental period was 1.5 years.

The mean number of new carious surfaces for those who received no chocolate was 0.6, the corresponding figure for those who received chocolate being 0.7. Statistical analysis showed that this difference was ascribable to chance alone. The frequency of enlargements of already existent cavities was higher in the chocolate group: this difference was statistically significant. It must be borne in mind that these figures refer to a period of the investigation, when the registration method was not stabilised. This investigation shows the difficulties in studies of dental caries activity under uncontrolled conditions. Of definite disadvantage is also the lack of a pre-experimental registration of the dental caries activity.

Summary

A male group received a diet containing an ordinary amount of carbohydrates but an amount of sugar corresponding to twice the average Swedish consumption. Caries activity, which was known to be fairly low before the commencement of the study, remained low. The following 3 years the patients were placed on an ordinary Swedish diet and received a daily ration of 65 g. milk chocolate, which they ate between meals.

This change in the experimental conditions was accompained by a statistically significant increase in caries activity. However, another change in the diet was made when the chocolate consumption started.

Therefore an extended analysis was made of all patients in the Chocolate Group. This analysis comprised also those patients not

included in the main material. The correlation between the consumption of 65 g. chocolate per person per day between the meals was studied in 87 patients for 3 years. At the same time 95 patients were studied in the Control Group. It was shown in younger (<30 years) individuals that the consumption of chocolate was accompanied by a dental caries activity 3 times greater than before. This difference was found between the periods with and without chocolate consumption in the same individuals as well as between the Chocolate and Control Group. In older individuals (>30 years) the increase was insignificant.

In a parallel investigation on a group of the personnel (mean age 34 years) at the hospital, no difference could be observed between a group who ate 54 g. chocolate daily and a control group who ate no chocolate.

It must be pointed out, however, that in this study of the personnel the control of the chocolate consumption was not satisfactory.

THE CARAMEL GROUP

Sixty-two patients with an average age of 35.6 years at the beginning of the study received 345 g. of stale, sugar-rich bread at one meal a day during the first year of Carbohydrate Study I. This study was, however, interrupted in order to check the preliminary results obtained in the 24-toffee Groups at the end of the first year of Carbohydrate Study I.

It was therefore not possible to draw any conclusions from this study about the effect of stale, sugar-rich bread.

During the second year of Carbohydrate study I and the first year of Carbohydrate Study II the patients received a daily ration of 22 caramels of an ordinary commercial type. It is clear from Table 34 that 3 of 62 patients consumed only part of the ration. The ration corresponds to 100 g. carbohydrates, of which different kinds of sugar represent 70 g.

During the first year of this study the caramels were served in two portions, one immediately after breakfast and one immediately after lunch. According to the personnel, two thirds of the patients consumed most of the caramels as soon as they received them. Many of them put more than one caramel at a time in

the mouth. During Carbohydrate Study II the caramels were served between meals in 4 portions of 5 to 6 caramels each.

In order to bring the total consumption of sugar up to the level in the Sucrose Group during Carbohydrate Study I, the patients received not only caramels, but also 200 g. sucrose in solution. This extra sugar ration was withdrawn during Carbohydrate Study II. The change from Carbohydrate Study I to Carbohydrate Study II thus implied no change in the caramel ration, but a decrease in the total sugar consumption from 300 g. to 170 g.

The only purpose of this study was to find out whether the consumption of caramels is followed by an increase in caries activity or not. As soon as a supplementary examination performed during the first year of Carbohydrate Study II showed that caries activity had undoubtedly increased, the caramel ration was replaced by an iso-caloric quantity of fat during the remaining part of Carbohydrate Study II. Thus the patients received caramels only during some 6 months of Carbohydrate Study II.

The data of caries activity during the first half year of Carbohydrate Study II, expressed as the number of new carious lesions per person per year, could have been obtained by multiplying the registered number of new cavities during the first half year of Carbohydrate Study II by two. Such calculations were, however, regularly avoided in view of the fairly great error of the method of registration of dental caries. The figures for caries activity, as recorded in the tables and diagrams during the first year of Carbohydrate Study II therefore indicate the caries activity for the last six months of the period during which the patients received a caramel ration, and the first six months of the postactive period.

The figures for the activity during the first year of Carbohydrate Study II are therefore lower than the figures that would have been obtained, if the consumption of caramels had continued for the whole year. Therefore such a value cannot be used for the comparison of caries activity recorded under other conditions in the other groups. This again emphasises the importance of intragroup comparisons in the analysis of the data obtained in the present investigation.

After withdrawal of the caramel ration, this group received the

same food as the Control Group, and may be classified as a post-active group.

Caries Activity

The introduction of the caramel ration was accompanied by an increase in caries activity (Table 34 and Fig. 12). This increase was, however, more gradual than in the other sweet groups. After withdrawal of the caramel ration, caries activity returned to a level corresponding to that recorded during the Vitamin Study and the first year of Carbohydrate Study I. The changes in the mean caries activity were accompanied by changes in the distribution of the number of newly carious surfaces (Fig. 12).

Statistical Analysis

The χ^2-analysis (Table 35) showed highly significant differences between the period during which the patients received caramels and the rest of the entire period of the investigation. A probable difference ($5\,\% > P > 1\,\%$) was also found between the two periods during which the patients received caramels. This latter difference was also reflected in the average caries activity and in the shape of the distribution (Table 34 and Fig. 12). The mean values for caries activity during the second year of Carbohydrate Study II (postactive period) were slightly higher than during the Vitamin Study and the first year of Carbohydrate Study I. The χ^2-analysis also showed a probable difference between these periods, depending on the conditions prevalent during the second year of Carbohydrate Study II. No difference was demonstrable between the Vitamin Study and the first year of Carbohydrate Study I.

Discussion

The statistical analysis distinctly showed that the introduction of the caramel ration was accompanied by an increase in caries activity and that this increase diminished on replacement of the caramel ration with an isocaloric amount of fat. A noteworthy observation was the delay in the rise of the curve for caries activity; a rise that appeared despite the fact that the values recorded

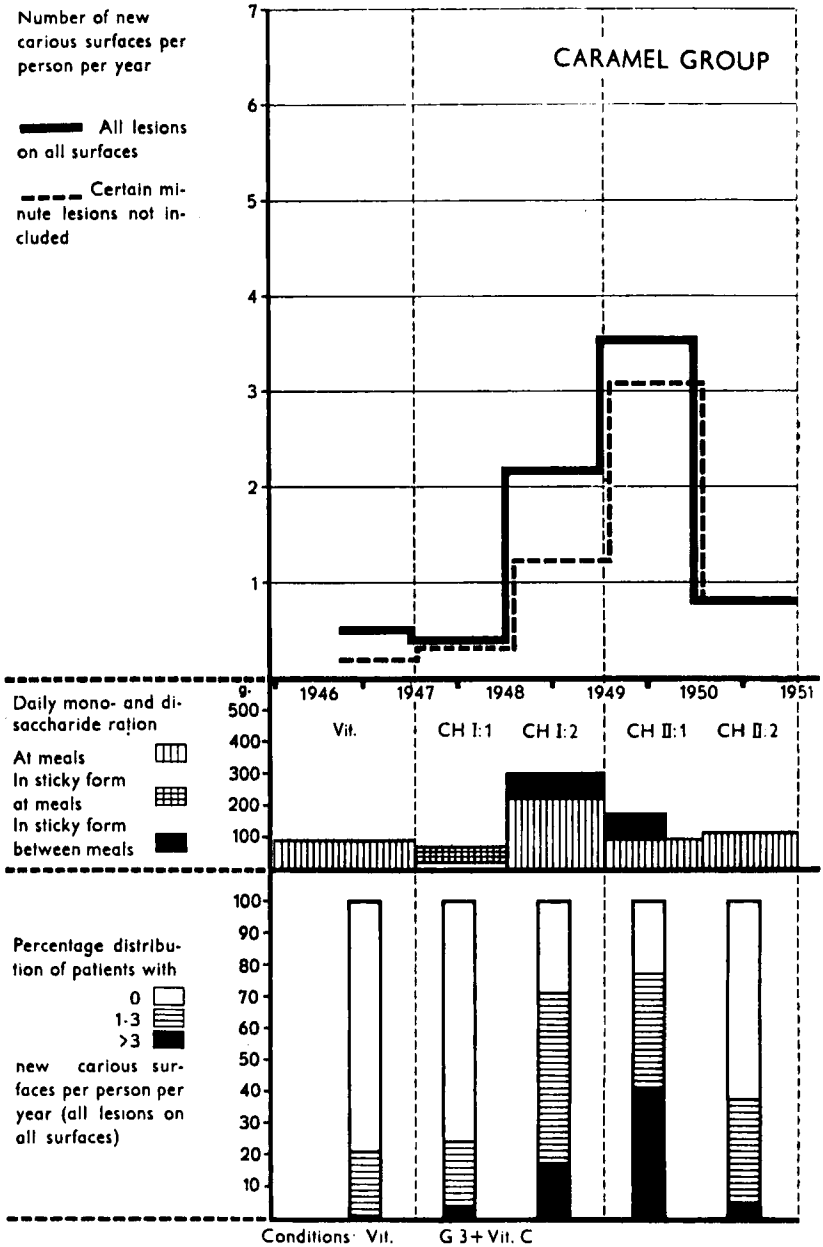

Number of new carious surfaces per person per year
All lesions on all surfaces
Certain minute lesions not included
CARAMEL GROUP
1946
1947
1948
1949
1950
1951
Vit.
CH I:1
CH I:2
CH II:1
CH II:2
Daily mono- and disaccharide ration
At meals
In sticky form at meals
In sticky form between meals
Percentage distribution of patients with
0
1-3
>3
new carious surfaces per person per year (all lesions on all surfaces)
Conditions: Vit. G 3+Vit. C
CH I: 1 G 4+345 g. stale sugar-rich bread at 1 meal
: 2 G 4+ 22 caramels+200 g. sucrose in solution
CH II: 1 G 5+ 22 caramels
: 2 G 5+ 40 g. margarine

Fig. 12.

TABLE 34

Survey of the results in the Caramel Group. (62 patients)

		Vitamin Study	Carbohydr. Study I		Carbohydr. Study II	
			1st year	2nd year	1st year	2nd year
		Vit.C	Stale, high-sugar bread 345 g at one meal	22 caramels 155 g between meals + 200 g sugar in sol.	155 g in 4 portions between meals (10 % red. of basic diet)	No suppl. carbohydrates Cal. compensation 40 g margarine
	Number of patients who consumed					
	> the supplement			—	1	
	= „ „			59	58	
	< „ „			3	3	
	0 „ „			—	—	
Surface losses per person per period	*Primary caries*					
	Per Westin's index-surfaces	0.48	0.34	1.92	3.02	0.66
	Per 148 surfaces	0.50	0.42	2.16	3.55	0.81
	Ibid. but Cwd., Rtg., Ml excl.	0.23	0.35	1.24	3.06	0.84
	Primary caries according to distribution of lesions[1]					
	Mandib. mol.	0.08	0.12	0.57	0.71	0.16
	Mandib. inc.	0.08	0.08	0.69	1.27	0.15
	Maxill. mol.	0.22	0.08	0.26	0.46	0.13
	Maxill. inc.	0.10	0.08	0.42	0.63	0.24
	Previously intact teeth	0.13	0.18	1.05	1.60	0.21
	Cementum caries	—	0.06	0.71	1.64	0.45
	Total surface losses per 148 surfaces					
	Primary caries	0.50	0.42	2.16	3.55	0.81
	Enlargements	0.34	0.95	1.00	1.31	1.15
	Loss of teeth					
	periodontitis	0.23	0.18	0.16	0.29	0.18
	other causes	0.24	0.15	0.14	0.37	0.30
	Total:	1.31	1.69	3.47	5.52	2.44

[1] Third molars not included.

TABLE 35

Statistical analysis of the changes in caries activity in the Caramel Group. Westin's index-surfaces

Comparison	χ^2-value	Degrees of freedom	Probability (P) of the changes being due to chance only
All periods with one another	85.48	8	$0.1\% > P$
The first two periods and the last in relation to the third and fourth	64.07	2	$0.1\% > P$
The third period with the fourth	9.10	2	$5\% > P > 1\%$
The first two periods in relation to the fifth	7.11	2	$5\% > P > 1\%$
The first period with the second	1.04	2	$P > 50\%$

during the first year of Carbohydrate Study I were under-representative by the method of calculation used.

In the interpretation of this phenomenon it should be remembered

1) that during Carbohydrate Study I most of the patients consumed their caramel ration immediately after the meals, while during Carbohydrate Study II, the caramels were consumed mainly between meals,
2) that the diet prescribed for Carbohydrate Study I was not the same as that for Carbohydrate Study II, and
3) that the time necessary for the initiation and development of a carious lesion may be rather long.

Table 34 also shows interesting changes in the localisation of new carious lesions. While caries activity was relatively high in the maxillary and mandibular premolars and molars of the groups accounted for before, the highest activity recorded in association with the consumption of caramels was seen in the incisors and canines of the lower jaw. The frequency of cavities in the cementum or cemento-enamel junction was high in this group. This finding must, however, be judged in the light of the fact that in this group of patients the average age was highest.

These observations may either suggest that the type of caries observed differed from the ordinary one or that this change in the distribution is simply an accompaniment of increased caries activity. It should be pointed out that even if the analysis of the increase in activity is based only on those cavities that appeared in the enamel, the changes in this group will still be statistically significant.

Summary

The consumption of 155 g. (=70 g. sugar) of sweets between meals by 62 males with an average age of 34.9 years was accompanied by a statistically significant increase in caries activity. On withdrawal of the caramel ration without any other reduction in carbohydrates, caries activity diminished to its previous level. The decrease occurred while the patients were on a dietary regime corresponding to ordinary Swedish standard diet with a consumption of refined sugar at meals corresponding to the household consumption.

8-TOFFEE GROUP

40 male patients with an average age of 26.3 years at the beginning of the investigation, were placed on a low-carbohydrate, high-fat diet during the first year of Carbohydrate Study I. The patients then received 60 g. sweets *i. e.* 8 toffees per day for 3 years. During Carbohydrate Study I half of the ration was served at breakfast and the other half at lunch. According to the personnel, most of the patients ate their ration immediately after the meals. During Carbohydrate Study II the ration, still 8 toffees, was served only between meals. This ration corresponded to 50 g. carbohydrates, 40 g. of which consisted of different kinds of sugar.

During Carbohydrate Study I the patients also received 250 g. sucrose in solution in order to bring the sugar intake to the same level as in the other groups. For the same reason, during Carbohydrate Study II the patients received 25 g. sugar in solution at meals so that the total sugar ration was the same as the average Swedish consumption. Thus, the change from Carbohydrate Study I to Carbohydrate Study II involved a decrease in the total sugar consumption, but not of the sugar consumed between meals. The con-

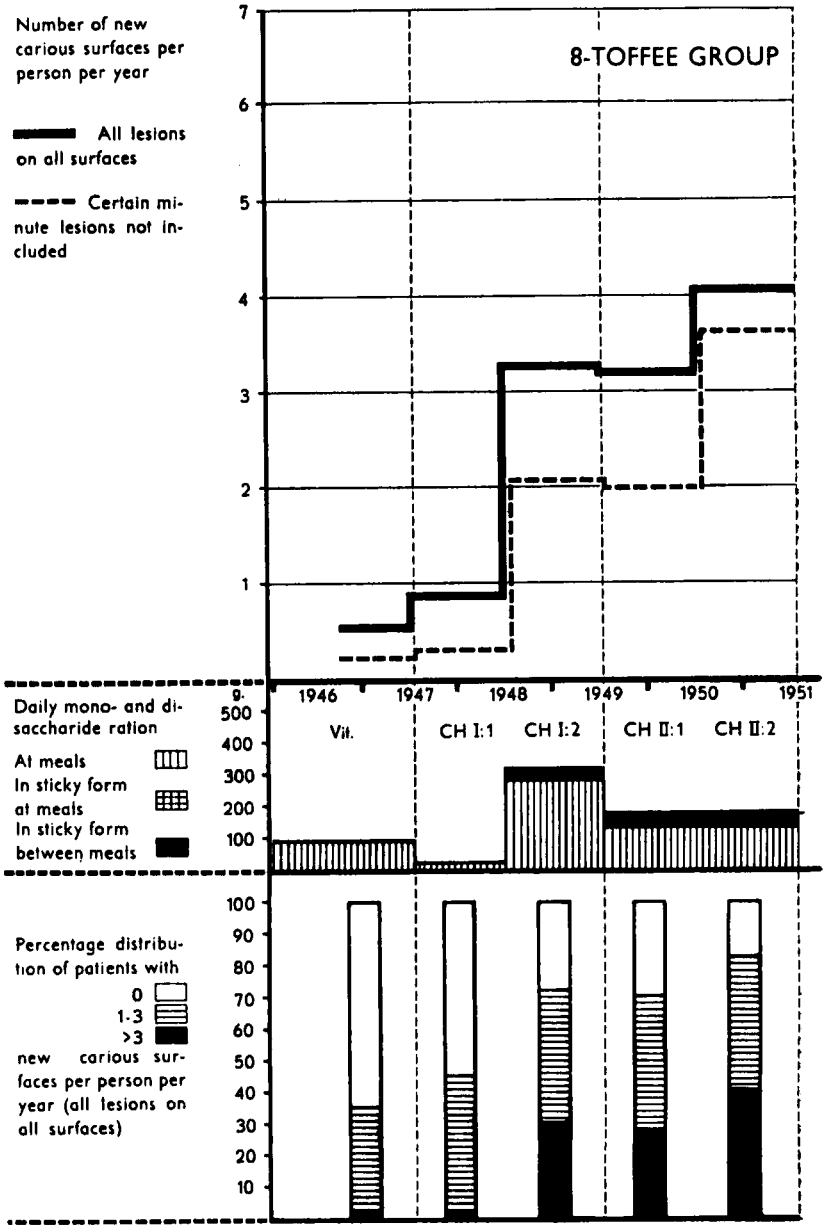

Number of new carious surfaces per person per year
All lesions on all surfaces
Certain minute lesions not included
8-TOFFEE GROUP
7
6
5
4
3
2
1
Daily mono- and disaccharide ration
g.
At meals
In sticky form at meals
In sticky form between meals
500
400
300
200
100
1946
1947
1948
1949
1950
1951
Vit.
CH I:1
CH I:2
CH II:1
CH II:2
Percentage distribution of patients with
0
1-3
>3
new carious surfaces per person per year (all lesions on all surfaces)
100
90
80
70
60
50
40
30
20
10
Conditions: Vit. G 3
CH I: 1 G 4+150 g. margarine
: 2 G 4+8 toffees+250 g. sucrose in solution
CH II: 1 G 5+8 .. + 25 .. ..
: 2 G 5+8 .. + 25 .. ..

Fig. 13.

TABLE 36

Survey of the results in the 8-toffee Group. (40 patients)

		Vitamin Study	Carbohydr. Study I		Carbohydr. Study II	
			1st year	2nd year	1st year	2nd year
			No suppl. carbohydrates Cal. compensation 150 g margarine	8 toffees 60 g between meals + 250 g sucrose in sol.	8 toffees 60 g in 4 portions between meals + 25 g sucrose in sol.	
	Number of patients who consumed					
	> the supplement			—	—	—
	= „ „			34	32	33
	< „ „			5	3	1
	0 „ „			1	5	6
Surface losses per person per period	*Primary caries*					
	Per Westin's index-surfaces	0.50	0.80	3.03	2.78	3.58
	Per 148 surfaces	0.55	0.88	3.28	3.20	4.05
	Ibid. but Cwd., Rtg., Ml excl.	0.23	0.30	2.08	2.00	3.63
	Primary caries according to distribution of lesions[1]					
	Mandib. mol.	0.10	0.28	0.88	0.90	0.90
	Mandib. inc.	0.03	0.13	0.75	0.48	0.65
	Maxill. mol.	0.20	0.35	0.68	0.98	1.02
	Maxill. inc.	0.18	0.05	0.78	0.53	1.13
	Previously intact teeth	0.30	0.38	1.48	1.75	1.65
	Cementum caries	—	—	0.38	0.20	0.88
	Total surface losses per 148 surfaces					
	Primary caries	0.55	0.88	3.28	3.20	4.05
	Enlargements	0.38	1.25	1.15	2.80	2.13
	Loss of teeth					
	periodontitis	0.10	—	0.53	0.35	1.35
	other causes	0.25	0.45	0.28	0.48	0.53
	Total:	1.28	2.58	5.23	6.83	8.05

[1] Third molars not included.

trol of the conditions in this group showed that some patients ate only part of their sweet ration. Therefore the true average consumption was about 45 g. of sweets.

Caries Activity

The mean caries activity recorded with the patients on a low-carbohydrate, high-fat diet (Table 36 and Fig. 13) was, if anything, higher than during the Vitamin Study. The marked reduction in the carbohydrate content and especially the sugar content of the diet had thus not depressed caries activity to nil in these patients. The introduction of sweets was accompanied by a marked increase in caries activity, which reached a level of 3 new carious surfaces per year. It was noteworthy that this level was reached already during the first year of the trial, when the initial cavities were also taken into account. The distributions of the patients with regard to caries activity showed pronounced changes (Fig. 13 and Table 11). As in the caramel studies, the frequency of major cavities did not increase so quickly as that of the minor ones. When caries activity was evaluated on the basis of definite cavities the increase in dental caries was most pronounced during the third year of sweet consumption.

Statistical Analysis

The χ^2-analysis showed that the consumption of toffees was accompanied by a statistically significant increase in the caries activity (Table 37). The individual years before respectively during

TABLE 37

Statistical analysis of the changes in caries activity in the 8-toffee Group. Westin's index-surfaces

Comparison	χ^2-value	Degrees of freedom	Probability (P) of the changes being due to chance only
All periods with one another	38.02	8	0.1 % > P
The first two periods in relation to the last three	34.67	2	0.1 % > P
The first period with the second	0.92	2	P > 50 %
The last three periods with one another	2.12	4	P > 50 %

the sweet consumption did not differ statistically from one another.

Discussion

The reason why caries activity did not appreciably decrease when the patients were on a low-carbohydrate, high-fat diet might be, that the observation time was too short or that the susceptibility to caries was greater in this group than in the rest of the material. This is supported by the average age of the group being lower than that of the others. Judging by the observations made in this group, the consumption of toffees between meals was accompanied by a definite increase in caries activity. This increase was largest for the molars and premolars, although it was fairly high for the incisors and canines. This is discussed further on page 344.

Summary

40 males with an average age of 26.3 years at the commencement of the study were given a low-carbohydrate, high-fat diet for 1 year. Practically no refined sugar was used in the preparation of the food. This diet had no demonstrable effect on caries activity, which was low from the beginning. With the patients on the same basic diet, but with 8 toffees served between meals for 3 years, the caries activity increased. This increase was noted during the first year. When calculated on the basis of definite cavities, the caries activity showed a maximum during the third year (see Fig. 13).

During the last 2 years of the study period the patients were on an ordinary Swedish diet including an amount of sugar corresponding to the average Swedish consumption.

24-TOFFEE GROUPS

During Carbohydrate Study I and II, 48 males and 39 females with an average age of 31.0 and 31.1 years at the beginning of the investigation were studied under identical conditions. During the Vitamin Study the males had received a dietary supplement of 1 mg. fluorine as bone meal (1.8 g.), which was spread on bread.

The females received an addition of calcium as the lactate and vitamins A, C and D.

During Carbohydrate Study I these patients were allowed to eat toffee practically *ad libitum*. However, for purpose of standardisation and control, the daily toffee ration was limited to 24 per patient. This amount corresponds to 120 g. sugars.

In these groups, too, the toffees were consumed both at and between meals. Table 38 shows that 12 of the 48 males did not eat any of their toffee ration during the second year, while 31 ate their entire ration. Two of the patients also ate toffees they received from other patients, while 3 did not consume all their ration. During the first year the actual amount each of the patients consumed was not checked.

Half of the females ate their entire ration. The remainder ate only a varying proportion. However, on the whole, the consumption of toffees by females was greater, because only 2 of them did not eat any toffee at all (Table 40). The actual consumption of toffees during the first year was not evaluated with certainty in this group either.

At the time of these studies (1947—1949) the magnitude of the error of the method of recording caries had not been determined. Therefore the caries activity during that period was judged without regard to minor and doubtful cavities. Under these conditions it was doubtful still 1 year after the start of the study whether the increase in caries activity was statistically significant. This applies especially to the males. Therefore the study time was extended to the second year of Carbohydrate Study I.

According to the supplementary dental examinations, which were done at short intervals in these groups (Fig. 5, page 263), caries activity increased distinctly during the second year of Carbohydrate Study I. Therefore the experiment was stopped at the end of March 1949, *i. e.* earlier than originally intended. The toffees were replaced by an iso-caloric amount of fat. This additional fat ration was given until the beginning of Carbohydrate Study II, when the groups received basic diet G 5 + 40 g. margarine. During this latter period the patients were living under exactly the same conditions as the Control Group, but they have now been regarded as a special group, a post-active group.

Caries Activity

It is clear from Tables 38 and 40 and Figs. 14 and 15 that caries activity, when calculated on all types of carious lesions, increased strikingly already during the first year. As soon as the toffee ration was replaced by an iso-caloric amount of fat and the groups afterwards received the basic diet+fat during Carbohydrate Study II, the activity decreased to a level corresponding to that of the Vitamin Study. The changes in the distribution of the patients according to caries activity are striking. During the second year of Carbohydrate Study I all of the females were caries-active. The mean of the definite cavities showed an obvious lag. Caries activity calculated on definite cavities exceeds the activity as judged on all types of cavities in the female group during the latter part of the investigation. This calls for an explanation. If, for example, "caries without defect" (chalky spots) is not regarded as caries during the first year, many of these cavities enlarge and are then assignable to a type included in the Moulage System during the second year, and classed as new cavities, thus increasing the figures for the later periods.

Statistical Analysis

The χ^2-analysis (Tables 39 and 41) showed that the distributions for the two periods during Carbohydrate Study I differed essentially from the other distributions, which in turn did not differ significantly from one another.

Discussion

There is no doubt that this large consumption of toffee was associated with an increase in caries activity.

However, the two groups differed somewhat with respect to the development of this increase. The mean value for the caries activity was higher for the females; this was also apparent from the appearance of the distributions. Thus, all of the females were found to have active caries, while 10 of the males showed no new carious lesions during Carbohydrate Study I. However, 7 of these 10 patients had not consumed any of their ration during Carbohydrate Study I. It should be pointed out that during the last 18 months before the introduction of the toffee ration the males had

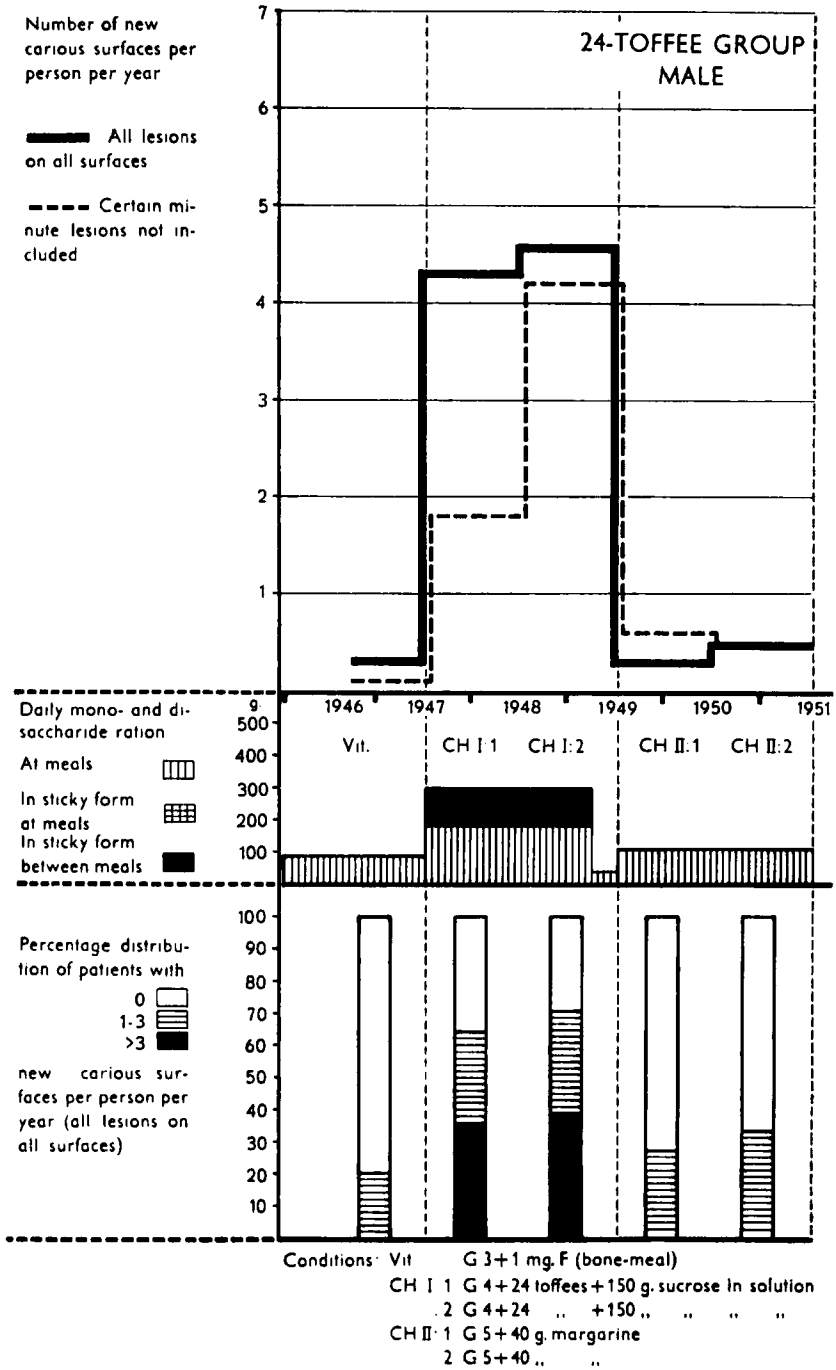

Number of new carious surfaces per person per year
All lesions on all surfaces
Certain minute lesions not included
24-TOFFEE GROUP
MALE
7
6
5
4
3
2
1
Daily mono- and disaccharide ration
At meals
In sticky form at meals
In sticky form between meals
g
500
400
300
200
100
1946
1947
1948
1949
1950
1951
Vit.
CH I:1
CH I:2
CH II:1
CH II:2
Percentage distribution of patients with
0
1-3
>3
new carious surfaces per person per year (all lesions on all surfaces)
100
90
80
70
60
50
40
30
20
10
Conditions: Vit G 3+1 mg. F (bone-meal)
CH I 1 G 4+24 toffees+150 g. sucrose in solution
2 G 4+24 ,, +150 ,, ,, ,, ,,
CH II: 1 G 5+40 g. margarine
2 G 5+40 ,, ,,

Fig. 14.

TABLE 38

Survey of the results in the 24-toffee Group (male, 48 patients)

		Vitamin Study	Carbohydr. Study I		Carbohydr. Study II	
			1st year	2nd year	1st year	2nd year
		1 mg F (bone meal)	24 toffees 180 g between meals + 150 g sucrose in sol.		No. suppl. carbohydrates Cal. compensation 40 g margarine	
	Number of patients who consumed					
	> the supplement			2		
	= „ „			31		
	< „ „			3		
	0 „ „			12		
Surface losses per person per period	*Primary caries*					
	Per Westin's index-surfaces	0.33	3.90	4.15	0.21	0.40
	Per 148 surfaces	0.38	4.29	4.58	0.33	0.50
	Ibid. but Cwd., Rtg., MI excl.	0.08	1.81	4.19	0.58	0.50
	Primary caries according to distribution of lesions[1]					
	Mandib. mol.	0.15	1.13	0.95	0.04	0.13
	Mandib. inc.	0.04	1.15	1.63	0.02	0.06
	Maxill. mol.	0.15	0.67	0.85	0.11	0.11
	Maxill. inc.	—	1.02	0.79	0.06	0.10
	Previously intact teeth	0.17	2.88	1.60	0.06	0.13
	Cementum caries	—	0.69	1.17	0.02	0.06
	Total surface losses per 148 surfaces					
	Primary caries	0.38	4.29	4.58	0.33	0.50
	Enlargements	0.27	0.42	0.79	1.00	0.94
	Loss of teeth					
	periodontitis	0.08	0.27	0.60	0.44	0.85
	other causes	0.48	0.31	0.52	0.37	1.90
	Total:	1.21	5.29	6.50	2.15	4.19

[1] Third molars not included.

TABLE 39

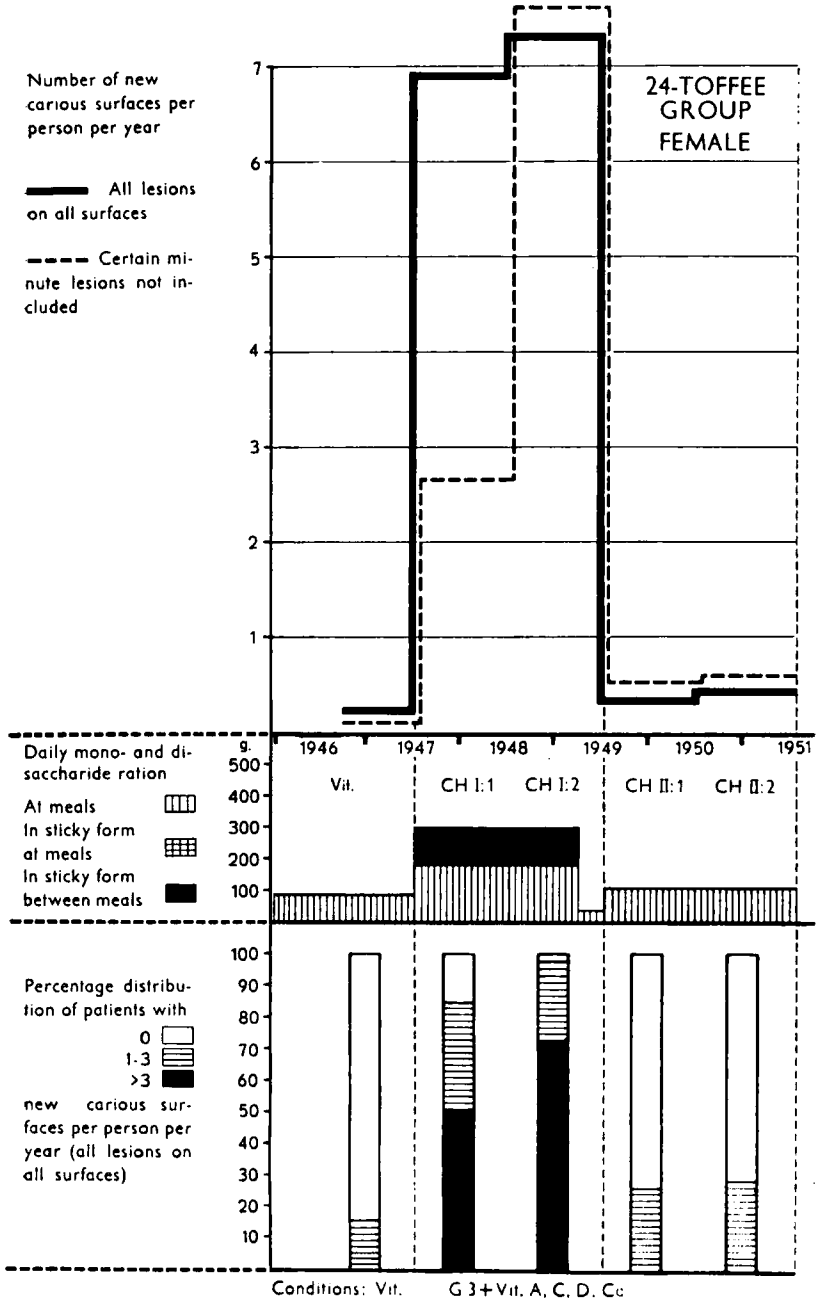
Statistical analysis of the changes in caries activity in the male 24-toffee Group. Westin's index-surfaces

Comparison	χ^2-value	Degrees of freedom	Probability (P) of the changes being due to chance only
All periods with one another	66.56	8	$0.1\,\% > P$
The second and third periods in relation to the others	62.94	2	$0.1\,\% > P$
The first period in relation to the last two	0.50	1	$P > 50\,\%$
The second period with the third	0.07	2	$P > 50\,\%$
The fourth period with the fifth	2.80	1	$10\,\% > P > 5\,\%$

received bone meal. As this was consumed together with the bread ration, it naturally came into contact with the dental surfaces, and because of its fluorine content, it might, at least theoretically, have offered a certain amount of protection against caries.

As in the Caramel Group, caries activity was highest for the incisors and canines of the lower jaw. The preponderance was, however, slight and these teeth were by no means the only ones attacked. The frequency of cementum caries was high (25 per cent of all lesions), which may suggest the occurrence of a special type of caries. It has, however, most probably something to do with the high average age of the patients.

In the broad sense of the term, caries activity also includes loss of surfaces by enlargement of earlier existent cavities. If the process producing continual increase of the size of a cavity is of the same nature as the initial cause of the lesion, the number of intact surfaces lost because of the enlargement of existent cavities should increase with the loss of surfaces from primary caries. This should then be the case in the 24-toffee Groups, in which a great increase in the activity of primary caries was recorded. The loss of surfaces because of enlargement of existent cavities was less during the consumption of toffee than later during Carbohydrate Study II — the postactive period. This may be ascribed to the late initiation of this process, which might have become significant if the toffee consumption had not been interrupted. But the study period spanned almost 2 years, and if the consumption of sugar



Conditions: Vit. G 3 + Vit. A, C, D, Ca
CH I: 1 G 4 + 24 toffees + 150 g sucrose in solution
: 2 G 4 + 24 .. + 150 .. ..
CH II: 1 G 5 + 40 g. margarine
: 2 G 5 + 40 .. ..

Fig. 15.

TABLE 40

Survey of the results in the 24-toffee Group (female, 39 patients)

		Vitamin Study	Carbohydr. Study I		Carbohydr. Study II	
			1st year	2nd year	1st year	2nd year
		Vit. A + C + D; Ca	24 toffees 180 g between meals + 150 g sucrose in sol.		No suppl. carbohydrates Cal. compensation 40 g margarine	
	Number of patients who consumed					
	> the supplement			—		
	= „ „			22		
	< „ „			15		
	0 „ „			2		
Surface losses per person per period	*Primary caries*					
	Per Westin's index-surfaces	0.23	6.13	6.46	0.28	0.38
	Per 148 surfaces	0.23	6.90	7.41	0.36	0.44
	Ibid. but Cwd., Rtg., Ml excl.	0.10	2.67	7.62	0.54	0.59
	Primary caries according to distribution of lesions[1]					
	Mandib. mol.	0.13	1.51	1.77	0.10	0.12
	Mandib. inc.	—	2.03	2.26	0.03	0.05
	Maxill. mol.	0.10	1.18	1.46	0.05	0.10
	Maxill. inc.	—	1.26	1.33	0.10	0.13
	Previously intact teeth	0.13	5.00	2.74	—	0.15
	Cementum caries	0.03	1.05	2.62	0.15	0.05
	Total surface losses per 148 surfaces					
	Primary caries	0.23	6.90	7.41	0.36	0.44
	Enlargements	0.13	0.77	1.49	1.31	1.15
	Loss of teeth					
	periodontitis	0.26	0.05	0.26	0.36	0.10
	other causes	0.21	0.18	0.31	0.59	0.42
	Total:	0.82	7.90	9.46	2.62	2.11

[1] Third molars not included.

TABLE 41

Statistical analysis of the changes in caries activity in the female 24-toffee Group. Westin's index-surfaces

Comparison	χ^2-value	Degrees of freedom	Probability (P) of the changes being due to chance only
All periods with one another	116.44	8	0.1 % > P
The second and third periods in relation to the others	112.92	2	0.1 % > P
The first period in relation to the last two	0.45	2	P > 50 %
The second period with the third	6.17	2	5 % > P > 1 %
The fourth period with the fifth	0.31	2	P > 50 %

TABLE 42

Frequency of enlargements of certain small carious lesions in the 24-toffee Groups.

Type of lesion	Group	Number of new lesions during CH I: 1	New lesions during CH I: 1 enlarged during CH I: 2	No enlargement	Lost by extractions	Per cent enlargements
Cwd	24-toffee Gr. male	67	37	30	—	55
	„ „ female	90	52	36	2	58
	Total	157	89	66	2	57
Rtg	24-toffee Gr. male	16	12	4	—	75
	„ „ female	18	16	2	—	89
	Total	34	28	6	—	82
M 1	24-toffee Gr. male	25	4	20	1	16
	„ „ female	33	8	24	1	24
	Total	58	12	44	2	21

plays an important rôle in the mechanism of enlargement it should have made itself felt, at least during the second year. That this was not always the case is apparent from an analysis of the subsequent development of those initial cavities of the type fissure caries (M 1), Cwd and Rtg-caries, which appeared during the first year of the large consumption of toffees in these groups. It is clear from Table 42 that only about half of these lesions

increased in size during the second year despite the great increase in the number of new carious lesions. In a study similar to the present BOYD (1950) states: "Many minor enamel lesions have appeared and then remained without advance for months or years, even though other cavities elsewhere in the same mouth or even in the same tooth may have progressed concurrently to dentinal involvement."

Summary

During a preparatory period 48 males and 39 females with an average age of 31.0 and 31.1 years, respectively, at the beginning of the study received ordinary Swedish food with an amount of sugar corresponding to the ordinary household consumption in Sweden.

During the following 2 years the total carbohydrate consumption remained unchanged, but the proportion between the different carbohydrates was varied, so that they then received refined sugar in a quantity equal to twice the average consumption. Of the daily ration of carbohydrates 160 g. was given as toffees, which was consumed mainly between meals. During the 2 subsequent years the total carbohydrate consumption remained unchanged, but then the patients received refined sugar at meals and in a quantity corresponding to the average household consumption in 1948. During these last 2 years all consumption of any food between meals was forbidden.

These changes in the carbohydrate distribution were accompanied first by a marked increase in caries activity *i. e.* during the time the patients were offered toffees, and by a marked fall to original level on withdrawal of the toffee ration.

The loss of surfaces because of enlargement of existent cavities did not significantly increase in association with the increase of caries activity.

GENERAL DISCUSSION

Some problems of importance in the evaluation of observations made in the individual groups of subjects were discussed earlier in connection with the presentation of the results. This section is concerned with more general considerations.

MATERIAL

A question that presents itself is whether the type of patients examined were suitable for the study of dental caries. The average age of the series was high, and mental development was low throughout.

In the evaluation of the general applicability of the conclusions suggested by the observations made in the present investigation it is of importance to discuss the following question.

Would the effect of any of the conditions or variables studied in the present investigation produce a stronger or weaker effect in people outside the institution, especially in the younger age groups? The answer to this question depends on how the caries susceptibility of these patients is judged.

Owing to the retraction of the gingiva with age, the cementum is more likely to be attacked than in lower age groups. The frequency of caries in the cementum or cemento-enamel junction was high in some of the groups.

For example, in the 24-toffee Group during the second year of Carbohydrate Study I and the Caramel Group during the first year of Carbohydrate Study II (Tables 38, 40 and 34) a large percentage of the new cavities were localised to the cementum or cemento-enamel junction. It is clear from table 43 that the frequency of cementum caries increased markedly with age. The relative preponderance of cementum caries in the Caramel Group, also when compared with other groups with high activity, must therefore be evaluated in the light of the fact that the average age of this group was higher than that of any of the others.

There was, however, also a correlation between the frequency of cementum caries and the experimental conditions. Thus when sugar was given between meals, the frequency of cementum caries was always higher than with any of the other experimental conditions used. See the survey tables on the opposite pages to the diagrams for the groups.

The high frequency of cementum caries might convey the impression that the changes in caries activity in this material were due mainly to this type of caries. A question that then presents itself is whether the results would be true if caries activity were calculated with the exclusion of the cementum cavities.

Such a calculation would, however, be fictitious as it would infer neglecting the important fact that gingival retraction might decrease the retention of foodstuffs on the enamel and thereby decrease its disposition to caries. Despite this objection the frequency of enamel caries was analysed for the Caramel Group. It was still found that the consumption of caramels was accompanied by a statistically significant increase of caries activity.

If the cementum is less resistant to caries than is the enamel, it might be argued that in the higher age groups the resistance in caries would be relatively low. An argument against such an assumption is, however, that when the series were taken together independently of the experimental conditions, the caries activity was twice as high in the lower age groups as in the higher (Table 43). In those individuals in whom the cementum was frequently exposed, then, caries activity was lower. Obviously this exposure of the cementum does not increase the susceptibility of the material to such an extent as to impair the applicability of the conclusions to lower age classes.

As dental caries cannot heal with *restitutio ad integrum*, the number of surfaces involved — caries frequency — increases with age. The relationship found between age and caries activity in the present material has long been known from other investigations. For example, it has been observed in large series (HOLLANDER & DUNNING 1939, KLEIN & PALMER 1941 and others) that the frequency curve shows the steepest incline during and immediately after puberty, after which it becomes flatter.

Three possible explanations of this relationship between dental caries and age may be considered.

1. Under ordinary living conditions young people may be more exposed to exogenic factors than elderly.
2. The teeth may undergo chemical and structural changes with age and thereby increase the resistance to caries, independently of the presence or absence of any earlier decay.
3. The relationship between dental caries and age may be interpreted as a sign that caries first attacks the most susceptible teeth and dental surfaces, and leaves the least predisposed intact.

The first of these possibilites, *i. e.* that the caries-producing factors are greater in young people than in elderly, cannot by itself explain the relationship between dental caries and age. In the present series, for example, on exposure of subjects to one and the same exogenous caries-producing factor the effect was greater in the lower age groups (Table 43).

TABLE 43

Relation between age, caries activity and cementum caries during all periods 1946—1951. Third molars not included

Age Group	Nr. of pat.		New carious surfaces				
			Total		Cementum caries		
		% of the whole material	Number	per person per period	Number	% of total	per person per period
Born:							
Earlier than 1910	151	34.6	719	0.95	384	53.4	0.51
1910—1919	148	33.9	525	0.71	114	21.7	0.15
1920—1929	113	25.9	923	1.63	70	7.6	0.12
1930 or later	24	5.6	326	2.72	7	2.1	0.06
Total	436		2493	1.14	575		0.26

As to the second possibility of the resistance of the dental surfaces increasing with age, depending on chemical and structural factors, suffice it here to state that if this is the case, it would infer that the experimental conditions used would have produced a still greater caries activity in a younger series than in the present one.

If the third point were the only explanation it would infer that the average resistance of a group of individuals could be expressed as the number of DMF surfaces or teeth: the higher the DMF-number the greater the resistance of the remaining surfaces..

In order to evaluate the DMF-values of the material, comparative analyses were made with other materials.

Children attending a grammar-school (*Katedralskolan*) in Lund were examined by the same dentists as performed the main registration in the Vipeholm investigation proper. The average individual number of DMF teeth recorded by them in 14-year old school children there was 15.4. The corresponding figure found by GUSTAFSSON & WIBOM (1952) in a 14-year old, public dental

clinic clientele was 11.5. This difference in frequency is probably ascribable to differences in criteria accepted in classing a tooth surface as decayed. In 20-year old men called up for military service WESTIN & WOLD (1943) found an average individual frequency of 18.44 DMF teeth.

Table 44 shows that among the 14-year old children at *Katedralskolan* the caries activity was higher than in any of the male groups in the Vipeholm material. Distribution of the children according to the number of new carious surfaces per individual per year in the *Katedralskolan* material showed the same pattern as in the active groups of the Vipeholm Hospital. Thus in some of the pupils the number of surfaces involved was markedly high, while in others there were only few or no new cavities (Table 45). Among these 14-year old children the number of surfaces lost per year was sometimes as high as 20 per individual.

In the beginning of the Vipeholm investigation the average age of the males was 32.2 years, and the average DMF-value was 15.6. At the start of the Carbohydrate Study I the DMF-values in all of the groups were not as high as that found by WESTIN & WOLD for 20-year old conscripts (18.44). This further infers that any increase in activity would not have been masked by too small a number of intact surfaces at the beginning of the investigation.

In view of the high average age of the subjects in the present material, the frequency of caries observed in the beginning of the study must be regarded as low and may be explained by any of the following possibilities.

a) The low caries frequency must be due partly to the fact that some patients (17 per cent of the total number of patients of the hospital) had less than 10 teeth at the beginning of the study and were therefore excluded from the series (cf. page 238).

b) It might be due to the fluoride content of the drinking water.

In a series consisting of 7,257 children aged 12—14 years DEAN et al. (1941, 1942) found on the average about 8.0 DMF teeth per child in districts in which the fluoride content of the drinking water was 0.0—0.1 mg./l, the corresponding figures for 0.4—0.5 mg./l and 1 mg./l being 5.0 and less than 3 DMF teeth respectively. Thus, in view of the fluoride content (0.4 mg./ml) of the drinking water used at Vipeholm, one might expect the caries frequency

TABLE 44

Caries activity in schoolboys at "Katedralskolan"

Age group	Number	New DMF surfaces per child per year
10	17	2.53
11	69	4.91
12	80	5.36
13	59	6.22
14	25	7.16
10—14	250	5.42

in the patients there to be about 30 per cent lower than in a group of subjects drinking flouride-free water.

As the patients did not enter the hospital until they were 8 years of age, before which the influence of fluorides is supposed to be of decisive importance, the fluoride content of the drinking water in Lund seems not to be the cause of the low caries frequency of the patients. RUSSELL & ELVOVE (1951), however, present results indicating that the fluorides have also a post-eruptive effect. As the school-children at *Katedralskolan* have the same drinking water, but the same caries frequency as the patients at Vipeholm Hospital despite their being 18 years younger, the fluoride content

TABLE 45

Distribution of schoolboys at "Katedralskolan" according to caries activity

New DMF surfaces per child per year	Number of children
0	18
1— 3	71
4— 6	82
7— 9	50
10—12	14
13—15	5
16—18	5
19—21	4
> 21	1

of the drinking water cannot explain why the dental caries frequency of the patients at the hospital was low.

c) The low frequency of caries may be ascribable to the assumption that mental deficiency is associated with increased resistance to caries.

This point was studied by grouping subjects according to degree of mental deficiency and comparing them with respect to caries activity and caries frequency. The patients were grouped (grades 0—6) in accordance with the method described by FRÖDERBERG (1952). The males were divided into 2 groups, those assigned to grades 0—3 forming one group, and those allotted to grades 4—6 the other, after which the frequency of caries observed at the beginning of the carbohydrate trial and the caries activity recorded during the trial were calculated (Table 46). As these values also vary with age, three age groups were distinguished.

It is clear from the table that the frequency of caries, as judged by the number of caries-free surfaces, was lower in the 0—3 grade group than in the 4—6 grade group. These two groups did not differ with regard to the average activity recorded during the study periods.

This suggests that mental deficiency is associated with a moderately decreased predisposition to dental caries, and thus that the institutionalised subjects were more resistant to caries than ordinary young people.

d) The lowness of the frequency of caries among the patients may also be explained by a possibly decreased exposure to caries-producing factors. If so, it is ascribable to the fact that most of them had spent long periods at institutions. It is known that caries activity decreases from year to year in institutionalised subjects. Readers interested in a survey of the literature on this point are referred to GUSTAFSSON, 1954.

In addition to the above aspects of resistance, certain other circumstances should be stressed concerning the question whether the caries-promoting factors under consideration are capable of exerting one and the same effect on non-institutionalised people.

As already pointed out (page 241 and 272), some of the subjects sometimes swallowed one or more toffees or caramels without che-

TABLE 46

Comparison between the intelligence groups 0—3 and 4—6 regarding caries frequency and caries activity

Born	Number of pat.		Nr. of intact surfaces per person at start of the Carbohydrate Study		Nr. of new carious surfaces per person per year. Average 1946—1951	
	0—3	4—6	0—3	4—6	0—3	4—6
Earlier than 1910	67	54	73	65	0.85	1.00
1910—1919	77	42	93	81	0.88	0.83
1920 or later	83	32	102	87	1.68	1.80

wing them. This means that the tendency of the sugar to be retained in the mouth was in reality less than that suggested by the number of caramels consumed. If caramel consumption increases caries activity, the increase seen in the present series must be smaller than it would have been if the caramels had been chewed before swallowing.

On page 240 it was mentioned that oral hygiene was poor or absent in the present material. This often resulted in massive deposits which would not be tolerated by normals. This favoured the retention of carbohydrates, and it does not sound unreasonable to suppose that any one and the same caries-accelerating factor might exert a greater effect than it would have in the presence of ordinary oral hygiene.

Summary

It is obvious that the high average age, the fairly low caries frequency observed at the beginning of the trial, the poor oral hygiene and the habit of some of the patients to swallow the sweets without chewing them, as well as the mental deficiency of the series, make it difficult to judge the caries susceptibility of the patients. However, numerous data presented in the literature show that the chemical and physical properties (e.g. increasing hardness, lower permeability) change with age in such a way as to increase the resistance to caries. In our opinion, age as such is the decisive factor and the other factors discussed above have only a

modifying influence. In view of the high average age of the patients it is therefore highly probable that the resistance to caries in the subjects studied was greater than in young non-institutionalised people. This infers that any variable producing an increase in caries activity in these patients will more than probably do so in a normal younger population. In addition, any of the factors that produced only a slight or doubtful increase in caries activity in the patients or an increase that could not be demonstrated with certainty owing to he sources of error of the method and to the smallness of the groups, might possibly cause a more distinct tendency or even statistically significant increase in caries activity in ordinary young people.

DISTRIBUTION OF CAVITIES AMONG VARIOUS TEETH AND TOOTH SURFACES

From the tables on the caries activity in the various groups (27, 34, 36, 38 and 40) it is apparent that on consumption of sugar between meals, up to 25 per cent of the new carious lesions were seen in the incisors and canines of the lower jaw, which usually show the lowest caries activity. This might suggest that the type of caries recorded differed from the ordinary type. This preponderance of carious lesions in the front teeth might, however, be ascribable to the high average age of the patients with the result that the number of hitherto intact surfaces of these teeth was much higher than for the molars, many of which had been attacked or lost already before the commencement of the investigation. Thus, at the beginning of the study there were altogether 3,327 intact incisors and cuspids, as against 2,407 intact premolars and molars. This means a ratio of 12 : 9 as against 12 : 20 in a caries-free mouth. Therefore even in groups with a low caries activity the frequency (16.7 per cent) of new carious surfaces of the incisors and cuspids of the lower jaw was higher than among 7—15 year old individuals (2.7 per cent) as calculated from data given by KNUTSSON & SCHOLZ (1950). The tables show that the preponderance of carious surfaces among the incisors and cuspids was greatest in those groups that received the largest sugar ration between meals.

TABLE 47

Frequency of new carious lesions in incisors and canines of the lower jaw in the 8-toffee Group.

	Number of new carious lesions per person per year	Number of new carious lesions in incisors and canines per person per year	
			per cent
The year before toffee consumption (No supplementary carbohydrates)	0.81	0.13	16
During toffee consumption			
1st year	3.09	0.75	24
2nd year	2.89	0.48	17
3rd year	3.70	0.65	18

However, a survey of the results in the 8-toffee Group showed that in this group with a smaller amount of sweets between meals, the caries activity in the incisors and cuspids of the lower jaw was the same during consumption of sweets between meals as when the patients were on a practically sugar-free diet (see Table 47).

Typical of "sugar caries" is supposed to be a relative preponderance of buccal caries. Table 48 shows that the relative fre-

TABLE 48

Frequency of facial (buccal) and lingual caries in intact teeth in relation to the consumption of sweets
Main material

	Total number of new carious lesions in intact teeth	Number of facial surfaces with new lesions		Number of lingual surfaces with new lesions	
			per cent		per cent
When sweets were not consumed	380	141	37	5	5
When sweets were consumed	935	407	44	2	1

quency of new carious lesions on the facial surfaces is not significantly higher during the consumption of sweets (44 per cent) than under other conditions (37 per cent), even if the groups with the highest sweet consumption are also included.

A detailed analysis of the distribution of new carious lesions will be given in a later paper.

INDIVIDUAL VARIATION IN DISPOSITION TO CARIES

In connection with the statistical analysis of the changes in caries activity it was pointed out that the distribution of the patients according to different activity classes is markedly asymmetric. A study of the caries activity in individual patients over a number of years showed that caries activity under identical conditions varied widely, not only from one individual to another but also from one year to another in one and the same patient. Thus, in some patients who consumed large quantities of sweets no new carious surfaces were observed, while in others on a practically sugar-free low-carbohydrate diet as many as 9 new cavities per year were recorded. In the 8-toffee Group there were persons in whom active caries was noted while they were on a sugar-free diet during the first year of Carbohydrate Study I but did not show any new carious surfaces the following year when they received totally 300 g. of sugar including 60 g. of sweets between the meals. Such variations in the disposition to caries and their effect in extended studies on the averages of caries activity require further study.

REGISTRATION OF CARIES

In the registration of caries a certain amount of errors must be expected especially in materials consisting of feeble-minded patients. A study of the literature failed to reveal any information about the magnitude of the error of the method observed by earlier workers in this field. The order of the error of the method in the present investigation was assessed on the basis of special control registrations (QUENSEL et al. 1954). This made it possible to make due allowance for the inaccuracy of the method in the interpretation of the results obtained.

Pits, deep fissures, and enamel hypoplasia are sometimes mistaken for caries (over-registration) by some examiners but not by others. Sometimes, however, carious changes are not recognised or not registered as such (under-registration). This results in discrepant recordings.

In the assessment of the accuracy of the method the tendency of the individual examiners to over- or under-registration was taken into account. It was, of course, necessary to assume that the tendency of a given examiner in one direction or the other was one and the same throughout the investigation. In a long-term study of the present type it cannot be guaranteed that the examiners sooner or later do not become aware of the experimental conditions. This point calls for a few comments.

Already before the present investigation was started persuasive evidence was available that sugar is a caries-producing substance. That the dietary addition of a substance rich in sugar would increase caries activity and that a reduction in carbohydrate consumption would be followed by a decrease in caries activity was probably suspected by the examiners. It therefore sounds reasonable to suppose that the tendency of an examiner to record doubtful changes as caries, for example, would be still more pronounced in the examination of subjects receiving such dietary supplements as might be expected to accelerate caries activity. It might likewise be imagined that any tendency of the examiner to over-register would diminish or that he would even be inclined to under-register as soon as he became aware of the withdrawal of such a caries-promoting supplement. This would result in too large an increase of the values recorded for periods during which the patients received a diet rich in sugar. On the other hand, the values noted for periods during which carbohydrate consumption was restricted would be too low.

In order to check whether the examiners really were influenced by their knowledge of the experimental conditions, the following control test was performed. After registration of the state of the teeth in a group of subjects receiving a caries-producing diet, some of the members were re-examined immediately afterwards together with subjects belonging to other groups with low activity (control registrations, Tables 4 and 5 in QUENSEL et al. 1954).

If the recordings were influenced by the knowledge of the experimental conditions, the second values would be lower. However higher values were recorded, which can partly be explained by new cavities developing during the 4 weeks between the two examinations. These findings argue against over- or under-registration because of knowledge of the experimental conditions.

In both the main and the supplementary registrations the number of DMF teeth was calculated for every group of patients. These values, of course, increase according to the number of new carious surfaces.

If knowledge of the experimental conditions influenced the examiners in deciding whether a lesion should be classed as carious or not, it is difficult to understand that the 5 different DMF-values for each of the 8-toffee Groups and the two 24-toffee Groups during the sweet-consumption should form the straight lines illustrated by the curves in Fig. 6 (page 284). If the examiners had been influenced, the effect would probably have been most obvious at the first examination after the introduction of the new experimental conditions, and the curves would then have been of a different and more irregular shape.

Finally, it should be pointed out that if the examiners had overdiagnosed caries in those groups in which an increase of caries activity was expected on account of the dietary addition of sugar, such an influence would have increased the activity figures in all groups with additional sugar. An increase in the dental caries activity did, however, not appear in the group receiving the largest amount of sugar (330 g. at meals). Moreover the examiners reported that they thought it strange that the consumption of 300 g. sucrose in solution and of new, doughy bread rich in sugar during the Carbohydrate Study I did not demonstrably increase caries activity.

Summary

Despite the fact that some of the evidence presented above was indirect, it appears very improbable that the changes observed in caries activity in the present investigation should have anything to do with the examiners' having been aware of the experimental conditions.

TABLE 49

Sugar- and sweet consumption in kg. per person per year in Sweden 1939—1953[1]

Year	Total sugar	Sweets
1939	52.7	7.6
1940	43.4	7.1
1941	38.7	6.7
1942	42.2	6.5
1943	39.9	6.3
1944	38.3	7.4
1945	38.0	7.3
1946	37.0	7.5
1947	36.4	7.7
1948	40.2	7.0
1949	42.9	6.6
1950	47.1	6.5
1951	42.3	4.8
1952	42.6	6.0
1953	41.2	

[1] According to "Statens Jordbruksnämnd" (The State Agricultural Marketing Board).

RELATIONSHIP BETWEEN SUGAR CONSUMPTION AND CARIES ACTIVITY

In some of the groups the dietary supplements used during Carbohydrate Study I gave the diets the character of extreme variants. For instance, in one group the diet was poor in carbohydrates, practically sugar-free but rich in fat, while in others the sugar content was more than twice the average Swedish consumption (see Table 49).

With a mean annual consumption of 45 kg per individual in Sweden and the sugar consumption of certain groups being very low, it is quite possible that some Swedes consume 80—90 kg sugar per year.

Therefore the large quantities of sugar used during Carbohydrate Study I probably represent a level just above the highest that might be expected outside the institution. In Carbohydrate Study II some of the conditions closely resembled those met with

outside the institution. For example, the total sugar consumption was the same as the average consumption outside the institution and the percentage incorporated in the food was also about the same as in most Swedish families. In certain respects, however, the conditions differed from those outside the institution.

Thus the bread eaten at every meal in the Bread Groups was very sweet (sugar content 15 %) but still of a type consumed in Swedish households at after-noon coffee and tea. The type of bread generally consumed at every meal in the households has, however, unlike in other countries, also a rather high sugar content (about 8 %).

The consumption of sweets between meals probably bordered the upper limit of the amounts consumed outside the institution. This was shown by the investigation of the amounts of sweets consumed at the elementary shools of Lund (QUENSEL & GUSTAFSSON, 1952). If those schoolboys who consumed most sweets were to buy toffee for the total amount of money they spent on all sorts of sweets, the daily consumption would be 8—9 pieces of toffee per boy. If they spent this money on chocolate only, the amount they would eat would be about half of that received daily by the Chocolate Group.

The consumption in the sweets groups in this investigation might be compared with the average consumption in Sweden, as calculated as the total consumption distributed among all inhabitants. The consumption in the 8-toffee Group and the Chocolate Group would then be three times this figure. Such an average figure is, however, too low as a large part of the population never or very seldom consume sweets.

The consumption of sweets during the carbohydrate studies differed in other respects from that outside the institution, in that the ration did not vary from one day to another and the type of preparation was one and the same throughout the study period.

It should also be borne in mind that the toffee used in the investigation was of a type of sweets that is not generally consumed in Sweden. As the intention was to study the retention of *sugar* in the present investigation, the toffee was specially prepared to contain ingredients other than sugar in the least possible amount. The toffee, however, resembled certain types of sweets

on the market, and is very similar in consistence and taste to English toffee. The weight of each toffee was the same as that of each caramel, which was of a type very popular in Sweden. The latter can be shortly characterised as a toffee containing milk powder; therefore the caramel mass when heated takes a brown colour.

These differences between the conditions inside and outside the institution must be seen in the light of the fact that the experimental variables used in the various groups had to be studied under uniform conditions. It was never the purpose of the investigation to try to determine the minimum amount of any kind of sweets that could be consumed by an ordinary person without injury to the teeth.

The purpose of the investigation was instead to study caries activity in relation to varying sugar retention on the surfaces of the teeth under standardised conditions. Sugar retention was increased by the addition of

I. large quantities of sugar,
II. sugar on many occasions throughout the day,
III. sugar in sticky form,
IV. sugar in concentrated form.

Sometimes these methods were used separately, sometimes in combination. As to the addition of sugar, four types of experimental conditions were used:

sugar given in small quantities at meals and with only a slight tendency to be retained on the surfaces of the teeth (Control Group);

sugar given in large quantities at meals and with only a slight tendency to be retained on the surfaces of the teeth (Sucrose Group) I above;

sugar given in large quantities at meals and with a strong tendency to be retained on the surfaces of the teeth (sticky preparation, Bread Groups) I+III above;

sugar given in large quantities also between meals, the latter with a strong tendency to be retained on the surfaces of the teeth (sticky preparation with sugar in high concentration, sweet groups) I+II+III+IV above.

As far as subsequent changes in caries activity is concerned, these conditions fall into two main categories, the first comprising the first two types above, in which the sugar was served at meals and in a form with only a slight tendency to be retained on the surfaces of the teeth. As the very sweet bread was served only once a day during the Carbohydrate Study I, the conditions and caries activity recorded during this period were regarded as belonging to this main category.

Table 50 shows that in this first main category the daily total amount of sugar given varied from 30 g. to 330 g. per person. The consumption of refined sugar per person thus ranged from 0.4 kg. to 110 kg. per year. Despite this wide variation in the sugar consumption caries activity was low and constant in all groups and throughout all the periods. Comparison of the means suggested no differences. The Sucrose Group with G 5+75 g. sucrose was the only group to differ from any of the others. Statistical analysis, however, failed to reveal any difference than those due to chance only.

But the frequency of persons with more than 3 new cavities was significantly higher for the first three conditions in table 50 than for the remaining three (12 of 442, as against 5 of 740). This thus suggests that the three last-mentioned conditions in table 50 are capable of producing a slight increase in caries activity. This conclusion is based on inter-group comparison and may be due to a possible inclusion of a few subjects with high caries susceptibility in this group. Furhermore, it is probable that the larger proportion of bread and potatoes in basic diet G 5 than in G 4 also favoured caries activity.

The relationship between the sugar consumption at meals and caries activity found in the present investigation is further apparent from the diagram given in Fig. 16. The broken line in this diagram represents the relationship between sugar consumption at meals and caries activity. On account of the above described, probably slightly higher frequency of caries in those groups receiving the three types of diets with the largest amounts of sugar, the curve shows a slight slope.

Thus the consumption, at meals, of sucrose in a form with only a slight tendency to be retained on the surfaces of the teeth, with

TABLE 50

Caries activity and sugar consumption 1. Low retention tendency. Sugar at meals

Diet	Sugar consumption		Nr. of observation units [1]	Nr. of new carious surfaces	Nr. of new carious surfaces per person per year	Nr. of observation units in activity classes		
	Total g/day	Sucrose kg/year				0	1–3	>3
G4 + 150 g. margarine	30	0 (0.4)	160	43	0.27	134	22	1
G4 + high-sugar bread at one meal	80	19	144	46	0.32	116	27	1
G3	90	21	436	149	0.34	340	93	3
G5 + 40 g. margarine	110	24	120	60	0.50	92	24	4
G5 + 75 g. sucrose in sol.	190	51	114	84	0.74	88	22	4
G4 + 300 g. sucrose in sol.	330	110	208	89	0.43	159	45	4

[1] One patient observed during one year = one observation unit.

a daily ration up to 300 g. a day and all observation time of up to 4 years, had no definite influence on the basic caries activity of 0.3—0.5 newly carious surface per year in this material.

The observations made in the subjects studied under the other main category of conditions, i.e. the consumption of sugar in a form with a strong tendency to be retained on the surfaces of the teeth were, however, altogether different. Table 51 summarises the resulting caries activity. It is clear from Table 52 that the consumption of only a fraction (13 %) of the total amount of sugar between the meals was sufficient to increase caries activity. Large differences were noted in the caries activity figures for the different conditions and periods. The differences were statistically significant: χ^2-analysis gave a value of 55.61 (12 degrees of freedom, $P < 0.1$ per cent).

TABLE 51

Caries activity and sugar consumption 2.
High retention tendency. Sugar also between meals

Diet	Sugar consumption		Nr. of observation units [1]	Nr. of new carious surfaces	Nr. of new carious surfaces per person per year	Nr. of observation units in activity classes		
	Total g/day	Sucrose kg/year				0	1–3	>3
G5 + high-sugar bread at all meals	160	40	82	107	1.30	52	21	9
G5 + 65 g. milk chocolate	140	32	94	110	1.17	47	38	9
G5 + 22 caramels	170	33	62	187	3.02	19	20	23
G4 + 22 caramels + 200 g. sucrose in sol.	300	84	62	119	1.92	22	31	9
G5 + 8 toffees + 25 g. sucrose in sol.	180	43	80	254	3.18	23	32	25
G4 + 8 toffees + 250 g sucrose in sol.	320	102	40	121	3.03	12	16	12
G4 + 24 toffees + 150 g. sucrose in sol.	300	84	96	386	4.02	36	27	33

[1] One patient observed during one year = one observation unit.

In all the groups of this category the activity increased earlier in the subjects receiving the sugar between meals (sweet groups) than in those who received sugar at all meals (Bread Group), where the increase was not apparent until the second year. A similar tendency was in the Caramel Group, where there was a definitely higher activity during the second year of caramel consumption than during the first year. As the actual experimental period of the second year was only 6 months, the difference between the two years was in reality still greater. But also in the other sweet groups the increase in caries activity was gradual when

TABLE 52

Sugar consumption between meals and caries activity

Diet	Sugar consumption			Nr. of new carious surfaces per person per year
	Total g. per person per day	Between meals		
		g. per person per day	% of total consumption	
G5 + 65 g. milk chocolate	140	30	21	1.17
G5 + 8 toffees + 25 g sucrose in sol.	180	40	22	3.18
G4 + 8 toffees + 250 g. sucrose in sol.	320	40	13	3.03
G5 + 22 caramels	170	70	41	3.02
G4 + 22 caramels + 200 g. sucrose in sol.	300	70	23	1.92
G4 + 24 toffees + 150 g. sucrose in sol.	300	120	40	4.02

the calculations were made on the definite cavities excluding initial lesions.

This time lag between alteration in the consumption of sugar and the change in caries activity has been observed in the investigations concerning the caries activity in different countries during the two World Wars. This lag must be borne in mind when correlating the sugar consumption with caries activity. It is possible that an increase in caries activity shows up much later than generally recognised, especially if the increase in the caries accelerating factors is fairly small. In the groups studied here the time lag appears, although the consumption of sweets between meals was increased from nil to very high values.

In Fig. 17 the values for caries activity in association with the consumption of sugar with a strong tendency to be retained on the surfaces of the teeth have been plotted.

According to the above mentioned longitudinal variations, the caries activity figures for the different years of sweet consumption are not always equivalent in the same groups. Therefore the value for the second year of sweet consumption was taken as representative for the different types of conditions (chocolate, 8 toffees,

caramels and 24 toffees). In the diagram these activity figures are also connected by a thin line with the activity figures for the group during the year preceding the sweet consumption. In this way the diagram illustrates the increase in caries activity for different amounts of sugar consumed between meals. As the 8-toffee Group has a higher starting value than the other groups, the increase is of the same order for all groups, although two such different activity values as 1.23 and 2.78 (Chocolate and 8-toffee Groups) correspond to almost the same sugar consumption.

Fig. 17 directed attention to the shape of the regression line for the relation between sugar consumption between meals and caries activity. Although the distribution of the values suggest an almost linear relationship, in our opinion the number of values available is too small to merit any definite conclusion. Furthermore, no activity values are available for the important consumption values between 0 and 30 g. per day, i.e. the range within which the average consumption of the population falls. However, the observations made in the present investigation provide convincing evidence that the consumption of sugar in a sticky form between meals does favour caries.

In this connection it is also of interest to discuss certain observations made in the supplementary studies. As already pointed out, the amount of sugar consumed between meals was about the same in the Chocolate Group (30 g.) as in the 8-toffee Group (40 g.), but the increase in caries activity was much greater in the 8-toffee Group. This difference was striking, especially if only the definite cavities are taken into account (Figs. 11 and 13, pages 306 and 324).

LUNDQVIST (1952) considered the time that sugar could be demonstrated in the saliva as a measure of sugar retention. He found that the saliva contained sugar for just as long a time in the Chocolate Group as in the 8-toffee Group. This suggests that, according to the chemo-parasitic theory, both conditions should equally favour caries. Possible explanations for the differences observed between the caries accelerating potencies of chocolate and toffee are the following (GUSTAFSSON 1952 a).

1. The retention of sugar on the dental surfaces in association with the consumption of chocolate is not so high as for toffee, be-

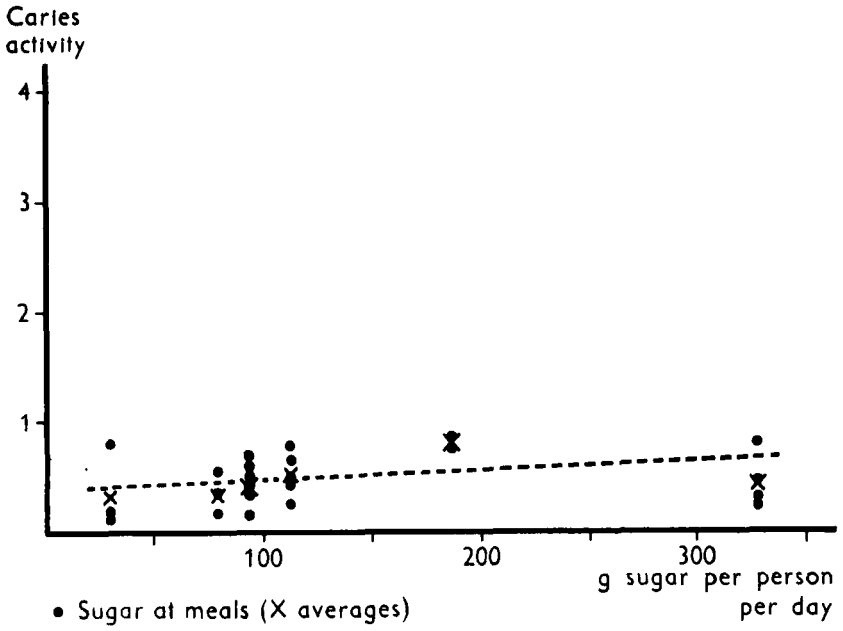


Fig. 16. The relationship between sugar consumption at meals and caries activity.

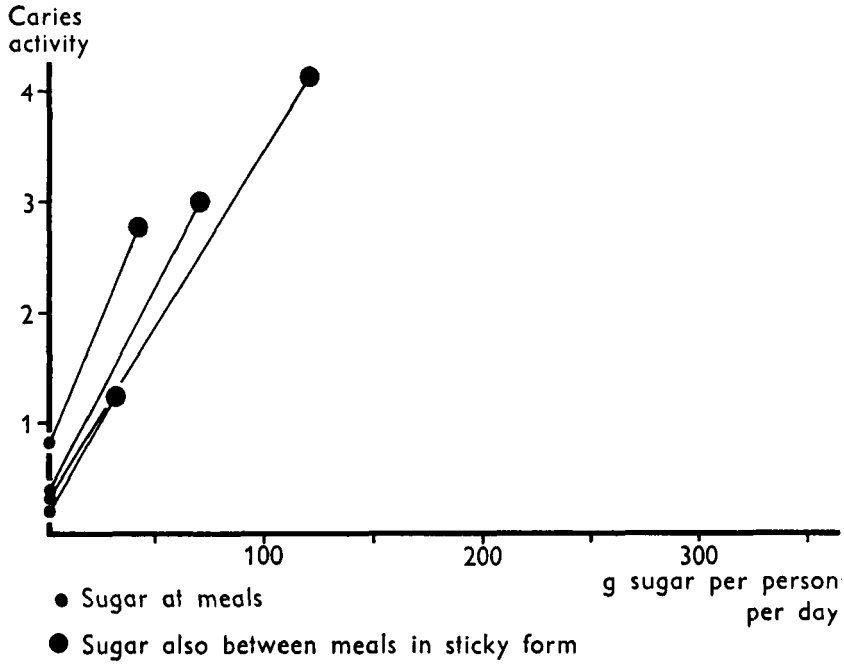


Fig. 17. The relationship between sugar consumption between meals and caries activity. Cf. p. 355.

cause the latter is "stickier". This difference in stickiness was demonstrated by the observation of LUNDQVIST that the "sugar time" for 11 g. chocolate was the same as for 7 g. toffee in the same persons.

2. Chocolate contains a large proportion of fat, which has been shown to decrease the caries-promoting effect of sugar in experimental animals (cf. page 293).

3. The concentration of sugar in chocolate is slightly lower than in toffee.

4. Chocolate might contain small amounts of anti-enzymatic or anti-bacterial substances (GUSTAFSSON 1952 b).

5. The caries susceptibility was greater in the 8-toffee Group than in the Chocolate Group.

It appears most likely that the divergence between the two groups is due mostly to the difference in susceptibility to caries, but the factors in 1—4 above may also have contributed.

Observations made in the Bread Groups also indicated that the retention factor, when measured as the time the sugar is retained in the saliva was less than might have been expected. LUNDQVIST (1952) found that the retention of sugar in the saliva of subjects belonging to these groups was on the average shorter than in any of those groups, including the Control Group, in which the members received sugar at meals and in a form with only a slight tendency to be retained on the dental surfaces. This might suggest the involvement of some other factor responsible for the difference between the bread groups and the sweet groups regarding caries activity. On the other hand it is questionable whether the "sugar time" of the saliva always reflects the actual conditions on the dental surfaces.

The course of caries activity following the withdrawal of the dietary addition of a caries-promoting factor was studied in three groups, the Caramel- and 24-toffee Groups. In all three groups caries activity diminished to the basic level within one year of the withdrawal of the dietary addition. This thus proves that it was this addition that caused the increase in caries activity.

In Carbohydrate Study I the effect of a pronounced reduction in dietary carbohydrates on existent basic caries activity was stu-

died in two groups. In view of the error of the method in relation to the number of patients in the groups and the low basic caries activity of the present material, it can hardly be accepted as suitable for the study of the effect of maximum carbohydrate restriction on dental caries. Moreover, the reduction in calories by the withdrawal of the carbohydrates had to be compensated by an increased amount of fats, so that it is not possible to say with certainty whether any decrease in activity should be ascribed to restriction of carbohydrates, excessive fat or to a combination of both.

An observation of practical importance was, however, that new carious lesions appeared despite reduction of carbohydrate intake to a minimum. This suggests the existence of some types of caries, in which sugar and other carbohydrates play only a minor rôle as a causal factor.

Comparison Between the Present Investigation and other Similar Studies

In a survey of the literature GUSTAFSSON (1954) pointed out the lack of agreement about the relationship between dental caries and sugar consumption in man. The Vipeholm investigation clearly showed that in the evaluation of the effect of the sugar intake on dental caries it is *not only the quantity* of sugar consumed that must be considered, but also the *form* in which it is served and whether it is consumed *at* meals or *between* meals. This was shown most distinctly in the present investigation in those groups in which *a reduction in the total sugar consumption was followed by an increase in caries activity when the subjects received a small portion of the reduced amount of sugar between meals.* This was most apparent in the Chocolate Group (Fig. 11).

In studies carried out by BOYD & DRAIN (1928), TOVERUD et. al. (1942) and BOYD (1943) on the effect of sugar restriction and avoidance of sweets etc. between meals on dental caries in diabetics, the subsequently observed decrease in caries activity was probably attributable, at least mainly, to the restriction of sugar between meals. This also applies to the therapeutic reduction of sugar in the investigations performed by the Michigan Group, HOWE et al. (1933) and BECKS et al. (For survey see BECKS, 1950).

In the only study with unlimited sugar intake between meals JAY *et al.* (1936) reported an increase in caries activity, but the evidence they produced has not been generally regarded as convincing.

MACK (1949) studied the effect of the consumption of 115 g. sucrose daily (including 57 g. sweets) but was unable to demonstrate any definite increase in caries activity. Although it is difficult to judge the results of this investigation, they do support the observation made in the present investigation that caries activity is largely independent of the amount of sugar used as long as it is consumed in a form with only a slight tendency to be retained on the surfaces of the teeth. MACK's result was negative, despite the fact that part of the sugar consumed as sweets at meals had a marked tendency to be retained. This should be compared with the observations made in the Sucrose Group during Carbohydrate Study I, when a certain part of the sugar was incorporated in the food and not, as originally intended in the drinks only. This might therefore have increased the tendency to retention in the present investigation.

The experimental conditions used by BOYD (1950) and the results he obtained were roughly the same as in the present Sucrose Group.

The effect of the consumption of sugar at meals and between meals has been studied earlier but no agreement has been attained as to whether or not an increase in the sugar intake is followed by increased caries activity. In the present investigation, however, the effect of the sugar intake was studied from various angles in one and the same material, which was observed for a long time, and the observations made were able to explain the differences between the results presented by earlier workers in this field.

Summary

The fact that dental caries activity increased when the consumption of sugar in sticky form was introduced, together with the fact that it decreased when such consumption was stopped, constitutes convincing evidence that sugar increases dental caries activity in man. When sugar was consumed in solution at meals, up to more than twice the Swedish consumption, no increase in

dental caries activity was observed. These results support each other to form strong evidence that sugar exerts its caries-promoting effect locally in the mouth in accordance with the widely accepted chemo-parasitic theory on the pathogenesis of dental caries.

CONCLUSIONS

Observations made in the present investigation suggested the following conclusions.

1. The consumption of sugar can increase caries activity.
2. The risk of sugar increasing caries activity is great if the sugar is consumed in a form with a strong tendency to be retained on the surfaces of the teeth.
3. The risk of sugar increasing caries activity is greatest if the sugar is consumed between meals and in a form in which the tendency to be retained on the surfaces of the teeth is pronounced with a transiently high concentration of sugar on these surfaces.
4. The increase in caries activity under uniform experimental conditions varies widely from one person to another.
5. Increase in caries activity due to the intake of sugar-rich foodstuffs consumed in a manner favouring caries disappears on withdrawal of such foodstuffs from the diet.
6. Carious lesions may continue to appear despite the avoidance of refined sugar, maximum restriction of natural sugars and total dietary carbohydrates.

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