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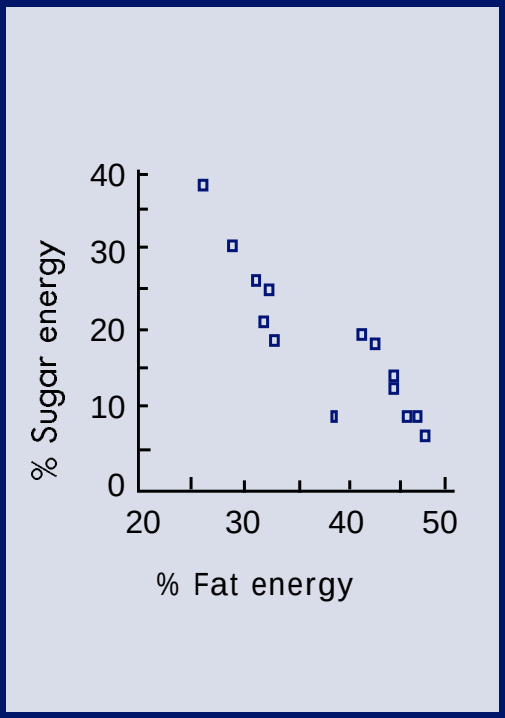

NUTRITIONAL AND HEALTH ASPECTS OF SUGARS

EVALUATION OF NEW FINDINGS

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NUTRITIONAL AND HEALTH ASPECTS OF SUGARS

EVALUATION OF NEW FINDINGS

by Michael Gurr

ILSI Europe

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For more information about its programmes and activities, please contact:

ILSI Europe
Avenue E. Mounier 83, Box 6
B-1200 BRUSSELS
Belgium
Telephone (+32) 2 771.00.14
Telefax (+32) 2 762.00.44

ILSI Press
1126 Sixteenth Street, N.W.
Washington, D.C. 20036 USA
Telephone: (+1) 202 659-0074
Telefax: (+1) 202 659-8654

ILSI Europe
Avenue E. Mounier 83, Box 6
B-1200 Brussels
Belgium
Telephone: (+32) 2 771.00.14
Telefax: (+32) 2 762.00.44

Printed in Belgium

ISBN 0-944398-65-0

FOREWORD

This booklet, written by Professor Michael Gurr, is based on a workshop entitled "Evaluation of the Nutritional and Health Aspects of Sugars" held in Washington, D.C., in May 1994. The workshop, organized jointly by the North American, European and Australasian branches of the International Life Sciences Institute (ILSI), brought together a group of eminent experts with the charge to critically review new knowledge regarding the role of sugars in human health.

The nutritional and health aspects of sugars were extensively reviewed by the United States Food and Drug Administration in 1986 and by the United Kingdom Department of Health in 1989. In view of the considerable amount of new information available on this subject, ILSI decided to commission a series of authoritative position papers. These were circulated to all panel members for critical review prior to the workshop.

Certain workshop topics were intentionally omitted from this concise monograph because they are featured in the ILSI Europe Concise Monograph on Starches and Sugars: A Comparison of their Metabolism in Man, which was published in 1991. The remaining papers, summarized here, focus on areas of possible controversy regarding sugars and health. The aim has been to provide a balanced view of each topic based on the latest research. The full report of the workshop was published in the American Journal of Clinical Nutrition, Volume 62, number 1(S) (July 1995).

Author: Michael I. Gurr
Scientific Editor: Andrew M. Prentice
Series Editor: Nicholas J. Jardine

CONTENTS

INTRODUCTION

Dietary energy is obtained mainly from carbohydrates and fats. Carbohydrate energy is provided by starches and sugars, which are the subject of another ILSI Europe concise monograph in which descriptions of their basic structures, metabolism and influence on satiety and physical performance can be found. This concise monograph concentrates on recent research into associations between health and the amounts and types of sugars in the diet.

Sugars are the simplest types of carbohydrates and are generally monosaccharides, such as glucose, galactose and fructose, or disaccharides, such as lactose and sucrose. Quantitatively, the most important simple sugar in the diet is sucrose, a disaccharide of glucose and fructose. Such has been its importance in diets that in the English language sugar is synonymous with sucrose. Sugars occur naturally within the structure of foods such as fruits or can be added during the preparation of foods either industrially or in home cooking. Sugars from these two sources are treated identically by the body.

Sugars, and especially sucrose, are prized for their sweetness and the attractiveness they add to the diet. They also play an important role in food processing, since high concentrations of sugars inhibit the growth of food spoilage bacteria and thus act as preservatives. Their presence in foods also contributes to energy intake.

However, the ready availability, relative cheapness, usefulness to the food processor and attractivess of sugars have led to relatively high consumptions in industrialized compared with nonindustrialized countries. Fears have been expressed of possible links between high sugars consumption and the prevalence of many common diseases of affluence, including obesity, diabetes, coronary heart disease and dental caries, as well as other conditions such as behavioural disturbances. These potential associations have been reviewed by the U.S. Food and Drug Administration (1986) and the U.K. Department of Health (1989). However, research into these matters has been intensive and new knowledge is continually being published.

This concise monograph reviews the health aspects of dietary sugars in the light of new scientific information. The reader seeking more detail is referred to the proceedings of a workshop on this subject cited in the Foreword.

CONSUMPTION OF SUGARS IN INDUSTRIALIZED COUNTRIES

Estimating consumption levels

The reliability of information about the consumption of sugars and other dietary components critically depends on the methods used to gather the information. In estimates of sugars consumption, two main approaches have been employed:

- "Disappearance data" reflect the flow or disappearance of commodities into various economic categories on a national basis. Food exports, stocks and raw materials going into sundry industrial uses are subtracted from figures for home production plus imports. The final figure is divided by the total population to arrive at an estimate of average consumption per person.

TABLE 1

Daily intake of total sugars in the USA

Sex and age (in years)	Average (g/day)	90th percentile (g/day)	Average (% energy)
Both sexes			
<1	65	103	35
1-3	79	137	27
4-6	101	170	27
7-10	114	187	26
Males			
11-14	142	242	26
15-18	140	238	24
19-22	121	221	22
23-50	106	193	20
>50	91	135	19
Females			
11-14	107	180	24
15-18	104	176	25
19-22	106	175	29
23-50	80	150	22
>50	75	168	22

Source: U.S. Department of Agriculture, National Food Consumption Survey, 1987-1988

- Direct surveys of intakes of individuals or groups of people are undertaken by various methods such as questionnaires, food diaries or records in which all food items eaten have been weighed. Estimates of sugars intakes can then be made by referring to appropriate tables of food composition.

The former approach might overestimate individual intakes because it does not allow for waste, for food channeled into the pet food industry or for conversions of one type of food into another, for example, the fermentation of carbohydrates into alcohol. Because this is the only type of information available in some countries, it is often the only way in which international comparisons can be made.

The survey approach probably underestimates consumption. None of the survey methods is ideal, and underreporting of intakes of foods, and thus nutrients, by individuals is recognized to be widespread and significant. Intakes may be underreported by as much as 20%.

When examining information on sugars intake, therefore, the reader should be aware of these limitations and realize that true intakes are unknown but probably lie somewhere between the estimates given by disappearance and survey data. Furthermore, as will be discussed later, methodology, terminology and sugars composition of food products differ between countries. For all of these reasons, comparability between North American and European data is limited. The word "consumption" will be used here when "disappearance data" are being cited, whereas the word "intake" will be used when information has been obtained from surveys of individuals.

TABLE 2

Average daily intakes of total sugars in six countries of the European Union

Country	g/day	% energy
The Netherlands	131	21.2
United Kingdom	100	18.4
Belgium	96	15.2
Ireland	90	14.6
Germany	80	13.9
Spain	51	8.0

Source: Gibney M, Sigman-Grant M, Stanton Jr JL, Keast DR, Consumption of Sugars, American Journal of Clinical Nutrition 1995;62(Suppl.1);178S-194S

Current consumption levels

On average, the consumption of sugars in the United States was about 170 g per person per day in 1992, according to disappearance data supplied by the U.S. Department of Agriculture (USDA). Information on sugars intakes in Table 1 is taken from the National Food Consumption Survey conducted by the USDA in 1987-1988.

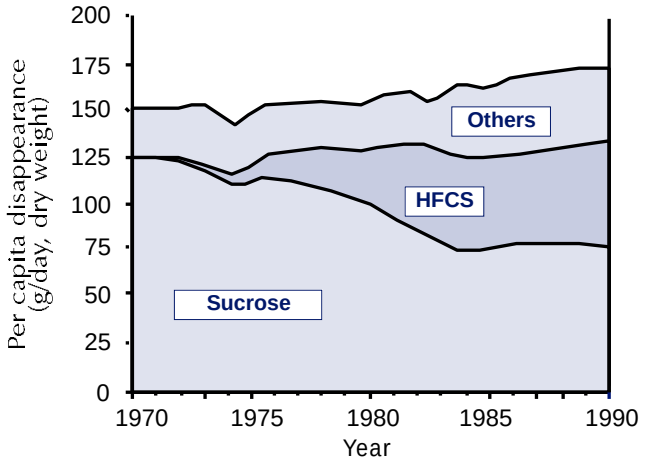
Similar survey information suggests that average intakes of sugars in the European Union are somewhat lower than in the United States (Table 2).

Trends in availability of sugars and other sweeteners

Although absolute levels of consumption do not show a clear relationship to national prosperity, on an international basis, the richer a nation becomes, the more sugars it generally uses. Figure 1 shows that in the United States the total amount of carbohydrate sweeteners remained fairly constant between 1960 and 1990, but from the mid-1970s there was a sharp rise in the consumption of sweet syrups derived from corn at the expense of sucrose, a trend that has not occurred in the European Union.

FIGURE 1.

Trends in the availability of sweeteners in the United States

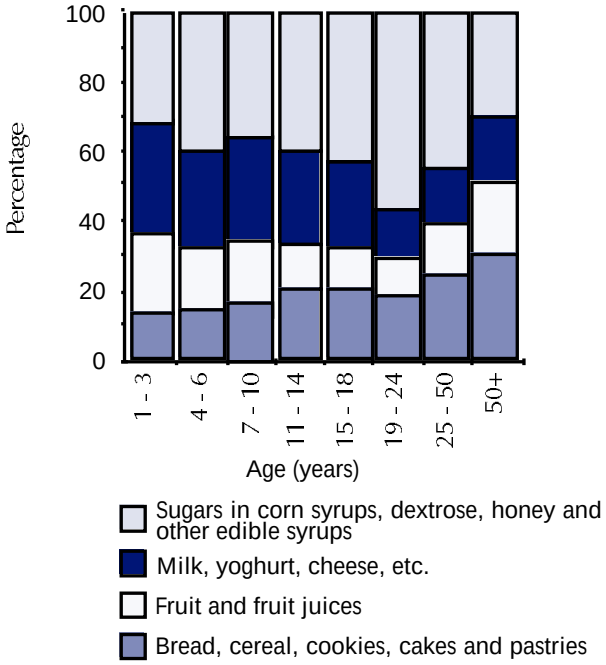


HFCS: High-fructose corn syrups, Others: Sugars in corn syrups, dextrose, honey and other edible syrups.

Source: Glinsmann WH and Park YK, Perspective on the 1986 FDA assessment of the safety of carbohydrate sweeteners: uniform definitions and recommendations for future assessments, American Journal of Clinical Nutrition 1995;62 (Suppl.1);161S-169S

FIGURE 2.

Sources of sugars in the U.S. diet (males only)



Source: U.S. Department of Agriculture, National Food Consumption Survey, 1987-1988

During the 1970s and 1980s, the consumption of caloric sweeteners remained fairly constant in the United States. However, the consumption of noncaloric intense sweeteners more than doubled between 1970 and the late 1980s.

Sources of sugars and other sweeteners in the diet

Figure 2 illustrates the wide variety of foods that are sources of sugars in the diets of male U.S. children and adults.

Intakes of fructose

Fructose is metabolized differently from glucose, and there are important differences between these two sugars in their effects on glucose concentration in the blood (see the section on Sugars and the control of blood glucose). Information on intakes of fructose compared with other sugars may therefore be important.

A major contributor to fructose intakes is sucrose. In the United States, high-fructose corn syrups have partly replaced sucrose (see Figure 1). These syrups, which have only a slightly higher fructose content than sucrose, have also contributed to fructose intakes in recent years. The ratio of fructose to total sugars rose in the United States between surveys conducted in 1977-1978 and 1987-1988, a trend that is unlikely to have occurred in countries that use less high-fructose corn syrup.

NUTRIENT INTAKES IN RELATION TO SUGARS CONSUMPTION

"Empty calories"?

Sugar (mainly sucrose) that is added to food in a refined form, sometimes in substantial quantities, to preserve, sweeten or enhance the structure of food in cooking contains no other nutrients. Thus, sucrose might displace other nutrients in the diet. For this reason sugar has attracted the pejorative description "empty calories", which assumes that diets rich in sucrose automatically have poor nutritive value.

An examination of the nutrient intakes of people who daily consume widely different amounts of sugars, however, shows that this assumption is not justified. An example taken from information on 25-50-year-old U.S. men is presented in Table 3. Intakes are expressed in amounts per 1000 kcal ("nutrient density"), since absolute intakes clearly depend on total amounts of food eaten.

Not surprisingly, according to Table 3, sugars consumption tends to parallel total carbohydrate consumption, although fibre intakes are marginally lower in high sugars consumers. Protein and fat intakes are significantly lower with higher sugars consumption. This poses no problems for the adequacy of protein intakes, but the inverse association with fat intakes has generated much interest among nutritionists (see below).

Intakes of B-group vitamins and several essential minerals tend to decrease with increasing sugars intakes. However, vitamin C and folic acid intakes are much higher in high sugars consumers owing to their association with sugars in fruit drinks. It is important to know whether these differences, although statistically significant, are nutritionally important. One way of assessing this is to express nutrient intakes in terms of the proportion of people who fail to meet a certain proportion (usually two-thirds) of the "recommended daily allowances" (RDAs). On this basis, the level of consumption of sugars seems to have little influence on nutritional status. Indeed, the proportion of high sugars consumers who do not meet at least two-thirds of the RDA for vitamin C is smaller than in low sugars consumers. Some have argued that decreased sodium intakes among high sugars consumers may be a benefit, since many dietary guidelines advise against overconsumption of this mineral.

In Europe, nutrient intakes are not significantly lower and are often higher in people who consume a higher proportion of energy from sugars. The supposition that sugars automatically replace foods rich in micro-nutrients to the point of adversely altering micro-nutrient intakes is therefore without foundation.

TABLE 3

Average daily intake of nutrients per 1000 kcal for different levels of sugars consumption of 25-50-year-old U.S. men

Nutrient	Level of sugars intake (g/1000 kcal/day) Low <26	Medium 27-60	High >61	U.S. RDA**
Protein (g)	48[a]	42[b]	35[c]	22
Carbohydrate (g)	91[a]	111[b]	140[c]	
Fibre (g)	7.2[a]	6.9[b]	6.8[b]	
Total fat (g)	45[a]	42[b]	24[c]	
Saturated fatty acids (g)	16[a]	15[b]	12[c]	
Cholesterol (mg)	197[a]	176[b]	139[c]	
Sodium (mg)	1932[a]	1757[b]	1544[c]	
Calcium (mg)	406[a]	371[b]	342[c]	276
Iron (mg)	7.3[a]	6.9[b]	6.4[c]	3.4
Zinc (mg)	6.5[a]	6.0[b]	5.0[c]	5.2
Thiamin (mg)	0.76[a]	0.74[a]	0.68[b]	0.5
Niacin (mg)*	12.5[a]	11.1[b]	10.0[c]	6.6
Riboflavin (mg)	1[a]	0.9[b]	0.8[c]	0.6
Folic acid (µg)	118[a]	122[a]	131[b]	69
Vitamin B6 (mg)	0.90[a]	0.83[b]	0.79[c]	0.7
Vitamin B12 (µg)	3.8[a]	2.9[b]	2.3[b]	0.7
Vitamin C (mg)	33.9[a]	49.8[b]	62.7[c]	21
Vitamin A (mg)*	522[a]	501[a]	536[a]	345
Vitamin E (mg)*	4.5[a]	4.4[ab]	4.1[b]	3.4

Source: U.S. Department of Agriculture Nationwide Food Consumption Data 1987-1988

Note: Numbers with differing superscripts are significantly different ($p<0.05$).

* Niacin, retinol or tocopherol equivalents

** Recommended Dietary Allowance per 1000 kcal per day. National Research Council, 10th Edition, 1989, Washington D.C.

Relationships between sugars and fat consumption

The suggestion that high-sugars consumers derive a lower proportion of energy from fat receives support from several studies that compared intakes across and between different affluent countries (Figure 3). This has sometimes been described as the "sugar-fat seesaw".

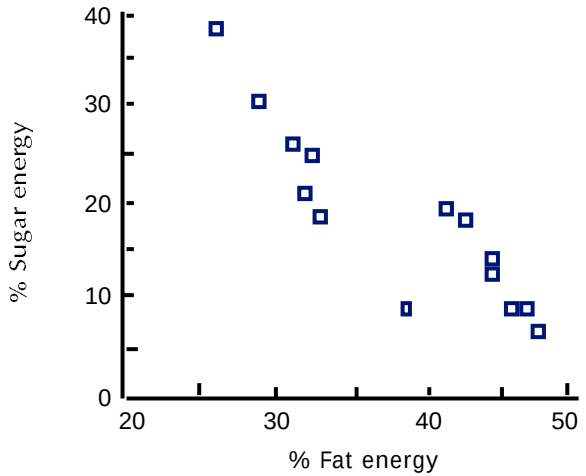
A contrary view, sometimes expressed, is that sugars have the disadvantage that they are frequently used in association with high-fat foods. However, although foods rich in both fat and sugars can easily be identified, surveys have shown that foods that are primary sources of sugars are only minor sources of fat, and vice versa. When the whole diet is considered, therefore, the inverse relationship between fat and sugars intakes illustrated in Figure 3 is widely observed.

These observations have important implications for people trying to observe dietary guidelines. The recommendation to consume not more than 35% energy from fat and 10% energy from added sugars is currently not being achieved in Western diets, and some scientists question whether meeting these two goals simultaneously can be attained in Western populations. Although such guidelines speak about "added sugars", in content analysis it is not possible to distinguish added sugars from those present intrinsically, nor does the body's metabolism make a distinction.

More research is clearly needed into whether low fat intakes are an unrealistic target when tied to such low sugars recommendations, or whether such goals could be achieved by innovative combinations of different foods. In view of recent evidence that sugars pose less of a problem with regard to weight control than does fat (see below), it is argued by some that the guidelines for sugars should be relaxed.

FIGURE 3.

Inverse relationship between intakes of sugars and fats in different affluent countries



Source: Gibney MJ, Dietary guidelines: a critical appraisal, Journal of Human Nutrition and Dietetics 1990; 3; 245-254

SUGARS AND THE CONTROL OF APPETITE

Sweetness and energy factors

Human beings have an innate preference for sweet foods, and the pleasurable aspect of sweetness undoubtedly influences food selection.

It is also well established that the ingestion of carbohydrates and the energy derived from them provide signals to the body that regulate food intake. It

appears that in the short term at least, carbohydrates are more satiating than fats, but less so than proteins. The possibility that appetite signals arising from sugars are different from other carbohydrates owing to their sweetness has been the subject of much speculation and research interest.

The effects of sugars on food intake may, therefore, be a result of both their pleasurable properties and their physiological effects. What sorts of research have been employed to investigate these questions?

Regulation of intake by the energy in sugars

One method for investigating whether the energy provided by sugars influences the body's ability to regulate overall energy intake is to give people a snack (usually a drink) and compare energy intake in a meal taken later. A free choice of foods is available for this meal, and the intake is compared with intakes in a control group given a premeal snack sweetened with a noncalorific sweetener. A "hunger rating" is determined at different times after the test drink to assess the subjects' desires to eat.

Although there has been some inconsistency in the results of such studies, perhaps because of differences in experimental design and individual responses, the research clearly shows that children compensate for the energy in a sugary snack by decreasing their energy intake during a meal that comes shortly after the snack. Adults, by contrast, compensate less.

Sweetness and appetite control

There are many hypotheses about the effects of sweetness on appetite and subsequent food intake. Although some studies suggest that appetite may be stimulated by sweet foods or drinks, there is little convincing evidence that there is a consistent effect of sweetness on subsequent food intake over a period of time.

In summary, there is no conclusive evidence that either the energy content or the sweetness of sugars necessarily contributes to increased appetite or food intake in the short or long term. The hypothesis that sugars are unique among carbohydrates because their pleasurable properties override controls on food intake remains unsupported. Further short- and long- term studies need to compare intakes of sugar and other mono- and disaccharides, as well as nonsweet carbohydrates and intense sweeteners, with sufficient numbers of participants to overcome problems of variability in responses between individuals.

SUGARS AND THE CONTROL OF BLOOD GLUCOSE

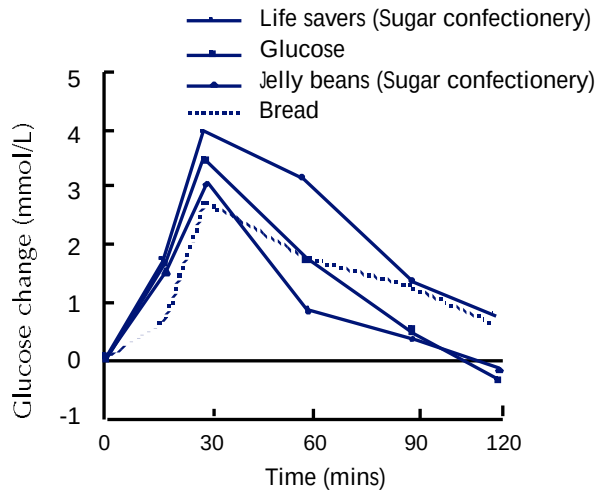
Diet in the management of diabetes

Two important aims in the dietary management of diabetes are to optimize the control of blood glucose concentrations and to minimize the risk of dangerously low blood sugar in people treated with insulin.

During the last two decades, there have been some radical changes in the dietary advice given to diabetic patients about how to control their blood glucose. Originally a general restriction of dietary carbohydrates was advised, resulting in diets that were relatively rich in fat. As possible adverse effects of excessive fat consumption on the cardiovascular complications of diabetes began to be appreciated, advice on carbohydrates was relaxed. Consumption of complex carbohydrates was encouraged and avoidance of simple

FIGURE 4.

Changes in blood glucose after consumption of different carbohydrates



The curves show changes in plasma glucose concentrations after a subject has been given 50 g of pure glucose (the "reference food") or portions of white bread or high-sugar confectionery items each containing 50 g of available carbohydrate. The glycaemic index of 50 g of glucose is set at 100. In some publications, white bread containing 50 g of available carbohydrate is used as the "reference food". To adjust glycaemic index values based on pure glucose so that the glycaemic index of white bread = 100, multiply by 1.36. Some authors now regard the white bread reference as preferable because of concerns about the excessive sweetness of glucose, because of the possibility that the osmotic effect of glucose may cause delayed gastric emptying and because bread stimulates the secretion of insulin better than does glucose alone.

Source: Wolever TMS and Brand Miller J, Sugars and blood glucose control, American Journal of Clinical Nutrition 1995;62 (Suppl.1);212S-221S © American Society for Clinical Nutrition

sugars was still advised. More recently, even the concerns about sugars are thought to have been exaggerated, although the belief that meals containing sugars result in higher blood glucose than meals containing equivalent quantities of starch has persisted in the minds of lay and scientifically trained people alike. This belief, based on studies with severe limitations, has now been revised.

Glycaemic index of foods

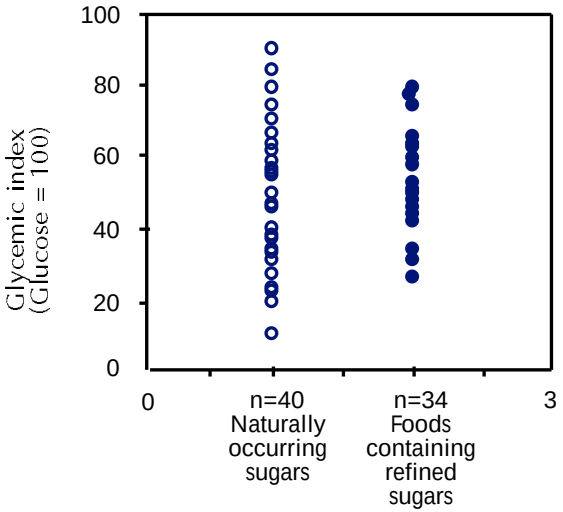
An important advance in our understanding of the impact of dietary carbohydrates on blood glucose has followed the abandonment of experiments that studied the effects of simple sugars alone in a drink in favour of those that deal with commonly eaten foods and meals. When meals containing carbohydrates are digested, the constituent sugars, dominated by glucose, are absorbed into the blood. The concentration of glucose in the blood rises to a maximum in about 20 to 30 minutes and then returns slowly to the fasting level after 90 to 180 minutes as glucose is taken up into tissues, a process that requires insulin (Figure 4).

The "glycaemic index" concept has been developed as a way of comparing the influence of individual foods or carbohydrates on the overall profile of glucose metabolism. In this method, the glycaemic index of a food is measured by the area under the blood glucose concentration curve over a period of time after the food is consumed (Figure 4) compared with the response to a reference food that contains an equimolar amount of available carbohydrate. The reference has frequently been glucose itself, with a dose of 50 g of glucose having a glycaemic index of 100. This is the convention used in Figures 4 and 5 of this monograph. However, more recently it has become routine practice to use white bread containing 50 g of available carbohydrate as the reference standard (see the legend to Figure 4 for further details).

The glycaemic index method has revealed some interesting facts about the effects of carbohydrate foods on blood glucose that have overturned many strongly held beliefs. One such belief is that the blood glucose response to starches is less than that of sugars because of the slower digestibility of starch.

FIGURE 5.

Glycaemic indices of foods with a high natural sugars content compared with foods containing refined sugars



The figure shows glycaemic indices of 74 different foods, taken from publications worldwide. Forty foods had high natural sugars levels and 34 were manufactured foods with added refined sugars. As in Figure 4, the foods compared all contained 50 g of available carbohydrate and the glycaemic index is based on the use of 50 g of glucose as the "reference food".

Source: Wolever TMS and Brand Miller J, Sugars and blood glucose control, American Journal of Clinical Nutrition 1995;62 (Suppl.1);212S-221S © American Society for Clinical Nutrition

These ideas arose because early experiments had tested raw starch, which indeed has a low glycaemic index. Many cooked starches, such as that in instant potato, are digested so rapidly that their glycaemic impact is similar to that of glucose. Glycaemic index correlates well with the digestibility of starch. For example, the starch in lentils produces small glycaemic effects compared with the starch in bread. In general, there is little distinction between glycaemic indices of foods containing naturally occurring sugars and those with "added" refined sugars (Figure 5).

There are important differences between glycaemic indices of monosaccharides, notably glucose and fructose. Fructose has a glycaemic index of only about 23. The glycaemic index of a sugar can be predicted on the basis of the molar ratio of glucose to other monosaccharides in the sugar molecule. This explains why maltose (a disaccharide with two glucose units) has a score close to glucose at 100, whereas sucrose (a disaccharide of glucose and fructose) has a glycaemic index of only 61. Honey, which contains mixtures of glucose and fructose, has index values ranging from 58 to 87 in different experiments.

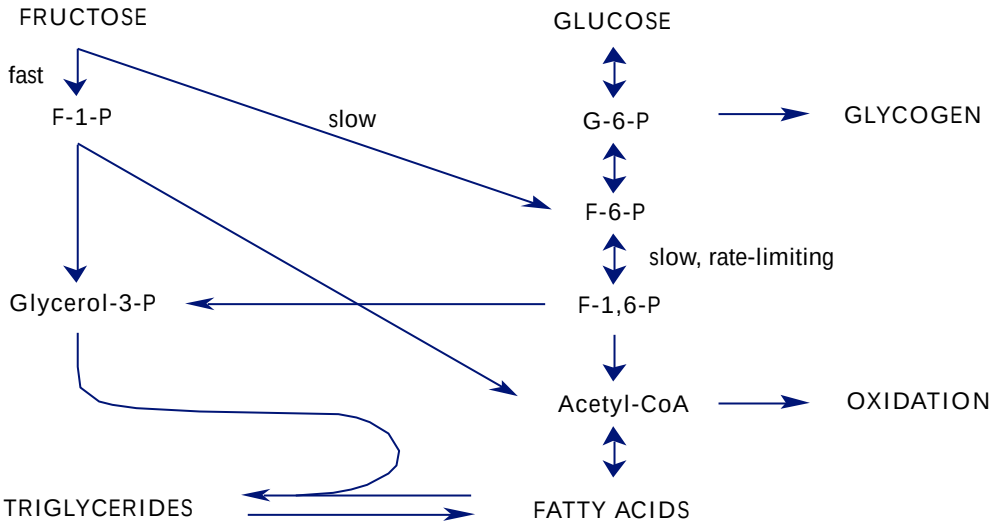
Thus, many factors influence the glycaemic index of a food. These include its physical form, which in turn affects digestibility, the way in which the food is prepared and the presence of nutrients other than carbohydrates, such as fats.

Metabolism of fructose and sucrose: importance in diabetes

The low glycaemic index of fructose may be explained by differences in its metabolism compared with glucose. Fructose is rapidly metabolized in the liver, bypassing the slowest step in glucose metabolism (see the Metabolism of glucose and fructose box). A proportion of

BOX 1

Metabolism of glucose and fructose



Abbreviations: F = fructose, G = glucose, P = phosphate

- The ubiquitous enzyme (hexokinase) that catalyses the addition of a phosphate group to position 6 of glucose does not carry out this reaction efficiently with fructose. Glucose formation from fructose is important only if fructose provides a major source of dietary carbohydrate.
- The metabolism of fructose is confined mainly to the liver, where a special enzyme is present that utilizes fructose (fructokinase, which phosphorylates position 1 of fructose).
- Fructose-1-phosphate bypasses the slowest step in the pathway for glucose metabolism, which results in faster metabolism of fructose than glucose in the liver.
- Fructose metabolism produces end products that may be readily made into triacylglycerols (triglycerides).
- Fructose also seems to facilitate the transport of fatty acids stored in adipose tissue to liver, where they can be used to make more triacylglycerols, which may be exported into the plasma as very low density lipoproteins (VLDL).
- Fructose can slow down the removal of VLDL from the plasma, thus helping to maintain already high blood concentrations.

fructose is transformed into glucose via fructose-6-phosphate replacing rather than adding to normal glucose production in the body. Thus, fructose is said to have a "sparing effect" on glucose metabolism.

Although the effects of sugars on the control of blood glucose are qualitatively similar in diabetic and healthy people, there is some evidence that in diabetics the effects may depend on the severity of their diabetes. Differences in blood glucose and insulin responses between foods sweetened with sucrose and those sweetened with fructose appear to be smaller in diabetics than in healthy people. When sucrose and starch are exchanged and when intakes are moderate and consumed in a mixed meal of commonly eaten foods, there is no significant impact on either blood glucose or insulin concentrations in people with non-insulin-dependent diabetes. Similarly, in people with the insulin-dependent form of the disease, there is little evidence that in the long term, replacement of starch by sucrose, calorie for calorie, has any significant impact on the control of blood glucose.

In summary, it is clear that sugars added to foods are no more likely to compromise blood glucose control than are naturally occurring sugars or most cooked starches. Nevertheless, the degree of glycaemia following a meal can vary depending on the source of the sugar or starch, its method of preparation, the composition of the whole meal and the individual's own metabolism. Easily digested carbohydrates that produce large blood glucose and insulin responses, whether in the form of sugars or starches, may increase average blood glucose levels in patients with diabetes, and may present a hazard to individuals with particularly severe diabetes.

Many patients with diabetes appear to be unwilling to do without sweet-tasting foods. It may become more difficult to restrict dietary fat (now recommended for diabetics) if sucrose were to be removed from the diet. If the moderate use of sucrose helps limit the intake of foods rich in fat and of starches with a high glycaemic index, then its inclusion in diets may be psychologically and therapeutically useful.

DIETARY SUGARS AND HUMAN LIPID METABOLISM

Sugars and blood triglycerides in healthy people

Although it has been said for over 30 years that sustained high levels of dietary sugars result in elevated concentrations of lipids (particularly triglycerides) in the blood, scientists are by no means unanimous on this point. Among possible reasons for this are that many different dietary and other environmental factors influence concentrations of blood triglycerides. In many cases these factors interact with each other in a complicated manner. Thus, obesity, excessive alcohol consumption and diets rich in carbohydrates (irrespective of simple sugars intake) can all cause rises in blood triglycerides, whereas increased physical activity or a high proportion of dietary fatty acids coming from fish oils can have the opposite effect.

Resolution of these questions is important since high blood lipid concentrations are normally accepted as increasing the risk of developing coronary heart disease, especially in those with diabetes.

Recent research shows that sugars intakes typical of diets in the industrialized nations have little impact on blood triglycerides. However, for some "sensitive" people, plasma triglycerides may rise in response to atypically high intakes of sucrose or fructose. There is some suggestion that these effects occur mainly in men

and are not important in women. Most studies supporting this contention have been of short duration, and the few long-term studies suggest that the lipid-raising effect of sugars may be attenuated after a few weeks. The effect appears to be more pronounced in those who already have elevated blood concentrations of triglycerides and insulin.

Sugars and blood cholesterol

By contrast, few studies demonstrate any important effects of sugars on blood cholesterol concentration. Where these effects have been observed, intakes were much higher than the average intakes in developed countries. Some studies have suggested that there is an interaction between dietary sucrose and saturated fatty acids such that the rise in blood cholesterol in response to saturated fatty acids was greater when sucrose rather than starch provided a large proportion of dietary carbohydrate. However, in those studies, sucrose consumption was much higher than average and the additional rise in blood cholesterol was small.

Total dietary carbohydrates or individual sugars?

Another contentious issue is the influence on blood lipids of the proportion of energy supplied by dietary carbohydrate, irrespective of the composition of the carbohydrate. Taken together, most studies suggest that fasting blood concentrations of triglycerides are higher when the habitual diet contains a high proportion of carbohydrate (greater than 55% of energy) to fat. The results have led some authors to advise caution on the widespread adoption of low-fat diets. Others, however, contend that these results have been overinfluenced by experiments in which increases in total dietary carbohydrate were accompanied by increases in sucrose intake. When sucrose was maintained at a constant level in the diet, effects on blood lipid concentrations were minimized. This seems still to be an unresolved issue.

Sugars and lipid metabolism in diabetes

Interest in the roles of sucrose and fructose in diets for diabetics has stemmed from the fact that the glycaemic response to fructose is much less than to an equivalent amount of glucose, as described above. Consequently, sweetening foods with fructose is an attractive option for diabetics. Moreover, replacement of glucose by fructose may help improve glycaemic control, since the metabolic utilization of fructose is largely independent of the secretion of insulin.

However, there are certain other aspects of fructose metabolism that are potentially undesirable for diabetics. Although glucose and fructose are similar molecules, they are metabolized differently as described in the Metabolism of glucose and fructose box. The knowledge summarized in the box, albeit gained mainly from experimental animals and not from human beings, suggests that fructose has the potential to generate higher blood concentrations of triglycerides.

Elevated levels of triglycerides are a feature of non-insulin-dependent diabetes. Some scientists have proposed that they may be in part responsible for the severe vascular disease often affecting diabetics, but the matter remains unresolved. Nevertheless, strong associations among plasma triglycerides, overweight, insulin insensitivity, high blood pressure and vascular disease in non-insulin-dependent diabetes provide strong motivation for minimizing plasma lipid concentrations in these patients.

In marked contrast to healthy subjects, however, there is no consistent elevation of triglycerides by dietary sugars in insulin-dependent and -independent diabetics even when consumption of sugars approaches 220 g/day.

Although a few hypotheses have been suggested, the scientific basis for this unexpected finding is as yet unknown.

In conclusion, consumption of sugars in the amounts typical of "Western" diets does not appear to promote high concentrations of triglycerides in the blood. Raised concentrations are sometimes seen when atypically large amounts of sugars are consumed, especially by those who appear to be peculiarly sensitive to dietary sugars. This predisposition may relate to an individual's sensitivity to insulin. Further research is needed into links between insulin sensitivity and responses of blood lipoproteins to sugars immediately after meals. No consensus exists about whether these effects of dietary sugars are transient or long lasting, and this can be resolved only by careful studies of at least a year's duration.

SUGARS AND OBESITY

Obesity as a major health problem

Carbohydrates, particularly refined sugars, are still widely assumed to be fattening. It is important to know whether sugars specifically influence the development of obesity because of the high prevalence of this condition in most developed countries and among affluent people in developing countries. For example, in the United States and the United Kingdom more than a quarter of the population is estimated to be obese, and the prevalence is increasing in adults and children alike. The severity of several degenerative diseases is exacerbated with obesity.

Body weight regulation: a matter of balance

Maintaining stable body weight requires that total energy consumed be balanced against total energy expended. An increase in body weight, which in the context of obesity means mainly an increase in body fat, occurs only when energy intake exceeds energy expenditure. Since there is no conclusive evidence that either the energy content or the sweetness of sugars necessarily contributes to increased appetite or food intake (see the earlier section on appetite), research attention has tended to concentrate on energy expenditure.

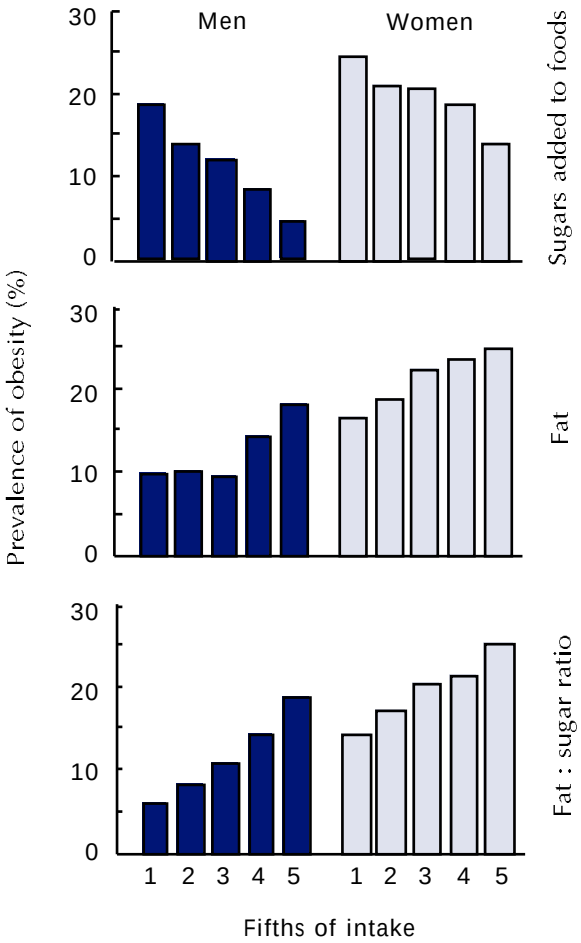
Carbohydrates and energy expenditure

The body has two main sources of fuel: carbohydrates and fats. To enable the body to extract usable metabolic energy, these fuels must be oxidized through complex metabolic pathways. These pathways differ considerably for fat and carbohydrate, and alterations in the ratio of carbohydrates to fats in the diet have profound effects on the mixture of metabolic fuels oxidized. The body quickly responds to acute large increases in carbohydrate consumption by increasing its oxidation of that fuel. By contrast, fat oxidation is hardly affected by increases in fat intake when carbohydrate intake is held steady.

The significance of these effects in terms of body weight regulation is that the composition of the diet seems to be of little consequence over a wide range of carbohydrate-to-fat ratios, provided that food is consumed in line with energy requirements. However, if carbohydrate is consumed in excess, it will lead to positive fat balance through its sparing effect on fat oxidation.

FIGURE 6.

Reciprocal association between intake of sugars and obesity



Source: Prentice AM and Jebb SA, Obesity in Britain: gluttony or sloth?, British Medical Journal 1995;311;437-439 © British Medical Journal

Current views of sugars and obesity

The balance of research evidence now suggests strongly that diets rich in fat are more likely to promote the development of obesity than those in which carbohydrates, including sugars, predominate. The chief reasons for this can be summarized as follows:

- Storage of carbohydrate as glycogen in the body is limited. When stores are full, the body adapts rapidly to oxidize carbohydrate in excess of requirements.
- Storage of fat is virtually unlimited, and the body adapts only very slowly to oxidizing excess fat.
- Energy balance is thereby much more easily regulated at high intakes of carbohydrate than of fat.
- The human body has limited ability to convert carbohydrate into fat, and the old idea that "starchy foods are fattening" is being discarded.
- Each gram of fat consumed has more than twice as many calories as each gram of carbohydrate. High-fat, energy-dense diets promote passive over-consumption of energy.

These ideas are consistent with epidemiologic observations from a wide variety of countries that there is a strong inverse association between sugars consumption and obesity (see Figure 6). Since there is also a tendency for sugars and fat consumption to be inversely associated, one possible explanation is that high fat intakes may facilitate weight gain in many people, which would overwhelm a "protective effect" of sugars.

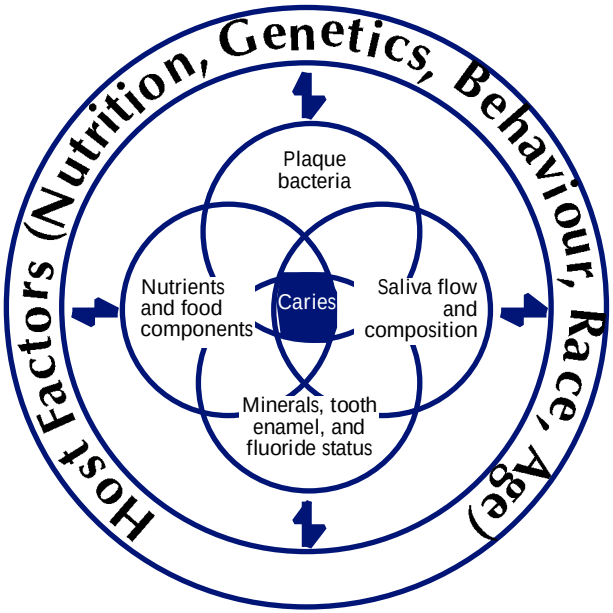
SUGARS AND ORAL HEALTH

Diseases affecting the teeth

Dental caries affects the hard tissues of the teeth. Bacteria that accumulate in a dense mass as plaque on the surface of the teeth, ferment sugars to form acids that demineralize the hard tissue underneath. This can eventually result in total decay of the dental tissues.

FIGURE 7.

Factors influencing the development of dental caries



Source: Navia JM, Carbohydrates in human nutrition: the importance of food choice in a high carbohydrate diet, American Journal of Clinical Nutrition 1994;59(Suppl);719S-727S

Periodontal disease is also now regarded as involving bacterial infection, but affecting the gums rather than the teeth.

Development of dental caries

The many interacting factors that affect caries development are shown in Figure 7. A key role is played by cariogenic bacteria, mainly those species that produce lactic acid by fermenting sugars. Saliva protects teeth by its buffering action, preventing extreme acidity or alkalinity. It also contains antibacterial compounds and is a vehicle for minerals such as calcium and phosphorus, which counteract demineralization and promote remineralization and repair of early lesions. Remineralization of teeth in the presence of fluoride results in more resistant enamel.

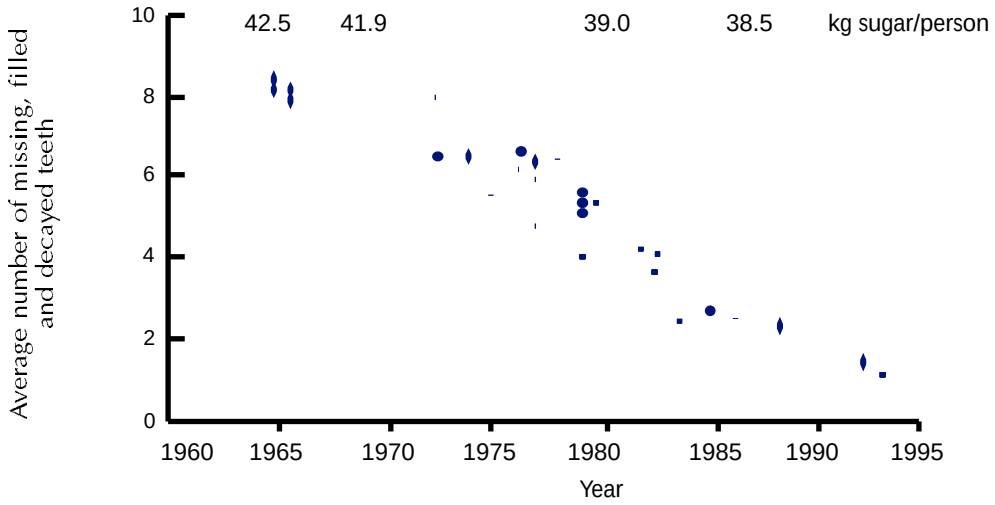
Starches and sugars are important components of food residues that become trapped in various niches in the mouth. There they provide nutrients for bacteria and support the development of active plaque. It is inaccurate to describe these substances as "cariogenic", since they do not directly damage the teeth but influence caries indirectly by creating conditions for local fermentation and acid accumulation.

Importance of oral hygiene

Oral hygiene plays an important role in removing unwanted food residues from the teeth and dislodging plaque. Recognition of the importance of the protective effect of fluoride has led to its widespread addition to dental hygiene products and some water supplies. This has coincided with remarkable declines in dental caries in developed countries (Figure 8).

FIGURE 8.

Decrease in the prevalence of caries in 12-year-old children in The Netherlands



Source: König KG, Changes in the prevalence of dental caries: how much can be attributed to changes in diet?, Caries Research 1990;24(Suppl.1);16-18 © Karger

Sucrose and the prevalence of caries

For a long time, it was widely stressed that refined sugar consumption was the single most important factor in promoting the then high prevalence of tooth decay in developed countries and that avoidance of sugar was the most effective way of preventing the disease. This was certainly a strong association before the widespread advent of fluoride and other improvements in oral hygiene. One reviewer, analysing data from 47 nations up to the 1970s, concluded that half the variability in dental caries prevalence could be explained by sucrose availability.

This situation has changed conspicuously during the last 20 years, especially in countries where fluoride toothpaste or fluoridated water is widely used and children have been taught good toothbrushing habits. Recent studies have highlighted the fact that caries prevalence correlates well with sucrose consumption in communities where oral hygiene is poor and where fluoride is absent, but not elsewhere. Sucrose has been particularly targeted because the stickiness of some products that contain sucrose can result in particularly prolonged adherence to tooth surfaces. Starches which lodge in convenient niches can be readily hydrolysed and fermented in the mouth and can have caries-promoting properties equal to those of sugars in certain circumstances. Again, the importance of oral hygiene in dislodging sticky or otherwise firmly adhering food residues cannot be stressed too strongly.

In summary, diseases of the teeth are complex processes influenced by many local factors as well as those intrinsic to the host. Nutrition plays a role by supplying nutrients for maintaining dental health but also by supplying substrates for bacterial fermentation. Sugars are but one aspect of the total dietary influence. It is now recognized that the most important factor in the dramatically reduced prevalence of dental caries is good oral hygiene with fluoride toothpaste.

SUGARS AND BEHAVIOUR

Early theories

The notion that food, especially sucrose, might adversely affect behaviour seems to have been first suggested in the early 1920s. In 1947 sugar was said to be associated with a condition described as "tension fatigue syndrome", and in the 1970s it became fashionable to relate sugar consumption to a condition called "functional reactive hypoglycaemia". Belief in a relationship between sugar and antisocial behaviour has since become so strong that in the United States it has been used in court cases as a defence argument.

Because sugar is a major dietary constituent, it is natural that there should be interest in any possible effects on behaviour, even in only a small proportion of the population. Interest in sugar as a possible offending agent grew in the 1970s after several studies appeared to demonstrate correlations between children's intake of sugar and hyperactive behaviour. Since a limitation of such studies is that they cannot determine causal relationships, it is equally possible that the behaviour caused the increase in sugar intake as that sugar intake caused the behaviour. Controlled intervention studies were needed to resolve this issue.

Hyperactivity as an allergic response

The first hypothesis to be tested was that hyperactivity was the result of an allergic response to various foods, and sucrose was assumed to be one of the important factors in those diets. In two studies, children were placed on restricted diets and challenged with the presumed offending foods or with a placebo. Improvements in behaviour were reported in children whose diets were restricted, and deterioration was reported on challenge with various foods. However, sugar was only one of several restrictions or challenges. Moreover, the behaviour assessments were made by parents or family doctors and were not always confirmed by an independent psychologist. Because of these design flaws, it was not possible to demonstrate that sugar had specific effects on the children's behaviour. It remains possible that some children's hyperactive behaviour could be associated with an allergic response not to sugar, but to specific protein impurities, but this has not been proven.

Hyperactivity as a response to low blood glucose

A second proposal was that some children may experience "functional reactive hypoglycaemia" in response to sucrose. This is a clinical condition, largely unexplained, in which blood glucose drops to dangerously low levels even when the diet is relatively rich in carbohydrates. It was further proposed that this condition would lead children to display increased muscular activity. There is little experimental support for this view.

It is difficult to design experiments to test these proposals in such a way that interpretation of results is unequivocal. Few, if any, studies fulfilled all the necessary criteria for an "ideal" experiment. Nevertheless, they were consistent in not demonstrating

a significant specific effect of sucrose on aggressive or disruptive behaviour, muscular activity or cognitive performance. There are some signs that the lay press is now beginning to discuss this research, and this may lead to a change in attitudes. Much work, however, needs to be done to assure parents and consumers generally that there is no evidence that sucrose is associated with behavioural problems.

Other behavioural effects of sucrose have been proposed, such as memory enhancement and mild sedation. However, at the moment these are simply areas of active research without any real evidence for practical implications in normal diets.

In conclusion, there is no firm scientific evidence that the presence of sucrose in diets is related to hyperactivity or other behaviour disorders.

SUGARS AND AGING

Nutritionists have long been intrigued by the idea that particular diets may increase life span or that specific nutrients may promote or retard the aging process. In industrialized countries with significant increases in the elderly population, the quality of life in old age becomes ever more important. A relevant question now is whether nutrition can assist in "adding life to years rather than years to life".

There do not seem to be any important age-related changes in the sense of taste, taste perception for sucrose, intestinal hydrolysis of sucrose or absorption of glucose or fructose. As discussed above, diets containing reasonably high concentrations of sucrose consumed over relatively long periods do not appear to compromise blood glucose control or insulin sensitivity. To date, the only known way of extending life span and delaying the onset of various age- related degenerative diseases is by restricting energy intakes and this applies only to experimental rodents. Few studies have been made of dietary composition, and even fewer have specifically examined dietary carbohydrates. One such study, in which two thirds of the diets eaten to appetite consisted of carbohydrates, appeared to show that animals lived longer when the carbohydrate component was starch than when it was mainly sucrose. This needs confirmation.

One possible mechanism for the influence of sugars on aging that is being actively investigated is a process called "glycation". This involves the chemical linkage of sugar molecules to proteins. Since it is irreversible, glycation can result in deterioration in the function of many body proteins, including enzymes, connective tissue proteins and crystallin, the main protein of the lens of the eye. Moreover, glycation is entirely dependent on the concentration of sugars in the blood or tissues to which the proteins are exposed over long periods.

Another contributor to the aging process, it has been suggested, is oxidation of important proteins by "free radicals". Recently there has been considerable research interest in the idea that when glycated proteins break down they generate large local concentrations of free radicals which create further damage, thus accelerating the aging process. The extent to which such changes are influenced by such factors as the level of dietary sucrose is an area of active current research.

SUMMARY

Sugars impart a pleasant taste to many foods, contribute to texture and improve the qualities of certain foods in cooking and processing. Yet concerns have been expressed that overconsumption of sugars may contribute to a variety of health problems, and sugars have often been dismissed as merely "empty calories". This concise monograph summarizes the proceedings of a workshop, convened in 1994 to review older literature, to evaluate the results of recent research and to identify new directions for future research. It is clear from the presentations that considerable new information has become available that questions the validity of certain earlier assumptions.

The accumulation of data in developed countries on actual intakes of sugars from all food sources, show that intakes per person are consistently lower than "disappearance data" indicate. Although there are several reasons why the latter may overestimate individual consumption, the workshop addressed the important problem of underreporting of intakes by individuals. It was recognized that additional research is needed to understand the total impact of underreporting on the pattern of nutrient intakes, especially among very high or low consumers of sugars. Better information on sugars consumption also reveals the presence of certain trends. In the United States, but less so elsewhere, the composition of sugars intakes has undergone significant change over the past 20 years as high-fructose corn syrups have replaced sucrose as sweeteners, especially in soft drinks, resulting in slightly higher intakes of fructose.

The availability of actual consumption figures has allowed analysis of total sugars intake relative to the nutritional adequacy of the diet and to compliance with dietary guidance. In European and U.S. dietary surveys, the division of people into high or low consumers of sugars has revealed that there is little dilution of the nutritional quality of the diet in high sugars consumers. It is now well established that sugars and fat consumption in developed countries frequently has an inverse association. This is partly because foods that are major sources of sugars are not necessarily major sources of fats, and vice versa. Dietary guidance that focuses on limiting fat intakes of populations may be successful but may be associated with an increase in the percentage of energy from sugars. The implications of the fat-sugar association need to be considered. Thus, it will be important to evaluate whether recommendations for intakes of fats and sugars are of equal importance for public health policy and to determine whether focusing on reduction of sugars intake may inadvertently complicate efforts to lower fat intakes.

There have been challenges to previous notions that blood glucose and insulin responses to a meal could be explained simply by differences in the molecular structure of simple sugars and the chemically more complex starches, or by the presence of sugars naturally present within plant cell structures as distinct from those added during food processing. The fat content of a meal and several aspects of the physical properties of sugars and other carbohydrates in foods are among factors that contribute to the blood glucose response as expressed by the "glycaemic index". Important questions have been raised about appropriate dietary strategies for people, especially diabetics, for whom careful management of blood glucose is important. These strategies cannot be based simply on the sugars content of individual foods but must consider the physiological responses to meals.

The non-insulin-dependent form of diabetes is a major, and increasing, health problem in industrialized countries, and research has clearly shown that sugars do

not cause the disorder. Improved strategies for managing the disease have been developed as a result of better understanding of the glycaemic and insulinaemic effects of different foods and through recognition of the contributions made by glucose intolerance and insulin insensitivity in obesity and a sedentary lifestyle. As in obesity, further knowledge of the interaction between nutritional and genetic factors will help in identifying those most likely to develop the disease and in offering advice to the general public for its prevention and treatment.

Because of the pleasant taste of sugars, many have assumed that consumption of sweet foods will result in excess consumption and obesity. Recent research suggests that sucrose in the diet does not override regulatory controls on energy balance and does not excessively stimulate appetite in normal healthy adults and children. Indeed, within populations, intake of sugars is inversely associated with the prevalence of obesity, and the current view is that a high proportion of dietary fat is more likely to be linked with excess energy intake and obesity than a high proportion of sugars. Further research is needed to confirm this concept and its significance for public health policy. Many unresolved issues remain. Better understanding is needed of how preferences for certain foods are related to food selection and total energy intakes. Important goals for research at the basic level are to increase understanding of the mechanisms for regulation and integration of food intake, substrate oxidation and energy storage, and especially the interactions between nutritional and inherited factors.

Sugars and starches in food, which can be fermented by bacteria in the mouth to form acid, have the potential to promote dental caries. In developing countries, with limited access to dental care, caries formation is related to sugars intake. In developed countries, heightened awareness of the importance of dental hygiene and the increased addition of fluoride to toothpaste and water have resulted in a low prevalence of caries despite relatively high sugars intakes.

New areas of investigation into the relationship between sugars intake and health include aging, mental and athletic performance and behaviour. The topic of sucrose intake and aging is an opportune area for investigation. Current research using animal models is defining the most important variables and may lead to investigations in humans to determine whether intake of sugars affects longevity or the process of aging. There is no good evidence to support a role for sugars consumption in promoting hyperactivity and disruptive behaviour in children. However, recent suggestions of a role for glucose, aside from its function as a fuel, in facilitating mental processes deserves further study.

GLOSSARY

Carbohydrates: Components of foods containing carbon, hydrogen and oxygen. The term carbohydrate encompasses simple sugars, monosaccharides (e.g., glucose) and disaccharides (e.g., sucrose), oligosaccharides (several monosaccharide units) and polysaccharides. Starch is the only important food polysaccharide that can be digested in the small intestine. Starch and simple sugars are "available carbohydrates". The undigestible (nonstarch) polysaccharides are the main components of "dietary fibre".

Coronary heart disease (CHD): A condition in which the main arteries supplying the heart are blocked and no longer able to supply sufficient blood, and therefore oxygen, to the heart muscle (myocardium), which may then quickly die. The main cause of reduced blood flow is the accumulation of plaques, a disease known as atherosclerosis.

Dental caries: A disease affecting the hard tissues of the teeth resulting in progressive decay. Bacteria that accumulate in a dense mass as plaque on the surface of the teeth ferment sugars to form acids that demineralize the hard tissue underneath. Periodontal disease is a related bacterial infection that affects the softer supporting tissues of the teeth.

Diabetes mellitus: A metabolic disorder in which the hormone insulin is ineffective either because of failure of the pancreas to secrete it (type I, insulin-dependent [IDDM] or juvenile-onset diabetes) or because target tissues are insensitive to its action (type II, non-insulin-dependent [NIDDM] or maturity-onset diabetes).

Glycaemic index: A method for assessing the comparative effects of different carbohydrates on the pattern of changes in the concentration of glucose in the blood following a meal. A dose of 50 g of glucose is assigned a glycaemic index of 100, given by integrating the area under the curve when blood glucose concentration is plotted against time.

Hydrolyse: To split a chemical compound into its constituents by the addition of water. Hydrolysis may be purely chemical or catalysed by enzymes. Digestion is normally achieved by enzyme-catalysed hydrolysis.

Hyperglycaemia: A greater than normal concentration of glucose in the blood, most frequently associated with diabetes mellitus.

Hyperlipidaemia: A condition arising from an increased concentration in the blood of cholesterol, triglycerides or both. These lipids are in the form of lipoproteins.

Insulin: A hormone secreted by the pancreas in response to consumption of food. It circulates in the blood and assists in the transport of glucose into cells, and activates or suppresses the activities of various enzymes.

Metabolism: The highly integrated network of chemical reactions catalysed by enzymes that occurs within the cells of the body.

Metabolic pathway: A series of enzyme-catalysed reactions that follow each other in sequence, permitting one compound to be converted into another. Most metabolic pathways are under strict regulation.

Obesity: Excess accumulation of body fat, often defined as a body mass index (BMI) of greater than 30. BMI is the ratio of body weight in kilograms to height in meters squared.

Polysaccharide: A carbohydrate polymer formed by the linking of many monosaccharides.

Substrate: The substance on which a specific enzyme exerts its effects.

Sucrose: A disaccharide of glucose and fructose.

Sugar: Simple carbohydrates, generally with a sweet taste and soluble in water. The term is usually reserved for mono- and disaccharides (see Carbohydrates). In nonscientific English, however, the disaccharide sucrose is referred to as "sugar".

Triglycerides: Compounds of glycerol and three fatty acids. Synonymous with triacylglycerols (the official chemical name).

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