European Journal of Clinical Nutrition (1999) 53, 503–513

http://www.stockton-press.co.uk/ejcn

Review
Guidelines for sugar consumption in Europe: Is a quantitative approach justified?

CHS Ruxton[1]*, FJS Garceau[1] and RC Cottrell[1]

[1]*The Sugar Bureau, Dolphin Square, London SWIV 3PW*

Objectives: There is incongruity between the sugar consumption guidelines set in different European countries. A number have adopted maximum limits ranging from 10–25% energy, while others have no quantitative recommendations at all. This raises the question whether or not there should be a common European guideline for sugar consumption.
Design: This paper examines if such a goal for sugar is merited and reviews the published literature on associations between sugar consumption and dental caries, obesity and micronutrient dilution.
Results: Evidence showed that higher intakes of sugar were related to leanness, not obesity, and had no detrimental effects on micronutrient intakes in most people. In the case of dental caries, there was a relationship between frequency of sugar intake and the incidence of decay. However, in populations where fluoride use was adequate, associations between sugar intake and caries rarely reached statistical significance.
Conclusions: The available evidence does not justify a common quantitative recommendation for sugar. It is suggested that dental caries merits a more integrated public health approach where advice on the frequency of foods containing fermentable-carbohydrates is placed in context alongside oral hygiene.
Descriptors: sugar; obesity; dental health; micronutrients; dietary guidelines

Introduction

Population dietary targets were conceived in many European countries as a means to prevent diseases of undernutrition. They served their purpose well until advances in nutritional knowledge necessitated a reassessment of their value in relation to diseases of affluence such as obesity and heart disease. More recent guidelines, for example UK Department of Health (1991) or Deutsche Gesellschaft fur Ernahrung (1991), not only set recommendations for energy, protein and micronutrients but suggested limits on intakes of fat and sugar. While fat guidelines are similar across European countries at 30–35% energy, there are wide differences in guidelines for sugar intake and many countries do not have one at all. If sugar is indeed a public health issue, it is reasonable to explore whether a common quantitative recommendation for its consumption in Europe is justified.

Expert panels which argue for a sugar guideline develop their arguments in three ways. Firstly, by asserting that sugar is the main cause of dental caries and that a population shift towards a lower absolute sugar intake (as opposed to a different pattern of consumption) would result in an appreciable decrease in caries incidence. Secondly, by proposing that sugar could contribute to obesity, either by being preferentially stored as body fat or by accentuating appetite leading to overconsumption. Thirdly, by arguing that sugar intakes in excess of recommendations could displace micronutrient-dense foods from the diet, resulting in a greater risk of vitamin and mineral deficiency. These three contemporary theories arose from work carried out in the 1960s and 1970s, much involving animal models. In the last 10 y, research on the relationship between sugar and health has moved on substantially leading to a greater availability of relevant human data. Still earlier theories relating to coronary heart disease and diabetes have been dismissed by expert committees (Department of Health, 1989; FAO, 1998). Therefore the focus of this present paper is on obesity, dental caries and micronutrient dilution.

Terminology for sugars differs across Europe. The UK favours a national definition (Department of Health, 1989) in an attempt to distinguish sugars which are viewed as potentially cariogenic from those which are not. Therefore, sugars in whole fruit were named 'intrinsic' and were deemed to be harmless to teeth, while sugars added to food and those existing naturally in fruit juice were named 'non-milk extrinsic' (NME) and were deemed to have a harmful effect. In the absence of any accepted analytical method, tinned fruits and other selected foods items have been arbitrarily assumed to contain 50% extrinsic and 50% intrinsic sugars. Milk sugars were defined as extrinsic but were viewed as harmless to teeth when present naturally in milk and milk products. Such a classification of sugars was not based on scientific research and it remains impossible to distinguish between intrinsic and extrinsic sugars using any form of chemical analysis. The quantitative guideline in the

*Correspondence: Dr CHS Ruxton. The Sugar Bureau, Dolphin Square, London SW1V 3PW
Contributors: Dr Ruxton wrote the current paper; Ms Garcaeau collated data for the tables and wrote sections relating to European intakes and European recommendations; Dr Cottrell wrote original internal document upon which this paper was based.
Guarantor: Dr CHS Ruxton.

UK refers only to NME sugars. Other European countries do not use this classification but favour terminology such as 'total sugars', which would include fruit and milk sugars, and 'added sugars' which would not. These terms are used in this paper alongside 'sucrose' which refers only to table sugar, and 'sugar(s)' which can be viewed as an umbrella term.

European sugar intakes

National studies reporting sugar intakes were located for each of the 15 countries in the European Union. Where more than one study was available, that based on individual rather than supply or household data was selected as it was felt to be the more relevant method of data collection.

The data on sugar consumption in the EU are diverse (Table 1) showing intakes ranging from 51 g total sugars per day in Spain to 131 g per day in the Netherlands. The difference in presentation of the information prevents full comparison as some countries, such as France, Germany and Denmark report refined sugar or sucrose while most of the others report total sugars. A few do not specify the classification so it is assumed that the data refer to total sugars. Some intakes are expressed as a proportion of energy and these figures range from 8% in Spain to 21% in the Netherlands.

The methods used to collect the data include 24 h recalls (Belgium and Spain), 2 day diet history (Netherlands) supply data (Sweden, Portugal, Italy, Greece and Finland), 7 day weighed inventories (France and UK), 7 d food records (Germany, Denmark and Ireland) and an estimate from consumption of sugar-containing foods (Austria). Survey sizes differ (for example, Germany 21 000 subjects *vs* Ireland 859 subjects), as does the range of ages surveyed (for example, France 2–85 y, Belgium 25–74 y and UK 16–64 y).

Only 8 out of the 15 EU countries have carried out nationally representative dietary surveys. These are Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands and the UK. Data from Spain is made up from several regional surveys. Data for the remaining countries were obtained from supply figures which are a blunt tool compared with individual surveys since it is unclear who is consuming what within the population. Supply data also significantly overestimate actual consumption.

Recommendations for sugar intakes in European countries

Recommendations for population sugar intakes are as diverse as the intake data (Table 2). There are no sugar guidelines in Austria, Belgium, France and Ireland. In Italy and the Netherlands there are recommendations for total sugars that include added and fruit sugars (10–15% energy and < = 25% energy, respectively). In the UK, it is recommended that intakes of NME sugars do not exceed 10% of energy (11% if alcohol is excluded).

In Denmark, Finland and Sweden, a maximum of 10% energy from added sugars is recommended for children and people on low energy diets (defined as less than 8 MJ/d). There is no quantitative guideline for the remainder of the population. Germany, Greece and Spain have recommendations for a maximum of 10% total energy intake from added sugars. Once again, the lack of consistency in sugar terminology used in the European countries hinders comparison. France and Germany are the only countries which

Table 1 Estimates of sugar intakes in the 15 EU member states

Country	*Sugar intakes*	*Data source, quality and year of sampling*
Austria	101 g/d[a]	Two academic studies; no national survey; consumption of 'sugar and sugar containing foods'; 1991–92
Belgium	96 g total sugars/d (15% energy)[b]	National dietary survey; 1980–85
Denmark	51 g refined sugars/d[c]	National dietary survey; 1995
Finland	102 g/d[d]	Supply data; 1997 Dietary Survey of Finnish Adults only gives sugar and sweets consumption (quintiles cut-off points only); 1994
France	37 g sucrose/d[e]	National dietary survey; 1994
Germany	43–65 g sucrose/d (9–14% energy)[f]	Re-analysis of national dietary survey; 1997
Greece	89 g/d[c]	Supply data; presently conducting a nutrition survey (EPIC)
Ireland	90 g total sugars/d (15% energy)[b]	National dietary survey; 1988
Italy	80 g/d[c]	Supply data; 1997 (National dietary survey exists but no sucrose data given)
Luxembourg		See Belgian figures
Netherlands	131 g total sugars/d (21% energy)[b]	National dietary survey: 1987–88
Portugal	87 g/d[c]	Supply data; 1997
Spain	51 g total sugars/d (8% energy)[b]	Regional dietary survey; 1990
Sweden	121 g/d[c]	Supply data; 1997 Government survey 'Dietary habits of the Danes' 1995–no sucrose data given
UK	100 g total sugars/d (18% energy)[g]	National dietary survey; 1986–87

[a]Elmadja (1994); Bundesministerium fur Land-und Forstwirtschaft (1997).
[b]See Gibney *et al* (1995) for original references.
[c]Danish Veterinary and Food Administration (1996).
[d]FO Lichts (1998).
[e]Association Sucre/Produits Sucres, Communication Consommation (personal communication).
[f]Linseisen (1998).
[g]Gregory *et al* (1990).

Table 2 National recommendations for sugar intakes in the 15 EU member states

Country	*Sugar guidelines*
Austria	No quantitative recommendation
Belgium	No quantitative recommendation: total CHO should provide 55–75% total energy with starch contributing minimum 50%, moderate sugar intake (Ministere des Affaires Sociales, de la Sante Publique et de l'Environnement, 1997)
Denmark	Maximum 10% energy from added sugar for children and people on low energy diets (Asp, 1997)
Finland	Maximum 10% energy from added sugar for children and people on low energy diets (National Nutrition Council, 1989)
France	No quantitative recommendation (Dupin *et al,* 1992)
Germany	Maximum 10% energy from sucrose (Deutsche Gesellschaft fur Ernahrung, 1991)
Greece	Maximum 10% total energy from added sugar (Comite European des Fabricants de Sucre, personal communication)
Ireland	No quantitative recommendation
Italy	Between 10–15% energy from total sugar (Comite Europeen des Fabricants de Sucre, personal communication)
Luxembourg	See Belgian data
The Netherlands	Up to 25% energy from total sugars (Voorlichtings-bureau voor de Voeding, Zo eet Nederland 1992, 1993)
Portugal	No quantitative recommendation
Spain	Maximum 10% energy from added sugar (Serra-Majem *et al,* 1995)
Sweden	Maximum 10% energy from added sugar for children and people on low energy diets (Asp, 1997)
UK	Maximum 10% energy from NMES (Department of Health, 1991)

CHO = carbohydrate; NMES = non-milk extrinsic sugars

have published figures on sucrose intakes. No quantitative recommendations have been made by France.

Do European populations meet their own particular guidelines for sugar? In the Netherlands, Denmark, Germany and Spain, where the intake data are expressed the same way as the guidelines, the guidelines are being met by all except Germany. The other figures are more complex to interpret. Assuming an average daily energy intake of 2000 kcal, the percentage energy from total sugars in Greece, Italy and Sweden would be 17%, 15% and 23% respectively. The Italian population therefore meets its guideline while those of Greece and Sweden do not, although Sweden's guideline (like Denmark's) applies only to those with low energy diets. In the case of Finland and the UK, the guidelines use different terminology from the national intake data. Again using 2000 kcal/d as a standard energy intake and assuming that 70% of total sugars are NME sugars (Department of Health, 1989), Finland would exceed its guideline at 13% energy from added sugars. As for the UK, intakes of sugar in Scottish middle-aged adults (Bolton-Smith & Woodward, 1995a) were found to be similar to the 10% recommendation, while intakes in UK 16–64 y olds were reported to exceed this at 15% of energy (Gibson, 1996).

Sugar and obesity

There is little doubt that the number of overweight people in Europe has increased in recent years. This is against a background of stable or decreasing energy intakes, if dietary surveys are to be believed. The causes of weight gain have been debated at length, lack of physical activity being viewed increasingly as the most dominant factor. Of the macronutrient components, dietary fat is recognised as the principal nutritional determinant of adiposity, with carbohydrate and protein exerting lesser effects (Prentice, 1995).

It is popularly believed that sugar is 'fattening' and, as such, is a cause of obesity. The description would be justified if consumption of sugar resulted in a greater fat deposition per unit of energy than other dietary components or if sugar encouraged overconsumption of energy because of its pleasant taste. In addition, if there were a causative role for sugar in obesity, it is probable that sugar consumption would relate to the degree of overweight in a population. The central question is therefore, 'To what extent might sugar influence either the behavioural or the metabolic factors that contribute to obesity?'.

Metabolism of dietary components

Early research hypothesised that excess carbohydrate could convert into body fat in humans and prompt the development of obesity. The work has since been criticised for being based on animals which depend on this pathway to synthesise body fat since their natural diets contain very little fat (Acheson *et al,* 1984). Work on humans has provided a great deal of evidence to challenge this idea.

Björntorp and Sjöström (1978) suggested that only 1% of carbohydrate in a mixed meal is stored as fat, the remainder being metabolised or stored as glycogen. Later Acheson *et al* (1984) found that when humans were fed meals containing substantial amounts of carbohydrate, either as starch or sugar, negligible amounts of body fat were synthesised. Even in subjects with large glycogen stores, net *de novo* lipogenesis did not occur after a high carbohydrate meal. Instead, it was observed that thermogenesis was stimulated. More recently, stable isotope work has confirmed that *de novo* lipogenesis from carbohydrates is a minor pathway in humans (See review by Prentice, 1995).

Observations in humans have led to the conclusion that fat, carbohydrate and protein are not readily interchangeable energy currencies. Instead, each macronutrient achieves its own balance via a combination of increased oxidation and storage within body compartments (Prentice, 1995). Carbohydrate intake stimulates carbohydrate oxidation and storage as glycogen, therefore under normal circumstances, excess glucose is oxidised rather than being converted to fat. In marked contrast, the capacity to store fat is vast and, since fat oxidation is poorly related to fat intake, there is much scope for augmentation of adipose stores. This concept underpins theories on the contribution of fat balance to the development of obesity (see review by Hill & Prentice, 1995).

Influence of carbohydrate and fat on appetite

Because sugar is calorific and tastes pleasant, it is assumed that overeating might occur either through sugar itself being overconsumed—the concept of a 'sweet tooth'—or by making other calorific foods more desirable. Particular attention has been given to combinations of sugar and fat in foods.

Metabolic, physiological and psychological processes are all involved in the control of appetite and satiety. All macronutrients contribute to the control of appetite but their potency to do so varies and appears unrelated to their energy density. Fat is the most energy dense nutrient but has a weak effect on appetite control. In contrast carbohydrates, despite their lower energy density, have an inhibiting effect on appetite (Prentice, 1995). There is a lack of consistency in the evidence on whether sugars and starches have similar effects on appetite and body weight. Raben *et al* (1997) found that a high-starch diet resulted in lower energy intakes and reductions in body weight after 14 d compared with a high-sucrose or high-fat diet. Lawton *et al* (1998) found that giving high carbohydrate sweet or high carbohydrate savoury snacks had similar effects on energy intake and body weight over 21 d.

Sugar consumption and obesity in different countries

If sugar consumption were a cause of overweight, it might be expected that a relationship exists between the per caput sugar supply in a country and the level of overweight or obesity. Such ecological comparisons between different countries may be suggestive but the substantial number of uncontrolled variables affecting obesity levels make any conclusions tentative. In addition, few European countries have adequate nationally representative surveys of body weight. Data from a wider selection of countries is prejudiced by different BMI cut-offs and inadequate dietary intake data (in general only supply data is available). One study that provides more comparable data was that conducted by the WHO.

The international MONICA project, which investigated coronary heart disease risk in 35–64 y olds, includes data on diet and BMI (WHO, 1988). The BMI of those in the top 10% of the distribution was compared with mean per caput

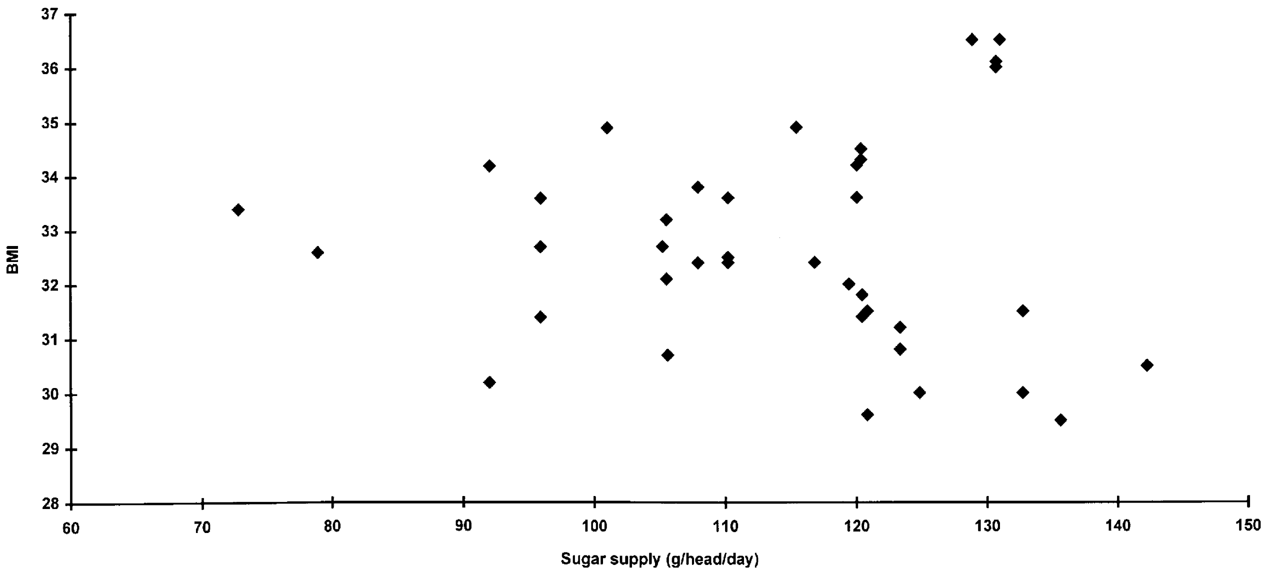

Figure 1 Relationship between obesity using 90th centile out-off and sugar supply data for 40 countries in females. Source of original MONICA data: WHO (1988); with outlier China omitted, $r = -0.04$, NS.

Table 3 Relationships between measures of body fatness and proportion of energy from fat and sugar in cross-sectional studies

Reference	*Study details*	*Relationship between obesity and sugar*
Miller *et al.* (1990)	American adults % body fat by hydrostatic weighing Diet by 3 d food diary Men 107; Women 109	Correlation with % energy from sugars **Men** $r = 0.14$; NS **Women** $r = -0.36$; $P < 0.001$
Gibson (1996)	UK adults Diet by 7 d weighed inventory Under-reporters excluded BMI Men 682; Women 501	Correlation with % energy from extrinsic sugars **Men** $r = -0.11$; $P < 0.001$ **Women** $r = -0.12$; $P < 0.05$
Gibson (1993)	UK children Diet by 7 d weighed inventory BMI 11–12 y olds: Boys 570; girls 533 14–15 y olds: Boys 327; girls 314	Tertiles of % energy total sugars; ANOVA **11–12 y olds:** Boys—low sugar > high sugar; $P < 0.01$ Girls—no association **14–15 y olds:** Boys—low sugar > high sugar; $P < 0.05$ Girls—low sugar > medium and high sugar; $P < 0.001$
Bolton-Smith & Woodward (1994)	Scottish adults Diet by food frequency questionnaire BMI Men 5768; Women 5858	Correlation with % energy extrinsic sugars **Men** $r = -0.26$; $P < 0.001$ **Women** $r = -0.16$; $P < 0.001$

sugar supply for the previous five years for each nation's study. Data for men and women were plotted separately and the results for women are shown in Figure 1. When the outlier China is excluded from the analysis (co-ordinates BMI 29.5; sugar supply 17 g/head/d), there appears to be a weak inverse relationship between sugar supply and BMI ($r = -0.04$) but this is not statistically significant (including China did not alter the significance of the relationship).

Dietary composition and body weight
A number of large population surveys of body weight and diet report an inverse relationship between indices of overweight and the proportion of energy as carbohydrate (Lewis *et al,* 1992; Baghurst *et al,* 1992; Hulshof *et al,* 1993; Crawley, 1993; Gibson, 1993; Bolton-Smith & Woodward, 1994). These studies have also shown that the proportion of energy from total sugars relates inversely to overweight (Table 3). However, one study which examined retrospective weight gain over two 2 y time periods (Colditz *et al,* 1990) found that higher sucrose consumers gained 0.15 kg more than low sucrose consumers over one of the time periods. In the other time period, there was no relationship.

Data from smaller cohort studies have also looked at the relationship between indices of overweight and energy sources. Miller *et al* (1990) examined the relationship between adiposity and macronutrient intake in 216 adults. He found that the proportion of energy from fat was positively correlated with body fatness whilst dietary energy from carbohydrate was negatively correlated. Dietary energy from sugars was significantly higher in lean women but there was no such relationship in men.

It could be argued that the overweight have deliberately reduced their sugar intake in an attempt to lose weight, or that those with a higher BMI specifically under-report sugar-containing foods. Gibson (1996) reported an inverse correlation between total sugar intake (as a proportion of energy) and BMI in adult men even when dieters and under-reporters were excluded. Bolton-Smith & Woodward (1994) found a similar result in their analysis of 11 626 adults and demonstrated an inverse relationship between BMI and the ratio of sugar:fat. It is, therefore, likely that the inverse relationship between sugars and BMI is simply not an artefact of reporting bias.

Since dietary fat and sugar appear to be inversely related, this may mean that goals to simultaneously reduce fat and sugar are unachievable (Drummond & Kirk, 1999). A few studies have investigated sugar intakes in those achieving the fat recommendation in various countries. Crawley (1993) studied British adolescents and found that, of a total sample of 4760, only 213 (4%) achieved a diet with fat supplying less than 33% of dietary energy. The mean intake of NME sugars in this group was 17.4% of dietary energy compared with 13.5% in the whole population. Hulshof *et al* (1993) reported that, of a sample of 5595 Dutch people aged 22–49 y, only 185 men and 154 women achieved the fat guideline of less than 35% dietary energy. Intakes of added sugars in the successful group corresponded to 13.6% of dietary energy in men and 11.6% in women. Bolton-Smith & Woodward (1994) found in a study of Scottish adults that fat goals were met by the third of the population who consumed around 19% of energy from sugars. In an intervention study (Drummond & Kirk, 1999), 90 middle-aged men were given one-off individual advice to reduce either fat (with sugar *ad libitum*) or both fat and added sugars and followed up for six months. Fat reductions were achieved in both groups but a sustained significant reduction in sugars was not. Despite similar energy intakes between the groups, there was a significant spontaneous weight loss of around 1 kg in the low fat *ad libitum* sugar group.

Sugar and obesity conclusion
Fat appears to be the principal dietary determinant in obesity rather than sugar (FAO, 1998). In epidemiological and intervention studies, a high intake of sugar is associated with a low intake of dietary fat and vice-versa suggesting that sugar may relate to leanness, possibly by displacing fat from the diet. The available evidence does not support any population dietary guideline for sugar intake on the grounds of a relationship with obesity (WHO, 1996).

Sugar and micronutrient dilution

At a population level, most industrialised countries enjoy diets that are adequate in energy and nutrients. In certain sub-groups intakes of some nutrients may fail to reach recommended levels, for example iron in women (Gregory *et al,* 1990). It has been argued that a high consumption of sugars might displace micronutrient-rich foods from the diet and increase the risk of deficiency. Such an effect has been labelled nutrient dilution.

Two main approaches are used by researchers to investigate this concern. The first is to compare segments of a population consuming different absolute amounts of sugars. The second is to adjust for energy intake and make comparisons within a population based on the percentage of dietary energy from sugars (or grams of sugars per unit of energy). Studies using the first approach report that, in most cases, energy and nutrient intakes are positively related to intakes of added sugars (Rugg-Gunn *et al,* 1991; Lewis *et al,* 1992; Gibson, 1993). Higher sugar consumers tend to consume more of everything suggesting that 'sugar intake is a weaker predictor of absolute micronutrient intake than total energy consumption' (Department of Health, 1989). The second approach examines the effect of a higher or lower *proportion* of sugars in the diet.

Studies in adults
Department of Health (1989) presented data on the micronutrient intakes of 217 adults divided into thirds according to NME sugars (g) per 1000 kcal. No significant trends were found among men but in women, there was a small decline in zinc and iron intakes with rising sugars. When compared with UK Recommended Daily Intakes (RDI), zinc intakes were adequate even for the highest sugar consumers, whilst women in all groups failed to meet the RDI for iron. For most micronutrients, intakes were highest in the middle third of sugar consumers which corresponded to a range of 11.7–16.1% energy from NME sugars in men and 7.7–12.6% in women. Gibson (1997a) found that a range of sugar consumption is compatible with adequate micronutrient intake when examining the diets of 2197 adults after grouping by fifths of NME, added or total sugar intakes.

Baghurst *et al* (1992) divided 2800 Australian adults into tenths according to percentage of dietary energy from added sugars. The range of intakes of added sugars was wide, for example in men it was from $<4.7\%$ energy in the lowest tenth to $>19.3\%$ energy in the highest tenth.

Intakes of vitamin B6, B12, carotene, folate, magnesium and zinc demonstrated an inverse trend with added sugar intake. However, the decline in micronutrient intakes was only significantly different from the median in the highest and lowest tenths. Across the broad range 4–16% energy as added sugars, there was no significant variation in micronutrient intakes. The researchers also calculated the proportion of individuals in each tenth of sugar intake who failed to meet 70% of the Australian RDI. This rose across the deciles for folate and vitamin A but for other nutrients there was no consistent trend.

Bolton-Smith & Woodward (1995b) analysed data from 11 626 Scottish adults to examine relationships between the proportion of different sugars in the diet and intake of antioxidant vitamins and fibre. Subjects were classified by fifths of total and extrinsic sugars intakes. A significant positive relationship was found between total sugars and intakes of all vitamins and fibre. For extrinsic sugars, vitamin and fibre intakes tended to be highest in the middle three fifths and lower at both ends of the distribution that is, an *n*-shaped curve. Similarly, when comparing intakes with recommended levels, the middle three fifths of extrinsic sugar consumers had the greatest proportion of people meeting recommended levels. Therefore, both high and low extremes of extrinsic sugar intake were associated with poorer antioxidant vitamin and fibre intake. The authors suggested that the middle fifths represented the majority with a 'healthy' sugar intake, corresponding to a total sugar intake of 12–20% of dietary energy, and an extrinsic sugar intake of 6.2–15.7% in men and 4.8–11.6% in women.

Lewis *et al* (1992) re-analysed data from the 1978-79 US Department of Agriculture Nationwide Food Consumption Survey, examining dietary records from 30 770 people aged 4–64 y. The 25% of the population with the highest percentage of energy from added sugars (16.1–24.4% energy) was compared with the 50% with moderate added sugar consumption, (7.6–14.4% energy). The lowest 25% of added sugar consumers was not considered. These high-sugar consumers tended to take in lower proportions of nutrients, but for vitamins A, B12 and C, thiamin, riboflavin, niacin, iron and phosphorus, average intakes still exceeded the RDA. Calcium and vitamin B6 intakes were below USA RDA in both high and moderate consumers, although to a greater extent in the higher sugar consumers.

Elderly South Africans ($n = 200$) were studied using a food frequency questionnaire (Charlton *et al,* 1998). Sugar intakes were divided into thirds by g/d and by percentage energy from added sugar. As expected, intakes of micronutrients rose across the thirds of added sugar intakes when expressed as absolute levels. Intakes of micronutrients fell across the thirds of added sugar intakes when expressed as a proportion of energy. The mean sugar intakes in each of the thirds for women were disparate at 6.7%, 15.6% and 26.6%. Average micronutrient intakes at all sugar levels did not meet Reference Nutrient Intakes.

Data for children

Rugg-Gunn *et al* (1991) investigated diet in 11–12 y old English children to examine the effects of high and low intakes of added sugars. Only children at the extremes of distribution were considered and this related to a mean of around 9% energy from added sugars in the low-sugar group ($n = 60$) and 19% in the high-sugar group ($n = 60$). Average intakes in the whole sample ($n = 405$) were approximately 15% energy. For each gender, nutrient intakes in the high and low groups were compared (Table 4). The only nutrient to vary with sugar consumption was vitamin D which was significantly lower in the high-sugar group. Correlational analysis of all children revealed significant positive relationships between added sugar intake and most nutrients (due to the effects of increasing energy intake). When proportion of energy from added sugars was considered, there was an inverse relationship with vitamin D (and with folate in boys). All other nutrients were not related. Mean intakes in the high and low sugar groups were also compared with UK RDA and it was found that a similar proportion of children in each group failed to meet the recommendations.

Gibson (1993) analysed the dietary intakes of 2705 adolescents from a national database to compare sugar intakes with nutrient density. Children were divided into thirds of sugar consumption using percentage energy from total sugars; the groups corresponded to $< 20.7\%$ in the lowest, 20.7–25.2% in the middle and $> 25.2\%$ in the highest. The relationships between total sugars intake and micronutrient density varied. Calcium and riboflavin tended to be positively related, iron and nicotinic acid negatively related, while thiamin and vitamins A and C were not related at all. The mean nutrient intakes across the sugar thirds were compared with UK recommendations (Department of Health, 1991). All groups of children exceeded the RNI for thiamin, riboflavin, niacin, vitamin C and vitamin A. Irrespective of which tertile they were in, all groups failed to meet the RNI for calcium, whilst girls and younger boys failed to meet the RNI for iron. As in the case of the Rugg-Gunn *et al* (1991) study, sugar intake did not reliably predict nutrient adequacy.

The same author (Gibson, 1997b) carried out a similar analysis on a national database of 1675 pre-school children, this time dividing the sample into fifths of percentage energy from NME sugars. The quintile cut-offs for boys were $< 12.2\%$, 15.8%, 19.9% and 24.9%. The quintile cut-offs for girls were 11.9%, 16.4%, 20.2% and 24.5%. Table 5 summarises the findings and shows that intakes of most micronutrients significantly declined with increasing proportional sugar intake. However, when a comparison was made with RNI (Department of Health, 1991), intakes of most micronutrients were above this level. The exceptions were vitamin D, which was below RNI for all sugar

Table 4 Micronutrient intakes in a sample of low and high sugar consumers aged 11–12 years

	Boys		*Girls*	
	High sugar $n = 30$	*Low sugar* $n = 30$	*High sugar* $n = 30$	*Low sugar* $n = 30$
Calcium (mg)	907	850	768	781
Iron (mg)	11.2	10.4	9.04	9.24
Retinol equivalent (mcg)	765	605	542	748
Thiamin (mg)	1.16	1.16	0.95	0.95
Riboflavin (mg)	1.56	1.63	1.28	1.33
Vitamin C (mg)	41.6	45.8	43.3	39.3
Vitamin D (mcg)	2.38**	1.40	1.60*	2.25
Folic acid (mcg)	120	107	96.6	109

*$P < 0.05$ **$P < 0.001$ difference between high and low sugar groups.
High sugar: mean daily intake 19% energy from added sugar.
Low sugar: mean daily intake 9% energy from added sugar.
Source:Rugg-Gunn et al (1991).

Table 5 Variation in micronutrient intakes with increasing NME sugar consumption in a sample of children aged 1.5–4.5 y (Figures for boys in bold)

	Quintiles of % energy from non-milk extrinsic sugars					
Nutrient	*1st*	*2nd*	*3rd*	*4th*	*5th*	*ANOVA*
Calcium (mg)	**798**	**666**	**679**	**597**	**517**	< 0.0001
	769	668	615	566	501	< 0.0001
Iron (mg)	**5.7**	**6.1**	**5.7**	**5.8**	**5.1**	0.0018
	5.4	5.6	5.6	5.3	5.1	NS
Zinc (mg)	**5.2**	**4.7**	**4.5**	**4.4**	**3.7**	< 0.0001
	5.0	4.6	4.3	4.0	3.7	< 0.0001
Thiamin (mg)	**0.87**	**0.86**	**0.85**	**0.80**	**0.73**	< 0.0001
	0.85	0.87	0.79	0.78	0.73	0.0009
Riboflavin (mg)	**1.43**	**1.28**	**1.27**	**1.18**	**1.01**	< 0.0001
	1.37	1.28	1.15	1.10	1.03	< 0.0001
Niacin equiv. (mg)	**17.4**	**17.1**	**16.8**	**16.3**	**15.2**	0.0005
	17.1	16.8	15.9	15.8	14.9	0.0006
Folate (mcg)	**136**	**141**	**136**	**128**	**126**	0.032
	135	137	131	128	119	0.006
Vitamin C (mg)	**36**	**44**	**48**	**54**	**71**	< 0.0001
	42	46	51	54	72	< 0.0001
Vitamin D (mcg)	**2.1**	**1.8**	**1.8**	**1.6**	**1.8**	0.022
	2.2	2.3	1.7	1.9	1.8	NS

Source: Gibson (1997b).

intakes; iron, which dropped below RNI in the top quintile and zinc which dropped below RNI after the second quintile. The author concludes that, while there was a downward trend in nutrient intakes with increasing sugar consumption, the effects of sugar on the adequacy of the diets were of minor significance at intakes of up to 20% of energy from NME sugars.

Sugar and micronutrient dilution conclusion

A broad range of sugar intakes appears to be compatible with adequate nutrient provision, although it is acknowledged that the true risk of deficiency can only be assessed using biological indicators. Where intakes of micronutrients were lower than desired in a population, the pattern was seen at both extremes of the sugar intake spectrum. One explanation of these findings is that most sucrose is consumed as an ingredient in foods such as breakfast cereals, milk puddings and fruit drinks (Gibney *et al,* 1995) which are good sources of micronutrients.

Can the available data predict an optimum range for sugar consumption? In adults, added sugar intakes between 5% and 16% of dietary energy did not have a detrimental effect on micronutrient intakes. In children, there are insufficient data to determine this precisely since there is much variation across nutrients. However, in general, it appears that the most micronutrient dense diets were achieved by those consuming average amounts of sugars, that is, 14–20% of dietary energy from added sugars.

Sugar and dental caries

The principle reason behind recommendations to reduce average sugar intakes is an expected reduction in dental caries prevalence. Caries levels have fallen substantially since the mid-seventies mainly due to the impact of fluoridated toothpaste and water supplies (Kandelman, 1997). However, there is a belief that greater improvements would occur if the population average for sugar consumption were to be reduced.

Dental caries is a dynamic process involving the metabolism of a carbohydrate substrate by oral bacteria to produce acid. Protective elements include saliva and host resistance (Kandelman, 1997). There is no doubt from the literature that frequent consumption of sugars is a key factor in the development of dental caries. However, two important questions are raised by the assertion that a recommendation for the amount of sugar consumed at a population level would reduce caries prevalence. These are: (a) is the amount of sugar intake *per se* related to prevalence of dental caries; and (b) will lowering the mean intake of sugar in a population result in a reduction in caries?

Is the level of sugar intake related to prevalence of dental caries?

Research on the process of dental caries development has led to assumptions that sucrose is the most important factor in the development of dental caries. It has been argued that the level of sugar in the diet determines caries experience and this has been the basis of calls for a reduction in average sugar consumption.

A cross-cultural study (Sreebny, 1982) provided the justification for many European sugar recommendations. WHO national oral health data were compared with per caput sugar supply data for a number of countries. A significant relationship (assumed to be linear) was reported between the level of sugar supply and the prevalence of dental caries at 12 y old, but not at 5 y. Countries with a per caput sugar supply of 50 g/d (18 kg p.a.) or less were found to have an average DMFT (a caries index referring to the number of decayed, missing or filled teeth) in 12 y olds lower than 3.0. Hence, 50 g/d was proposed as a possible 'safe' limit of sugar consumption.

However, at the time of Sreebny's study, data were available (WHO, 1991) for substantially more countries than were used, and it is not clear why these were excluded since Sreebny's paper gave no criteria for selection of data. Although inclusion of the extra data does not alter the correlation line, a number of the countries fall outwith the proposed cut-offs. Therefore, the suggested 'safe' limit for sugar consumption was not robust even at the time of Sreebny's publication.

A study by Woodward Walker (1994) updated the Sreebny work. All available data from the WHO Oral Health databank (WHO, 1991) were cross-matched with all available sugar supply data. Ninety countries were represented in both data sets. A weak significant correlation was demonstrated between sugar consumption and dental caries experience at 12 y old with 28% of the variation in DMFT explained by sugar consumption (Figure 2). When the original Sreebny cut-off points are applied to the new data, three countries have a DMFT above 3.0 and a sugar consumption of less than 50 g/d and 13 have a DMFT below 3.0 but a sugar consumption above 120 g/d. Further analyses demonstrated a weak correlation between sugar and caries incidence in developing countries, with sugar explaining 26% of the variance in DMFT. However in industrialised countries, there was no significant relationship between sugar and caries despite a broad range of sugar consumption from 80 g/d (22 Kg pa) to 195 g/d (54 Kg pa). Sugar explained less than 1% of the variation in DMFT score and the authors concluded that other variables, such as fluoride exposure, may have confounded any underlying relationships.

At an experimental level, there is clear evidence that the frequency of sugar consumption is more important than the amount. Gustafsson *et al* (1954) varied the amount and frequency of sugar (mainly as toffees) in the diets of mental asylum patients. When sugar was restricted to four main meals daily, amounts of up to 300 g/d did not significantly affect caries levels. However, when frequency was varied by giving 8–24 toffees between meals, caries incidence at the highest frequencies rose even when amounts as small as 50 g/d were given.

The Gustafsson study provided a model of sugar frequency in the absence of oral hygiene. Contemporary studies, since the introduction of fluoride toothpaste in the mid-seventies, find that amount of sugar is rarely associated with caries experience. Furthermore, in populations where oral hygiene is good, even frequency of sugar intake is diminishing as a caries predictor (Kandelman, 1997). Using data from a survey of 328 English adolescents, Beighton *et al* (1996) found a weak association between caries and frequency of intake of certain sugar-containing foods. Hinds & Gregory (1995) reported no relationship between absolute levels of NME sugars or total sugar-containing foods and caries in a representative sample of 1450 UK pre-schoolchildren. Amount and frequency of non-chocolate confectionery were the only dietary variables related to caries in this study, but even these associations failed to reach significance in children with good oral hygiene (Gibson & Williams, 1999).

The proportion of children who are caries-free continues to rise in nearly all industrialised countries. McMahon *et al* (1993) compared New Zealand pre-school children with and without caries, finding that there were no differences in dietary intakes or frequency of eating between the two groups. In a study of Italian teenagers (Petti *et al,* 1997), good oral hygiene was three times more likely to predict a low caries prevalence than a 'low cariogenic' diet. These studies suggest that diet is much less influential when oral hygiene is sufficient.

What constitutes a frequent intake? Gustafsson *et al* (1954) used sugar exposures of up to 24 times per day (in the absence of oral hygiene). In a comparison of high and low caries groups (Jones *et al,* 1996), the average frequency of 'sugar episodes' was around 12–14 in the high caries group and 3–5 in the low caries group. Eating frequency (excluding drinks) in caries free pre-school children ranged from 4–7 times per day in the McMahon *et al* (1993) study, while in the Gibson & Williams (1999) study of pre-schoolers, the median for consumption of sugar-containing foods was four times per day. These studies challenge the assumption that sugar should be kept to mealtimes, that is three times per day, since a frequency of eating which exceeds this would appear compatible with little or no dental caries.

Would lowering average sugar consumption result in a decrease in caries?

To examine whether sugar reductions at a population level relate to lower caries in practice, changes in sugar supply were plotted against changes in caries experience in 67 countries using the Sreebny (1982) and Woodward & Walker (1994) data sets (Figure 3). The results show reductions in both sugar supply and caries in 18 countries (lower left quadrant of Figure 3) but in 25 countries there has been an increase in sugar supply combined with a reduction in caries experience (lower right quadrant of Figure 3). The relationship between sugar reduction and caries is clearly unreliable.

This finding is borne out by reports from countries which, over the last 10–15 y, have experienced a dramatic decline in caries against a background of little change in sugar supply. The prevalence of caries in Europe continues to decline in those countries which previously had higher DMFT scores. In a review of caries prevalence in relation to diet, Marthaler (1990) concluded 'in those countries where caries prevalence is declining, the overall consumption of sugar is ceasing to be the most important

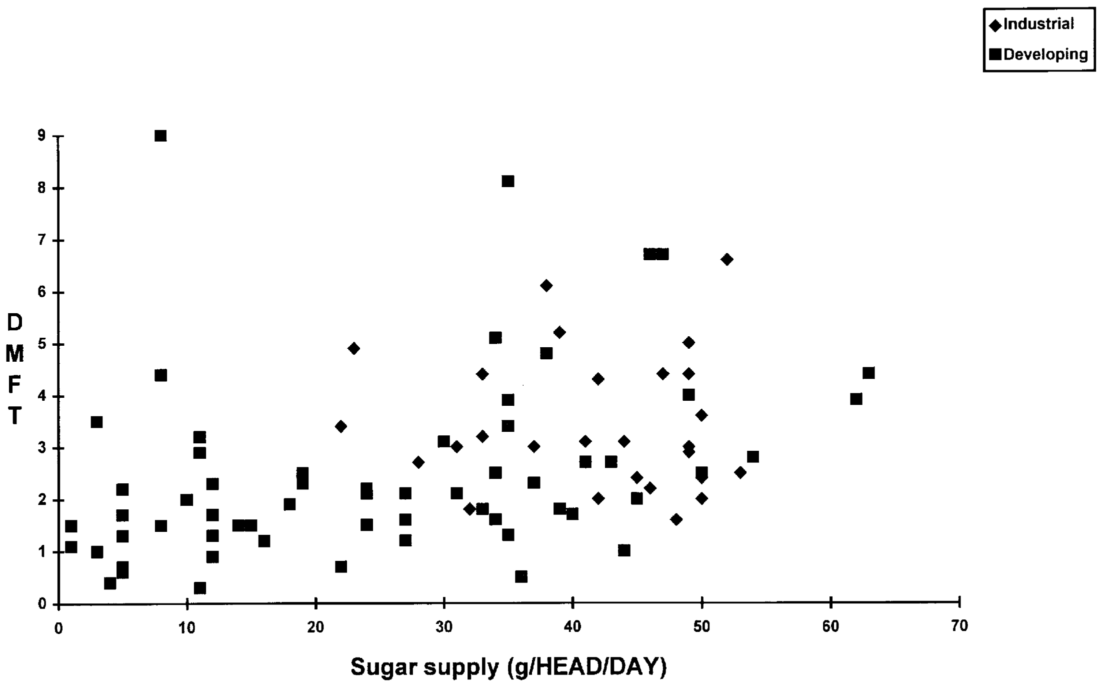

Figure 2 National sugar supply *vs* dental caries in 12 y olds for 90 countries. *Source:* Woodward & Walker (1994); industrial $r = -0.09$ NS: developing $r = 0.49$, $P < 0.01$.

determinant of average dental caries prevalence'. It would seem that changes in the average caries experience of a population cannot be predicted reliably from changes in sugar supply. This brings into question the value of using reduction in average sugar consumption as a public health measure.

It has been demonstrated that a range of sugar consumption is compatible with a low level of caries, however, the ultimate aim must be for caries to be virtually abolished. Although individuals can be caries-free whether they consume sugar or not, the available evidence suggests that even the total removal of sugar (or NME sugar) from the diet would not necessarily eliminate caries in a population (König, 1990).

Data from epidemiological studies (Sreebny, 1982; Woodward & Walker, 1994) suggest that, in the absence of a sugar supply, there would still be some caries. This is to be expected since other carbohydrates are potentially cariogenic (Kashket *et al,* 1996; FAO, 1998). This was not acknowledged in the UK recommendations (Department of Health, 1991) which suggested that NME sugars were uniquely cariogenic, while sugars inherent in whole fruits and vegetables, milk sugar and starches do not constitute a risk.

Investigations of the potential cariogenicity of various snack foods in humans demonstrated that plain crackers and raisins resulted in a slower but prolonged release of acid than some sugar-containing snacks (Kashket *et al,* 1996). This is because processing techniques such as extrusion enhance cariogenicity and retentiveness. Thus, there is evidence that dried fruit and certain starchy foods can be a caries risk. This was acknowledged by a joint FAO/WHO expert group (FAO, 1998) which rejected the terms 'extrinsic' and 'intrinsic' sugars in favour of 'a more scientific and rational approach to the role of fermentable carbohydrates in dental caries' emphasising a varied diet, oral hygiene and fluoride exposure.

Sugar and dental caries conclusion

The balance of evidence does not support the assumption that a reduction in the amount of sugar consumed by a population would lead to a predictable decline in dental caries prevalence. Comparison of international data indicates that a low sugar consumption does not necessarily relate to less caries, nor that a higher consumption inevitably relates to more. Present consumption levels are consistent with an absence of caries in many individuals within industrialised populations where oral hygiene and fluoride exposure are adequate. If it is accepted that frequency is important, not amount, there is an argument for revising sugar recommendations which are based on a quantitative approach, for example, those from Spain, Greece, UK, Italy and Germany.

Discussion

This paper reviews the available data on sugar intakes in EU countries and the various national guidelines for sugar consumption. In addition, literature reporting associations between sugar and obesity, micronutrient density and dental caries has been examined to explore and debate the justifications for a common quantitative sugar guideline in Europe.

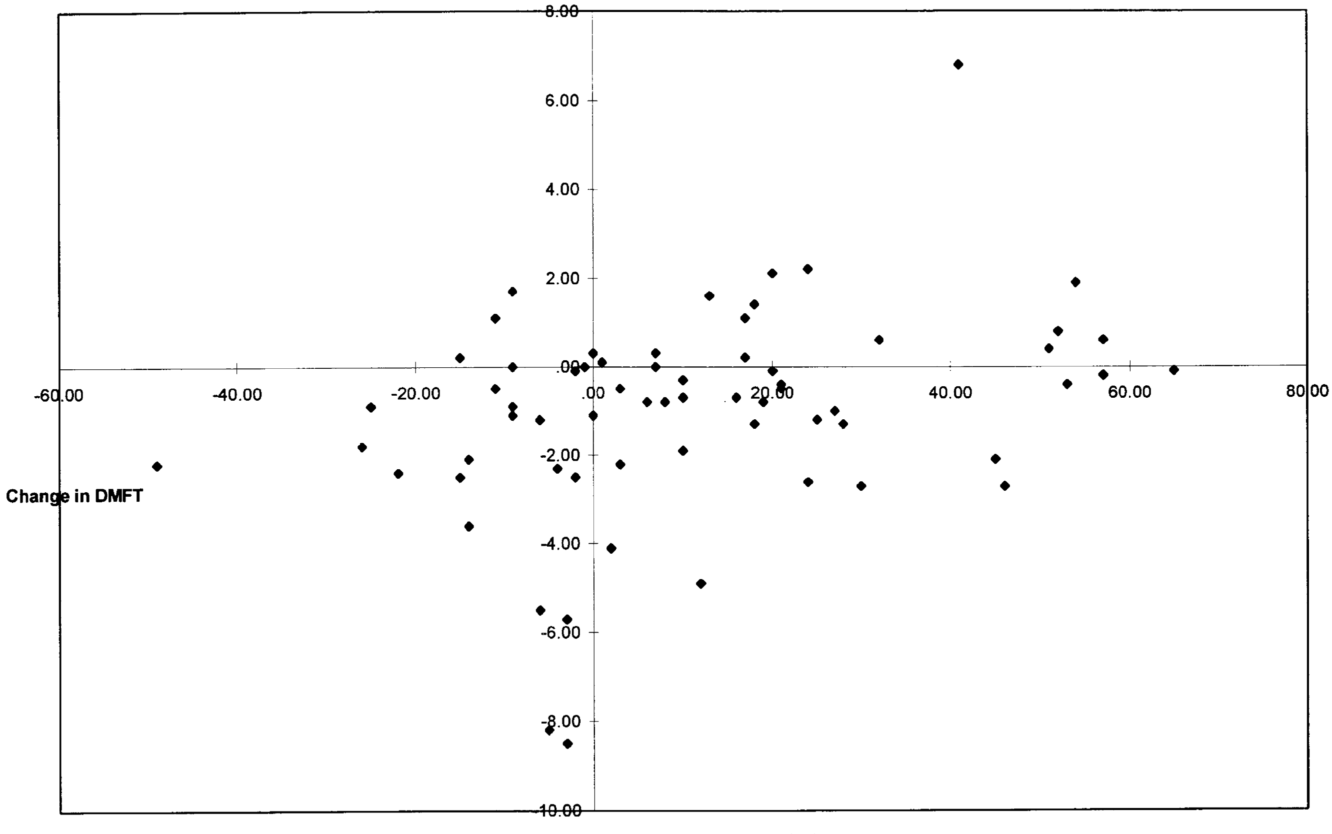

Figure 3 Changes in DMFT *vs* changes in national sugar supply in 67 countries between 1982 and 1994. Lower left quadrant = reduced sugar and caries ($n = 18$); Lower right quadrant = increased sugar, reduced caries ($n = 25$); Upper left quadrant = reduced sugar, increased caries ($n = 3$); Upper right quadrant = increased sugar and caries ($n = 15$); Points on the axis = sugar constant, caries changed ($n = 3$); sugar changed, caries constant ($n = 3$).

Sugar consumption in Europe varies considerably as does the methodology used to collect the data. Because of this, comparisons between countries using widely different dietary assessment methods should be treated with caution. Guidelines for sugar consumption vary too and it is obvious that in a number of countries that the quantitative guidelines have not been based on proper evaluation of national sugar intakes. Finland, Greece and Sweden base their quantitative guidelines on supply data, which provides a poor estimate of sugar intake. A number of the countries examined had quantitative guidelines for sugar consumption set at 10% of food energy yet there is no persuasive evidence to support such a figure.

Despite concerns about the adverse effects of sugar on body weight levels, the majority of epidemiological studies has demonstrated no positive correlations between sugar consumption and obesity, indeed the evidence points to an inverse relationship. Studies on appetite have shown links between sugar and appetite suppression rather than stimulation, while physiological studies have concluded that *de novo* lipogenesis from carbohydrate is a minor pathway in humans. Taking these findings together, it is unlikely that sugar is an important influence on the development or maintenance of obesity.

Concerns have also been expressed that high sugar intakes promote micronutrient dilution leading to a risk of micronutrient deficiency. Many studies looking at this issue have been published yet there is no consistency among the results. All that is clear is that, in some populations, intakes of specific micronutrients correlate inversely with sugar consumption but there is little evidence of inadequacy around the mean. Where micronutrient intakes fail to reach population recommendations, low intakes are seen at all levels of sugar consumption. However, it is acknowledged that these findings relied on reports of dietary intake and not biological measures of nutritional status which would provide a better estimation of adequacy. These data do not point to the conclusion that the average levels of sugars currently consumed by European populations constitute a threat to micronutrient status.

Dental decay is the only disease where sugar consumption impacts. Guidance should be given to European populations to help achieve reductions in caries but the key question is: 'What type of recommendations would be effective?' Recent studies suggest that there are no reliable relationships between the amount of sugar eaten and prevalence of dental caries. This is consistent with evidence that frequency of intake, not amount, is the relevant variable. Furthermore, the data on how changes in sugar consumption relate to changes in caries do not provide a strong case for the merits of wholesale dietary manipulation to reduce the percentage of energy coming from sugars.

Selection of policy options in health care is nowadays based on the concept of 'evidence-based medicine'. This principle is widely accepted in clinical medicine but seems yet to impact on nutritional interventions such as population dietary guidelines. To set targets for an *individual's* intake without clear evidence of need, or evidence of effectiveness, would present a challenge to any clinician. Incongruously to set such an objective for a population is considered reasonable. This argument is particularly relevant to sugar.

Epidemiology provides the main evidence on which to judge the oral health benefits to be expected from changes in population dietary habits (since few intervention studies have been attempted). However, the available data suggest that the dental health improvements to be expected from even total exclusion of sugar are likely to be modest (König, 1990).

Conversely, the success of interventions based on fluoride exposure, *via* toothpaste or water supplies, is well documented. Major improvements in caries rates have occurred in the developed world during the last twenty years against a background of stable sugar intakes and it is generally agreed that these have been due to fluoride toothpaste use, not dietary change (FAO, 1998).

Conclusions

Concerns that sugar consumption, at current levels in Europe, relates to obesity and has an adverse effect on micronutrient intakes are not supported by the available scientific literature. Dental health remains the main reason for limiting sugar consumption but the evidence strongly supports the formulation of advice based on frequency of sugar, not amount. In addition, there is a clear justification for placing sucrose guidelines in context alongside oral hygiene, fluoride exposure and the potential impact of foods containing fermentable carbohydrates other than sucrose (FAO, 1998).

It is apparent, therefore, that no reliable population-based quantitative targets can currently be set for sucrose, or indeed for sugars in general. The most practical way forward, if quantitative *nutritional* targets are required, might be to place sugars in the general category of carbohydrates until new data allow a nutritionally useful distinction to be made. This is precisely the approach taken by the FAO/WHO Expert Consultation on Food Based Dietary Guidelines (WHO, 1996). The committee declined to set a separate quantitative target for sugar preferring instead to endorse a figure for total carbohydrates which included sucrose.

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