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Dietary sugars intake and micronutrient adequacy: a systematic review of the evidence

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Guidelines for sugars intake range from a population mean of less than 10 % energy from free sugars, to a maximum for individuals of 25 % energy from added sugars. The aim of the present review was to examine the evidence for micronutrient dilution by sugars and evaluate its nutritional significance. From a web-based search of MEDLINE and hand search of linked papers, forty-eight relevant publications were identified on sugars (total sugars, non-milk extrinsic sugars, or added sugars) or sugar-containing drinks. These included five reports from expert committees, six reviews, thirty-three observational studies and four small-scale interventions. There was inconsistency between studies as to the relationship between sugars intake (however expressed) and micronutrients. The statistical patterns varied between nutrients and population groups. Curvilinear associations were found in some analyses, with lower nutrient intakes at both extremes of sugar intake; however, factors such as dieting and under-reporting may confound the associations observed. Some studies found statistically significant inverse associations but these were weak, with sugars explaining less than 5 % of the variance. Mean intakes of most micronutrients were above the RDA or reference nutrient intake except among very high consumers of sugars. The available evidence does not allow for firm conclusions on an optimal level of added sugars intake for micronutrient adequacy and the trends that exist may have little biological significance except for a few nutrients (for example, Fe). It is established that energy intake is the prime predictor of micronutrient adequacy. A better understanding of valid approaches to energy adjustment, misreporting and the assessment of micronutrient adequacy is crucial to further progress in this area.

Sugars intake: Micronutrient adequacy

Introduction

The aim of the present review was to collate and critically examine the evidence that dietary sugars compromise micronutrient intakes, to evaluate the nutritional significance and if possible to assess the range of sugars intake associated with micronutrient adequacy.

Methods

Relevant articles published between 1980 and 2006 were identified by searching the MEDLINE database (National Library of Medicine, Bethesda, MD, USA). Search terms included sugar(s) (total sugars, added sugars or non-milk extrinsic sugars (NMES)), sucrose, and soft drinks, sweetened beverages, (with) nutrient intake, micronutrient, nutrient dilution, or empty calorie. This web-based search was supplemented by a hand-search of linked references and recent articles in specialist journals. Studies were included if they examined the association between micronutrient intakes and consumption of sugars or soft drinks, whether they were surveys, reports, reviews or interventions. Simple temporal associations (trends in sugars intake) were not included. Citations and abstracts were imported into a bibliographic database (EndNote, version 8; Thomson ResearchSoft, Carlsbad, CA, USA)[1] and papers were obtained from journals, libraries or authors. Articles were classified according to their study design, dietary methodology, definition of sugars, subject age and country of origin. We noted reported associations with micronutrients, their nutritional importance (in comparison with dietary reference values) and the range of sugars intake associated with adequacy.

Abbreviations: CSFII, Continuing Survey of Food Intakes by Individuals; %EAS, percentage energy from added sugars; NHANES III, third National Health and Nutrition Examination Survey; NMES, non-milk extrinsic sugars.

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Results: overview of studies and methods

Forty-seven relevant papers and reports on the association between sugars and micronutrient intakes were identified. Four of the studies were interventions, while thirty-three were observational. There were also five major reports and six reviews.

Studies defined sugars in various ways (total sugars, NMES, added sugars, sucrose or ‘sugar’) and most express sugars intake as a percentage of energy intake. Some adjustment for energy is essential in seeking to quantify the independent impact of nutrients on health outcomes but there are various approaches with different strengths and weaknesses[2]. Forshee *et al.* have criticised the use of percentage energy from sugars as inherently biased because its application presupposes the displacement it seeks to prove[3]. This methodological debate is beyond the remit of the present review but the reader should be aware that estimates of the extent of dilution by sugars are a consequence of the methodology used.

The intervention studies are shown in Table 1[4–7], and the observational studies in Tables 2–4[3,8–39]. The major reports[40–44] are discussed in the ‘Recommendations from expert committees’ section and the reviews[45–50] in the ‘Reviews’ section.

Recommendations from expert committees

In the UK, the 1989 Department of Health Committee on Medical Aspects of Food Policy (COMA) report on dietary sugars and human disease[40] considered the issue of micronutrient dilution by NMES from the limited studies available at the time. No quantitative recommendations were given, but the report concluded (1) ‘that sugars intake is a weaker predictor of absolute micronutrient intakes than total energy consumption’ and (2) ‘that at any level of energy intake, a higher sugars intake is associated with lower micronutrient intakes’. This observation was clearest at the lowest energy intakes. Since 1990, a number of expert committees worldwide have issued guidance on recommended levels of sugars in the diet, although it is not always clear whether this is related to micronutrient dilution or other rationales. Recently, the WHO/FAO in their report on diet, nutrition and the prevention of chronic diseases reiterated their previous recommendation of less than 10 % energy from ‘free’ sugars, with the assertion that ‘higher intakes of free sugars threaten the nutrient quality of diets’, although no evidence was presented to support this proposed limit[41].

The report of the (UK) panel on dietary reference values set a target of 10 % of total energy from NMES but this was on the grounds of caries prevention[42]. The definition of NMES was intended to comprise sugars that are neither derived from milk nor incorporated within the cellular structure of food; in practice the NMES content represents added sugars, plus sugars in fruit juice and 50 % of the sugars in processed and dried fruit. The UK report commented at the time that data in support of any specific quantified targets for NMES were scanty.

In the USA, non-quantitative guidance on sugars intake was included in Dietary Guidelines for Americans.

Table 1. Interventions

Study	Regimen	Design	Diet method	Subjects	Length of study	Sugars intake
Heaton *et al.* (1983)[4]	Refined CHO diet (sugar in cereal and tea; no wholegrains, fruit maximum three times/week and vegetables or potatoes maximum three times/d) *v.* unrefined diet	Cross-over	Cross-over trial: 1 d record every 6 d (total 7 d)	Adults (thirteen with gallstones; fifteen diabetics)	12 weeks (2 × 6 weeks)	Refined sugar: 18.5 *v.* 1 % (gallstone patients); 4·5 *v.* 1 % (diabetics)
Cline *et al.* (2000)[5]	CHO soft drink (maltodextrin) *v.* placebo (aspartame) plus rations	Parallel RCT	10 d record	Sixty-three young men (army recruits)	11 d	Sugars not specified (CHO 61 *v.* 48 %)
West & de Looy (2001)[6]	Weight-loss diets containing sucrose (10 %) or low in sucrose (5 %)	Parallel RCT	2 d record	Sixty-eight adults, overweight	8 weeks	5 *v.* 10 %
Vasilaras *et al.* (2004)[7]	Simple CHO *v.* complex CHO *v.* habitual diet (control)	Parallel RCT	7 d weighed record	Forty-six adults, overweight	6 months	26 *v.* 16 % (*v.* 20 % control)

CHO, carbohydrate; RCT, randomised controlled trial.

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Table 2. Observational studies of added sugars

Study	Country	Diet method	Age group	Results	Range of sugars associated with highest micronutrient intakes*
Charlton *et al.* (1998)[8]	South Africa	FFQ	Older adults	Inverse associations with micronutrient density of thiamin, vitamin E, Fe, Zn, Cu, Mg (among men) and all nutrients except vitamin D and vitamin E among women. No association with energy intake	None given
Baghurst *et al.* (1992)[9]	Australia	24RCL	Adults	Weak negative trends found for B_6, folate, carotene, Mg, vitamin C (women only) but not for Fe, thiamin, riboflavin, niacin in women, or vitamin C in men. Positive association with Ca among men. Intakes above RDA across range 4 to 16 % sugars intake	4–16 %
Bowman (1999)[10]	USA	24RCL	All	Highest tertile (> 18 % energy; mean 26 %) had lower intakes of vitamins A, C, B_{12}, folate, and of minerals Ca, P, Mg and Fe and did not meet RDA for vitamins E and B_6, and Ca, Mg and Zn	< 18 %
Britten *et al.* (2000)[11]	USA	24RCL	All	Examined diet quality (not nutrient intakes). High sugar consumers ate less fruit but the association with diet quality depended on energy intake	None given
Forshee & Storey (2001)[12]	USA	24RCL	Children, youth	Both positive and negative associations were small and varied with age group. Children who consume more added sugars are predicted to consume more vitamin C, Fe and folates and less dairy. Adolescents who consume more added sugars are predicted to consume more vitamin C and Fe and less fruit	None given
Forshee & Storey (2004)[3]	USA	24RCL	Children, youth	Using an alternative statistical approach (energy partitioning) the association of energy from added sugars with micronutrient intake was inconsistent and small compared with energy from other sources	None given
Charlton *et al.* (2005)[13]	South Africa	24RCL	Older adults	Among women only, highest tertile sugar consumers (mean 18 % added sugars) had lower micronutrient intakes (and lower energy intake), and also suboptimal erythrocyte folate and plasma ascorbic acid status	'10 % appropriate in this population'
Kranz *et al.* (2005)[14]	USA	2 × 24RCL	Young children	Increasing added sugar consumption was paralleled by decreasing nutrient and food group intakes and increasing proportions of children with intakes below the DRI. Ca intake was insufficient in large proportions of children consuming 16 % or more from added sugar	< 16 %
Lewis *et al.* (1992)[15]	USA	3Ddiary	All	Lower intakes of eleven nutrients in high quartile consumers (16–25 %) *v.* moderate consumers (6–15 %)	6–15 %
Rugg-Gunn *et al.* (1991)[16]	UK	3WDR	Children	Consumption of large amounts of added sugars (19 *v.* 10 %) was associated with marginally lower intakes of several nutrients. Associations were not significant except for vitamin D	None given
Alexy *et al.* (2002)[17]	Germany	3WDR	Children, youth	No significant nutrient dilution by added sugars. The positive effect of fortification on nutrient densities was greater than the negative effect of added sugars	None given
Alexy *et al.* (2003)[18]	Germany	3WDR	Children, youth	A median intake of 12 % added sugars was associated with highest dietary quality as measured by nutrient intake score	6–12 %
Alexy *et al.* (2003)[19]	Germany	3WDR	Children, youth	A slight, but statistically significant, nutrient-dilution effect of added sugars and a significant reduction in intake of important nutrient-bearing food groups. No clear indicator on grounds of micronutrient dilution for a quantitative limit of added sugars	'No grounds'
Øverby *et al.* (2004)[20]	Norway	4Ddiary	Children	Negative association between the intake of added sugar and intakes of micronutrients (except vitamins C and E) and fruit and vegetables. Nutritional consequences of increasing added sugar in the diet differ strongly from one nutrient to another and across age groups	< 13 %
Flynn *et al.* (1996)[21]	Ireland	7dhistory	Adults	Diets higher in sugar are not necessarily more dilute in micronutrients. Eighty-three women classified by fat energy. Lowest quartile fat group had highest sugar intake (mean 12·4 % added sugar) and higher intakes of fibre, vitamin C and folate compared with high fat group (6 % sugar) but lower vitamin A	None given
Gibson (1997)[22]	UK	7WDR	Adults	Many nutrients showed a non-linear relationship with sugars energy (added, NMES, or total). Intakes fell in Q4 and Q5 (> 15 % added sugars or > about 17 % NMES) but were above RNI (except for Fe and folate among women)	< 15 % added sugars

24RCL = 24 h recall; DRI = dietary reference intake; 3Ddiary = 3 d dietary diary; 3WDR = 3 d weighed dietary record; 4Ddiary = 4 d dietary diary; 7dhistory = 7 d food history; 7WDR = 7 d weighed dietary record; NMES = non-milk extrinsic sugars; Q4 = fourth quintile; Q5 = fifth quintile; RNI = reference nutrient intake.

* Ranges correspond to cut-off points used for classifying tertiles or quintiles, or to group means, rather than a precise threshold. Intakes below this are not necessarily inadequate.

Table 3. Observational studies of other definitions of sugars

Study	Country	Definition of sugars	Diet method	Age group	Results	Range of sugars associated with highest micronutrient intakes*
Vanhapelto & Seppänen (1983)[23]	Sweden	Sugar (unspecified)	Diet history	Adults	Nutrient intakes were adequate in highest and lowest deciles of sugar, among both men and women. However, Fe was low in both groups of women	None given
Linseisen *et al.* (1998)[24]	Germany	Sucrose	7Ddiary	All	Sucrose energy was negatively associated with intakes of micronutrients, except Ca, vitamin E, vitamin C, and dietary fibre. Fewer individuals met recommendations in the high sucrose category under the condition of a comparable energy intake	Moderate intake (10 %)
Bolton-Smith *et al.* (1995)[25]	UK	NMES	FFQ	Adults	Both low and high extrinsic sugar intake associated with poorer antioxidant vitamin and fibre-containing diets. DRV for sugars err on the cautious side	6·5–15·6 % (men) and 4·8–11·6 % (women)
Gibson (1997)[26]	UK	NMES	4WDR	Pre-school children	The impact of nutrient dilution was small below about 20 % energy from NMES. Intakes of most micronutrients (except vitamin C) fell with increasing sugars intake but were adequate in comparison with DRV. Fe and Zn were low generally and below the EAR in the highest quintile (> 24 % NMES)	< 20 %
Gibson (2001)[27]	UK	NMES	4WDR	Older adults	Intakes of micronutrients tended to be highest at moderate levels of NMES (8–15 % energy). There was little evidence that poorer nutrient status (biochemical) was associated with higher levels of NMES	8–15 %
Gibson (1997)[22]†	UK	NMES	7WDR	Adults	Many nutrients showed a non-linear relationship with sugars energy (added, NMES, or total). Intakes fell in Q4 and Q5 (> 15 % added sugars or > about 17 % NMES) but were above RNI (except for Fe and folate among women). NMES intakes providing up to about 17 % of food energy did not compromise micronutrient intakes	< 17 % NMES
Farris *et al.* (1998)[28]	USA	Total	24RCL	Children	High consumers (top quartile, mean 19 %) had lower intakes of Fe, Zn and vitamins B_3, B_6, and E but higher intakes of Ca and vitamin D	None given
Naismith *et al.* (1995)[29]	UK	Total	7WDR	Children	Intake of niacin fell (but exceeded RNI), while vitamin C and Ca rose	< 27 % total sugars
Gibson (1993)[30]	UK	Total	14Ddiary	Children, youth	Inconsistent trends were observed. Vitamins A, C and thiamin were similar across tertiles, Ca and riboflavin increased, Fe and other B vitamins fell, although not all differences were significant	None given
Gibson (1997)[22]†	UK	Total	7WDR	Adults	Low consumers of total sugars (Q1; 11 % energy) had lowest intakes of Ca, vitamin C, riboflavin and folate. Energy intakes also low in Q1	> 11 % total sugars

7Ddiary = 7 d dietary diary; NMES = non-milk extrinsic sugars; DRV = dietary reference value; 4WDR = 4 d weighed dietary record; EAR = estimated average requirement; 7WDR = 7 d weighed dietary record; Q1 = first quintile; Q4 = fourth quintile; Q5 = fifth quintile; RNI = reference nutrient intake; 24RCL = 24 h recall; 14Ddiary = 14 d dietary diary.

* Ranges correspond to cut-off points used for classifying tertiles or quintiles, or to group means, rather than a precise threshold. Intakes below this are not necessarily inadequate.

† Gibson[22] used three definitions (added, NMES, total sugars).

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Table 4. Observational studies of food and drinks containing sugars

Study	Country	Definition	Diet method	Age group	Results	Range of sugars associated with highest micronutrient intakes*
Guenther (1986)[31]	USA	Soft drinks	24RCL and 2Ddiary	Children, youth	Weak negative partial correlations with intakes of Ca (−0·11), Mg (−0·06), riboflavin (−0·09), vitamin A (−0·08) and vitamin C (−0·06)	N/A
Harnack *et al.* (1999)[32]	USA	Soft drinks	2 × 24RCL	Children, youth	High soft drink consumers (> 9 oz/d; 255 g/d) consumed less milk and fruit juice	N/A
Ballew *et al.* (2000)[33]	USA	Soft drinks	24RCL	Children, youth	Carbonated soda consumption was negatively associated with achieving recommended vitamin A intake (all ages), Ca (< 12 years), and Mg (6 + years)	N/A
Mrdjenovic & Levitsky (2003)[34]	USA	Soft drinks	Recall	Children	Small study (*n* 30). Sweetened drink consumption (> 12 oz/d; 340 g/d) displaced milk from children's diets (122–147 g less milk per d) (because caregivers served less milk)	N/A
Storey *et al.* (2004)[35]	USA	Soft drinks	24RCL	Children, youth	Carbonated soft drink consumption among adolescent girls is modest (mean 12 oz; 340 g/d) and does not appear to be linked to decreased Ca intake	N/A
Marshall *et al.* (2005)[36]	USA	Soft drinks	3Ddiary	Young children	Consumption of added sugar beverages was inversely associated with intakes of Ca and milk	N/A
Frary *et al.* (2004)[37]	USA	Sweet food and drink	2 × 24RCL	Children, youth	Consumption of sweetened dairy foods and presweetened cereals had a positive impact on diet quality, whereas sugar-sweetened beverages, sugars, sweets, and sweetened bakery products had a negative impact	N/A
Rodriguez-Artalejo *et al.* (2003)[38]	Spain	Sweet food and drink	FFQ	Children	Consumption of sweetened soft drinks was modest but associated with a lower consumption of milk (−88 ml) and Ca (−175 mg/d)	N/A
Johnson (2002)[39]	USA	Flavoured milk	24RCL	Children, youth	Children who consumed flavoured milk had higher total milk intakes and lower soft drink and fruit drink intakes. Added sugars in nutritious foods such as dairy products may increase intakes of at-risk nutrients such as Ca	N/A

24RCL = 24 h recall; 2Ddiary = 2 d dietary diary; N/A = not applicable; 3Ddiary = 3 d dietary diary.
*Ranges correspond to cut-off points used for classifying tertiles or quintiles, or to group means, rather than a precise threshold. Intakes below this are not necessarily inadequate.

However, in 2000 the Dietary Guidelines Advisory Committee concluded that it was not possible to make specific recommendations regarding a maximum amount of sugars intake without further examination of typical dietary patterns[43]. The 2000 Dietary Guidelines Advisory Committee called for better definition of added and total sugars and more research to determine whether there are reasons to distinguish between the two. In 2002, new dietary reference intakes for macronutrients were issued by the Institute of Medicine following an extensive review of the international literature and reanalysis of data from the third National Health and Nutrition Examination Survey (NHANES III). The report[44] concluded that added sugars intake should not exceed 25 % of energy, based on reduced intakes of some micronutrients by certain groups (notably teenage girls) above this level, but also noted evidence for suboptimal intakes at very low levels (0–5 % of total energy from added sugars).

Reviews

Six reviews on this topic have been published since 1995[45–50]. All drew broadly similar conclusions, finding the evidence for micronutrient dilution to be inconsistent between nutrients and between age and sex groups. Where there was evidence for a negative impact of sugars on micronutrient intake, this was generally weak. The reviews also noted that some trends appeared non-linear, with suboptimal intakes at both very high and very low levels of sugars. They stressed the importance of considering dilution in the context of micronutrient requirements; for the general population with a sufficient energy intake, nutrient adequacy can be achieved across a wide range of dietary sugars. In attempting to quantify the optimal range, Bolton-Smith suggested 5–12 % (extrinsic sugars or NMES) for women and 6–16 % for men, the stricter range for women reflecting their lower energy intakes. For children, Ruxton *et al.* concluded that heterogeneity between nutrients made this difficult to determine precisely but suggested that the most micronutrient-dense diets were achieved by those consuming average amounts of added sugars (suggested as 14–20 %)[47]. The most comprehensive and recent review, by Rennie & Livingstone, found ‘no clear evidence of micronutrient dilution or a threshold for a quantitative amount of added sugar intake’[50]. However, they also highlighted methodological issues such as energy adjustment and misreporting that constrain or confound the evidence base. They suggested that future studies should attempt to quantify the magnitude of associations and also evaluate the role of particular foods, or food patterns, that may be leading to inadequate nutrient intakes. In a similar vein, Murphy & Johnson concluded that in giving guidance to consumers, the focus should be on nutrient-dense dietary choices rather than on sugars concentration alone[49]. The primary data on which these reviews were based will be discussed individually.

Interventions

Only four intervention studies were identified that involved diets high in sugars or, more generally, refined or simple carbohydrates (Table 1). The earliest study by Heaton *et al.* was a cross-over trial comparing the effects of a diet high or low in refined carbohydrate for 6 weeks each in twenty-eight adults who either had gallstones or diabetes[4]. Intakes of most vitamins and minerals were significantly lower on the refined carbohydrate regimens (except Ca, which was higher due to fortification of white bread). The diets were *ad libitum* and no restriction was placed on animal foods, but the subjects on the refined carbohydrate regimen were instructed to eat only white-flour products, to take sugar in drinks and on cereal, to eat confectionery and also limit their intake of fruit and vegetables and potatoes (i.e. displacement was built into the study by avoidance of wholegrain etc). Second, although adequacy was not commented on, nutrient intakes would not appear low, except perhaps for folate. In the study by Cline *et al.*[5] on military recruits undergoing a desert field exercise, the group given carbohydrate drink *ad libitum* in addition to rations had higher energy intakes but significantly lower intakes of protein, Ca, Mg and Zn, compared with those receiving a non-energy placebo drink. Although intakes of minerals and some B vitamins fell short of the RDA, biochemical data remained within reference ranges in both groups. In contrast with this study, an 8-week parallel-design weight-reduction study among sixty-eight men[6] found no evidence of micronutrient dilution that could be attributed to sucrose content. However, in this study the two contrasting regimens were both relatively low in sugar (5 *v.* 10 % sucrose). The fourth study using forty-six overweight participants in the Danish cohort of the CARMEN study[51] investigated the impact of two low-fat diets, one high in ‘simple carbohydrates’, the other high in complex carbohydrates over 6 months[7]. The high simple carbohydrates group (26 % energy simple carbohydrates) had lower intakes of Zn and vitamin B_{12}, compared with the complex carbohydrates group or habitual diet group, but this may be clinically unimportant given that intakes were above recommended levels. There were no other diet differences between the groups and the authors concluded that the micronutrient contents of the diets were similar. These interventions therefore appear to suggest a minor impact of high-sugar diets on some nutrients. However, the evidence is far from conclusive with regard to strength of association, causality, or importance for nutritional status.

Epidemiological studies relating to dietary sugars and micronutrient dilution

Most of the evidence in this area has been derived from observational studies, many of which are cross-sectional national or regional studies that are broadly representative of the population. Older studies tended to define sugars as total sugars, but since the late 1990s the majority have differentiated added sugars or NMES. The effect of using different definitions in the same dataset has also been assessed[22,25]. There is also inconsistency between studies in the assessment of micronutrient adequacy. This arises partly from different recommendations in various countries but also from different reference criteria (for example, reference nutrient intake, two-thirds of reference nutrient intake, estimated average requirement, lower reference nutrient intake) and different statistical approaches (mean *v.* prevalence) (Tables 2 and 3).

American studies using national datasets

Large American datasets have provided the basis for many observational studies, in particular the Continuing Survey of Food Intakes by Individuals (CSFII), its predecessor the 1977–8 Nationwide Food Consumption Survey (NCFS) and NHANES III.

In an early study using the 1977–8 NFCS, Lewis *et al.*[15] found that high consumers of added sugars (above 75th percentile or 16–25 % energy) took in lower percentages of the RDA for eleven vitamins and minerals than did their counterparts consuming 15 % added sugars or less (moderate consumers). There was considerable variation between nutrients and age groups but the median dilution was 13 (range 1–29) %. Ca intakes among 4–10 year olds were 18 % lower in high *v.* moderate consumers (95 *v.* 113 % RDA) and 16 % lower for 11–18 year olds (68 *v.* 84 % RDA).

Farris *et al.* investigated nutrient intake in relation to total sugars intake among 10 year olds in the Bogalusa study, and reported inverse trends with amounts of Fe, Zn, niacin, and vitamins B_6 and E, but positive trends with Ca and vitamin D[28]. This was consistent with the lower intakes of meat and higher intakes of milk among high consumers. The authors concluded that intakes of most vitamins and minerals were adequate among high sugar consumers (mean 19 % energy from total sugars). However, 24 and 21 % of low consumers (mean 9 % energy from sugars) and 44 and 34 % of high consumers had intakes of Fe and Zn, respectively, that were below two-thirds of the RDA.

Using 24 h recall data on over 14 000 individuals from CSFII 1994–6, Bowman[10] divided respondents into three groups based on percentage energy from added sugars (%EAS). These corresponded to <10 %, 10–18 % and >18 %EAS. High consumers (>18 %EAS; mean 26·7 %EAS) had lowest intakes of all micronutrients, although means still exceeded two-thirds of the RDA. Low consumers (<10% added sugars) did not have significantly higher nutrient intakes than average consumers (10–18% added sugars). Data on preschool children from the same survey were recently reported as showing that Ca intake was insufficient in large proportions of children consuming 16 % energy or more from added sugars[14], intakes of >21 % being problematic. By contrast, using the same database but employing a multiple regression method incorporating components of energy (kJ from sugars *v.* kJ from other foods), Forshee & Storey concluded that the associations between added sugars and micronutrients varied with age group and ranged from no association to a statistically significant association that was positive or negative. They commented that the effects of added sugars were so small as likely to be of no clinical importance[12]. In a study looking at dietary quality using the healthy eating index (rather than micronutrient intakes) in CSFII data, Britten *et al.* concluded that the association was complex and depended on energy intake. Most high consumers of added sugars had high energy intakes and their intake of food groups (other than fruit) was not consistently affected. Others compensated for the additional energy from sugars by reducing intake of other foods (fruit, vegetable, milk and grains)[11].

In the course of gathering evidence for dietary recommendations, the Institute of Medicine report[44] examined the median intakes of micronutrients at every 5th percentile of added sugars intake for each age and sex group in NHANES III. Reduced intakes of Ca, vitamin A, Fe and Zn were observed in some groups both at low levels of added sugars (<5 %) and at high levels above 25 % of energy. High sugar intakes were more common among adolescents than adults[44], although prevalence cannot be estimated very accurately from the 24 h data in this survey[52,53].

There was evidence of a subtle decline in energy intakes at both extremes of the spectrum (<5 %EAS and >30 %EAS)[44], similar to the pattern observed with Ca intakes. Forshee & Storey have argued that the association observed between %EAS and intake of micronutrients may be spurious and caused by the relationships between total energy and micronutrients[3]. They have criticised the use of percentage energy from sugars as fundamentally flawed, on the grounds that it does not properly control for energy but presupposes a 1:1 displacement. Using an alternative approach (energy partitioning) they concluded that energy (MJ) from added sugars had little or no association with diet quality (when energy from other sources is kept constant), whereas energy from other sources had a much stronger and more consistent association when energy from sugars is kept constant[3]. The approach of Forshee *et al.* has in turn been criticised as not adequately adjusting for total energy[54]. This is a conceptual controversy as much as a statistical one and the two approaches may be irreconcilable[55]. Given the discrepancy in results and the implications for policy, this deserves further scrutiny and debate by nutritionists, epidemiologists and biostatisticians.

Studies in Europe and other countries

We examined observational studies from Britain[16,22,25–27,29,30], Germany[17–19,24], Sweden[23], Norway[20], Spain[38], Ireland[21], Australia[9] and South Africa[8,13]. A few were based on small numbers of individuals, limiting the power to detect associations[21,29]. The results of studies on children and adults are discussed separately below, although findings were broadly similar.

Children. A review by Rugg-Gunn *et al.*, the earliest study of children, set the scene for the debate on 'empty calories' and micronutrient dilution[16]. This small survey of adolescents aged 11–14 years found mostly low-level and non-significant correlations for most nutrients with added sugars (g/MJ), except for vitamin D (r −0·25; $P < 0·001$), where there was a significant difference in intake between the highest (19 % sugars) and lowest decile (10 % sugars) (vitamin D 1·4 *v.* 2·4 μg/d). Subsequently, Gibson[30], from a nationwide sample of 2705 British schoolchildren, reported trends with micronutrient intake that were inconsistent: Ca and riboflavin increased with (total) sugars intake, while Fe fell and vitamins A and C and thiamin were similar[30]. Among pre-school children in the British National Diet and Nutrition Survey, we also found inverse associations

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between NMES (as a percentage of energy intake) and most micronutrients, but a positive association with vitamin C[26]. Lower intakes of meat, milk, fruit and vegetables and higher intakes of fruit juice and drinks largely explained these associations. Mean intakes of Fe, Zn and vitamin D in these young children were low at all levels of NMES; other nutrients were above reference levels. It was concluded that the impact of sugars was small below about 20 % NMES and of most significance for those with intakes >24 % NMES. A Norwegian study among children aged 4, 9 and 13 years found similar inverse associations of added sugars (percentage of energy intake) with most nutrients, except for vitamin C and vitamin E in some groups[20] while intakes of fruit and vegetables were 30–40 % lower among high sugar groups (above 18–22 % added sugars), compared with low sugar groups (below 11–13 % sugars). In Germany, a series of papers from the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study reported weak inverse associations between added sugars in the diet and micronutrient intakes[19]. The authors proposed that the positive impact of energy intake and fortification was larger than the negative impact of sugars[17]. Since nutrient intakes were generally adequate (or in the case of folate, inadequate) regardless of sugars intake, the authors did not consider that a quantitative limit on sugars intake was justified on ground of micronutrient dilution. However, on grounds of dietary quality, they suggested a range of 6–10 % energy from added sugars[18].

Adults. In a study of 2800 Australian men and women, Baghurst *et al.*[9] found that many (but not all) nutrients declined slightly with increasing added sugars intake but were generally regarded as adequate even in the top decile (>18 % added sugars). An early Swedish national study by Vanhapelto *et al.*[23] also found that intakes of minerals and vitamins were generally adequate in both the highest and lowest sugar consumers (deciles). However, Fe intakes among women were universally low, as is well established in many populations.

A number of studies have suggested that some associations with nutrients may be curvilinear, with nutrient intakes optimal at average levels of sugar intake. In a large study of over 11 000 adults in Scotland, diets either very high or low in extrinsic sugars were associated with the lowest intake of antioxidant vitamins, with optimal intakes in the range of 6–16 % for men, and 5–12 % for women[25]. Similar findings have been reported using data from British surveys (National Diet and Nutrition Survey series), where there was little evidence of compromised micronutrient intakes up to about 17 % energy from NMES (or about 15 % added sugars) among adults[22], and highest intakes in the range from 8–15 % energy from NMES in older individuals[27]. It is important to establish whether the low nutrient intakes seen with low-sugar diets are real (for example, an indication of high fat intake and poor diet quality, or low palatability and low energy intake)[56,57] or artifact (for example, due to unreliable records).

Two studies from South Africa by Charlton *et al.*[8,13] constituted the only evidence on micronutrient dilution from less developed countries. In 1998 they found inverse associations between the intake of most micronutrients and percentage energy from added sugars in a free-living elderly population[8]. More recently they found evidence of poorer nutrient intakes and status among women, but not men. This was in the context of lower energy intakes (the third tertile were only 86 % of those in the second tertile) and evidence of generally inadequate intakes and a poor nutritional status across all tertiles of added sugars intake. From a regression analysis they found that added sugars (g/d) explained at most 2 % of the variance in intake of different nutrients whereas energy explained between 20 and 64 %[13]. Similarly in the National Diet and Nutrition Survey of older individuals, we found that NMES (percentage of energy intake) explained between 2 and 4 % of the variance in intakes of ‘at-risk’ nutrients (Fe, Ca, riboflavin and folate), while energy explained between 20 and 40 %[27]. In Forshee’s regression analysis of CSFII data, correlations between %EAS and Ca ranged between $-0{\cdot}09$ and $-0{\cdot}29$ (1 to 8 % of the variance explained), whereas correlations between energy and Ca were 0·56 to 0·66 (31–44 % of the variance explained). These comparisons suggest that the independent influence of added sugars on micronutrient intake is relatively weak.

Studies relating to soft drinks and other sweetened beverages

Consumption of sweetened soft drinks is particularly high among American children and adolescents, and several studies have examined the putative displacement of micronutrients by soft drinks. Using 24 h recall data from the 1977–8 Nationwide Food Consumption Survey, Guenther noted weak negative correlations ($-0{\cdot}06$ to $-0{\cdot}11$) among teenagers between soft drinks and Ca, Mg, vitamin A, riboflavin and vitamin C and also with milk (Table 4)[31]. Subsequently, two studies based on the 1994 US CSFII data found high consumption of sweetened soft drinks among children and adolescents to be associated with lower intake of milk and fruit juice and their associated nutrients[32,33]. In the study by Harnack *et al.* intakes of Ca, riboflavin, vitamin A, folate and vitamin C were inversely associated with soft drink consumption but this was particularly evident among those consuming >26 oz/d (>737 g/d), who had reductions of 20–45 % compared with low or non-consumers[32]. Using 24 h recall data from children aged 2–17 years in CSFII 1994–6, Ballew *et al.* found that (carbonated) soft drinks were negatively associated with vitamin A at all ages, Mg intakes (among 6 year olds and over) and Ca (among under 12 year olds)[33]. By contrast, in the same survey Storey *et al.* found that intake of carbonated soft drinks was more modest among adolescent girls (age 14–18 years) and did not appear to be linked to decreased Ca intake[35]. Frary *et al*. found that consumption of pre-sweetened beverages, sweets and baked products had a negative impact on nutrients intake whereas sweetened dairy foods and cereals had a positive impact.[38] Among 645 pre-school children in Iowa, USA, Marshall *et al.* recently reported that sweetened beverages were significantly inversely associated with mean nutrient adequacy ratios (r $-0{\cdot}02$ to $-0{\cdot}25$), although associations with vitamin A and Cu were positive (r $+0{\cdot}19$, $+0{\cdot}21$)[36]. (A nutrient adequacy ratio is the ratio of an individual’s mean intake relative to their age- or sex-specific RDA.) Another study of only thirty children that reported displacement of milk by sweetened drinks[34] has been criticised[58,59]. Surveys from other countries have not found such strong associations with soft drinks as in the USA, possibly because consumption levels are lower. For example, among Spanish children aged 6–7 years, sweetened soft drinks were inversely associated with milk consumption and Ca intake, but this was partly offset by increased consumption of other dairy products, so that Ca remained above recommended levels[38]. In contrast to the American studies, there was a positive (but non-significant) association between soft drinks and fruit juice consumption, suggesting that inverse associations with nutrient-rich foods are not inevitable (Table 4).

Conclusions

The publications reviewed provide some evidence that diets containing a high proportion of added sugars are slightly lower in micronutrients than diets containing a moderate proportion of added sugars. However, results were not necessarily linear or consistent across nutrients, populations and age groups and quantification is hampered by different cut-off criteria in each study. Most of the evidence reviewed comes from cross-sectional observational studies. These provide good evidence of the range of dietary practices in real life but they cannot predict the impact of alterations in added sugars intake. Prospective and intervention studies are required to study these aspects, but these must have sufficient statistical power and use good dietary methodologies.

Studies based on percentage energy from total sugars have tended to show positive associations with vitamin C and sometimes with Ca[30], due to inclusion of sugars in fruit and milk. Studies defining sugars as NMES (which includes sugars in fruit juice and 50 % of the sugars in processed and dried fruit) have sometimes shown positive associations with vitamin C for the same reason. Associations of percentage energy from added sugars with vitamin C have variously been shown to be negative, positive or neutral. The majority of studies on soft drink consumption indicate that high intakes are negatively associated with some nutrients, especially those found in milk and fruit juice. The form in which sugars are consumed appears an important modifier of the impact of dilution. Soft drinks, sugar and sweets are more likely to have a negative impact on diet quality whereas dairy foods, milk drinks and pre-sweetened cereals may have a positive impact[37,45].

Optimal intakes of sugars are difficult to quantify because associations vary between nutrients and depend on food choice and composition. It is established that energy intake is the prime predictor of micronutrient adequacy and a modifier of the associations with sugars[11,55,56]. What is debated is the appropriate adjustment for energy[2]. Epidemiologists routinely use percentage energy (sometimes with additional adjustment for energy differences) to quantify the independent association of sugar or fat in diet/heath relationships and virtually all the studies considered in the present review used this method. Overall, the studies suggest micronutrient intakes are optimal at moderate levels of sugars in the diet, provided energy needs are met. Very high intakes of added sugars or NMES in excess of 20 % of energy are associated with lower intakes of several micronutrients. In some studies, very low intakes of all types of sugars (i.e. diets containing $<5\,\%$ energy from sugars) are also associated with poor nutrient intakes. More data are required to investigate whether this is associated with dieting, under-reporting, illness, unbalanced diets (for example, very high-fat diets) or other confounding factors. More studies are also needed from developing countries, where energy intakes, dietary variety and fortification may be more limited.

Ultimately the nutritional significance of dilution depends on whether micronutrient intakes are adequate with respect to requirements, or since these are largely unknown, compared with group recommended levels or cut-off points. Micronutrient intakes were commonly described as 'adequate' in the studies reviewed but the criteria varied. Comparison of group means with the reference nutrient intake (or two-thirds of the reference nutrient intake or estimated average requirement) is a common criterion against which adequacy is judged but it cannot assess the likely prevalence of inadequacy. The estimated average requirement cut-off point method is now established as the best measure of this[60] but estimates can be inflated by under-reporting and use of 24 h dietary data without correction for within-individual variation[53,61]. Conversely, use of the lower reference nutrient intake as a cut-off underestimates the true prevalence of inadequacy in populations[62]. Given the varied criteria, generalisations such as 'sugars compromise nutrient intakes' (or conversely 'micronutrient intakes are adequate irrespective of sugars intake') are unhelpful in resolving current public health issues. The available evidence does not allow for firm conclusions on an optimal level of added sugars intake on the basis of micronutrient adequacy; indeed, there is some doubt as to whether some of the associations seen between sugars intake and micronutrients reliably reflect meaningful biological relationships. A better understanding of valid approaches to energy adjustment, misreporting and assessment of micronutrient adequacy is therefore crucial to further progress in this area.

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References

1 Thomson ResearchSoft (2004) EndNote. http://www.endnote.com/
2 Mackerras D (1996) Energy adjustment: the concepts underlying the debate. *J Clin Epidemiol* **49**, 957–962.
3 Forshee RA & Storey ML (2004) Controversy and statistical issues in the use of nutrient densities in assessing diet quality. *J Nutr* **134**, 2733–2737.
4 Heaton KW, Emmett PM, Henry CL, Thornton JR, Manhire A & Hartog M (1983) Not just fibre – the nutritional

https://doi.org/10.1017/S0954422407797846 Published online by Cambridge University Press

consequences of refined carbohydrate foods. *Hum Nutr Clin Nutr* **37**, 31–35.
5 Cline AD, Tharion WJ, Tulley RT, Hotson N & Lieberman HR (2000) Influence of a carbohydrate drink on nutritional status, body composition and mood during desert training. *Aviat Space Environ Med* **71**, 37–44.
6 West JA & de Looy AE (2001) Weight loss in overweight subjects following low-sucrose or sucrose-containing diets. *Int J Obes Relat Metab Disord* **25**, 1122–1128.
7 Vasilaras TH, Astrup A & Raben A (2004) Micronutrient intake in overweight subjects is not deficient on an *ad libitum* fat-reduced, high-simple carbohydrate diet. *Eur J Clin Nutr* **58**, 326–336.
8 Charlton KE, Wolmarans P & Lombard CJ (1998) Evidence of nutrient dilution with a high sugar intake in older South Africans. *J Hum Nutr Diet* **11**, 331–343.
9 Baghurst K, Baghurst P & Record S (1992) Demographic and nutritional profiles of people consuming varying levels of sugars. *Nutr Res* **12**, 1455–1465.
10 Bowman S (1999) Diets of individuals based on energy intakes from added sugars. *Fam Econ Nutr Rev* **12**, 31–38.
11 Britten P, Basiotis PP, Davis CA & Anand R (2000) Is intake of added sugars associated with diet quality? In *Insight 21* [USDA Center for Nutrition Policy and Promotion, editor]. Washington, DC: USDA.
12 Forshee RA & Storey ML (2001) The role of added sugars in the diet quality of children and adolescents. *J Am Coll Nutr* **20**, 32–43.
13 Charlton KE, Kolbe-Alexander TL & Nel JH (2005) Micronutrient dilution associated with added sugar intake in elderly black South African women. *Eur J Clin Nutr* **59**, 1030–1042.
14 Kranz S, Smiciklas-Wright H, Siega-Riz AM & Mitchell D (2005) Adverse effect of high added sugar consumption on dietary intake in American preschoolers. *J Pediatr* **146**, 105–111.
15 Lewis CJ, Park YK, Dexter PB & Yetley EA (1992) Nutrient intakes and body weights of individuals consuming high and moderate levels of added sugars. *J Am Diet Assoc* **92**, 708–713.
16 Rugg-Gunn AJ, Hackett AF, Jenkins GN & Appleton DR (1991) Empty calories? Nutrient intake in relation to sugar intake in English adolescents. *J Hum Nutr Diet* **4**, 101–111.
17 Alexy U, Sichert-Hellert W & Kersting M (2002) Fortification masks nutrient dilution due to added sugars in the diet of children and adolescents. *J Nutr* **132**, 2785–2791.
18 Alexy U, Kersting M & Schultze-Pawlitschko V (2003) Two approaches to derive a proposal for added sugars intake for German children and adolescents. *Public Health Nutr* **6**, 697–702.
19 Alexy U, Sichert-Hellert W & Kersting M (2003) Associations between intake of added sugars and intakes of nutrients and food groups in the diets of German children and adolescents. *Br J Nutr* **90**, 441–447.
20 Øverby NC, Lillegaard IT, Johansson L & Andersen LF (2004) High intake of added sugar among Norwegian children and adolescents. *Public Health Nutr* **7**, 285–293.
21 Flynn MA, Suqrue DD, Codd MB & Gibney MJ (1996) Women's dietary fat and sugar intakes: implications for food based guidelines. *Eur J Clin Nutr* **50**, 713–719.
22 Gibson SA (1997) Do diets high in sugars compromise micronutrient intakes? Micronutrient intakes in the Dietary and Nutritional Survey of British Adults according to dietary concentration of 'added', 'non-milk extrinsic' or 'total' sugars. *J Hum Nutr Diet* **10**, 125–133.
23 Vanhapelto AT & Seppänen OR (1983) Nutrient intakes of persons with low or high consumption of sugar. *Näringsforskning* **3**, 82–85.
24 Linseisen J, Gedrich K, Karg G & Wolfram G (1998) Sucrose intake in Germany. *Z Ernahrungswiss* **37**, 303–314.
25 Bolton-Smith C & Woodward M (1995) Antioxidant vitamin adequacy in relation to consumption of sugars. *Eur J Clin Nutr* **49**, 124–133.
26 Gibson SA (1997) Non-milk extrinsic sugars in the diets of pre-school children: association with intakes of micronutrients, energy, fat and NSP. *Br J Nutr* **78**, 367–378.
27 Gibson S (2001) Dietary sugars and micronutrient dilution in normal adults aged 65 years and over. *Public Health Nutr* **4**, 1235–1244.
28 Farris RP, Nicklas TA, Myers L & Berenson GS (1998) Nutrient intake and food group consumption of 10-year-olds by sugar intake level: the Bogalusa Heart Study. *J Am Coll Nutr* **17**, 579–585.
29 Naismith D, Nelson M, Burley V & Gatenby S (1995) Does a high-sugar diet promote overweight in children and lead to nutrient deficiencies? *J Hum Nutr Diet* **8**, 249–254.
30 Gibson S (1993) Consumption and sources of sugars in the diets of British schoolchildren: are high-sugar diets nutritionally inferior? *J Hum Nutr Diet* **6**, 355–371.
31 Guenther PM (1986) Beverages in the diets of American teenagers. *J Am Diet Assoc* **86**, 493–499.
32 Harnack L, Stang J & Story M (1999) Soft drink consumption among US children and adolescents: nutritional consequences. *J Am Diet Assoc* **99**, 436–441.
33 Ballew C, Kuester S & Gillespie C (2000) Beverage choices affect adequacy of children's nutrient intakes. *Arch Pediatr Adolesc Med* **154**, 1148–1152.
34 Mrdjenovic G & Levitsky D (2003) Nutritional and energetic consequences of sweetened drink consumption in 6- to 13-year-old children. *J Pediatr* **142**, 604–610.
35 Storey ML, Forshee RA & Anderson PA (2004) Associations of adequate intake of calcium with diet, beverage consumption, and demographic characteristics among children and adolescents. *J Am Coll Nutr* **23**, 18–33.
36 Marshall TA, Eichenberger Gilmore JM, Broffitt MS, Stumbo PJ & Levy SM (2005) Diet quality in young children is influenced by beverage consumption. *J Am Coll Nutr* **24**, 65–75.
37 Frary CD, Johnson RK & Wang MQ (2004) Children and adolescents' choices of foods and beverages high in added sugars are associated with intakes of key nutrients and food groups. *J Adolesc Health* **34**, 56–63.
38 Rodríguez-Artalejo F, García EL, Gorgojo L, Garcés C, Royo MA, Martín Moreno JM, Benavente M, Macías A & De Oya M; Investigators of the Four Provinces Study (2003) Consumption of bakery products, sweetened soft drinks and yogurt among children aged 6–7 years: association with nutrient intake and overall diet quality. *Br J Nutr* **89**, 419–429.
39 Johnson RK, Frary C & Wang MQ (2002) The nutritional consequences of flavored-milk consumption by school-aged children and adolescents in the United States. *J Am Diet Assoc* **102**, 853–856.
40 Department of Health Committee on Medical Aspects of Food Policy (1989) Dietary sugars and human disease. In *Report of the Panel on Dietary Sugars*. London: H.M. Stationery Office.
41 World Health Organization and Food and Agriculture Organization (2003) *Diet, Nutrition and the Prevention of Chronic Diseases*. *WHO Techical Report Series* no. 916. Geneva: WHO.

https://doi.org/10.1017/S0954422407797846 Published online by Cambridge University Press

42 Department of Health (1991) *Dietary Reference Values for Food Energy and Nutrients for the United Kingdom*. London: H.M. Stationery Office.
43 Dietary Guidelines Advisory Committee (2000) *Report of the Dietary Guidelines Advisory Committee on the Dietary Guidelines for Americans*. Washington, DC: Departments of Health and Human Services and Agriculture.
44 Institute of Medicine (2002). *Dietary Reference Intakes for Energy, Carbohydrate, Fat, Fibre, Fatty Acids, Cholesterol, Protein and Amino Acids*. Washington, DC: Food and Nutrition Board.
45 Gibney M, Sigman-Grant M, Stanton JL Jr & Keast DR (1995) Consumption of sugars. *Am J Clin Nutr* **62**, Suppl. 1, 178S–194S.
46 Bolton-Smith C (1996) Intake of sugars in relation to fatness and micronutrient adequacy. *Int J Obes Relat Metab Disord* **20**, Suppl. 2, S31–S33.
47 Ruxton CH, Garceau FJ & Cottrell RC (1999) Guidelines for sugar consumption in Europe: is a quantitative approach justified? *Eur J Clin Nutr* **53**, 503–513.
48 Ruxton CH (2003) Dietary guidelines for sugar: the need for evidence. *Br J Nutr* **90**, 245–247.
49 Murphy SP & Johnson RK (2003) The scientific basis of recent US guidance on sugars intake. *Am J Clin Nutr* **78**, 827S–833S.
50 Rennie KL & Livingstone MB (2007) Associations between dietary added sugar intake and micronutrient intake: a systematic review. *Br J Nutr* **97**, 832–841.
51 Saris WHM, Astrup A, Prentice AM, *et al*. (2000) Randomized controlled trial of changes in dietary carbohydrate/fat ratio and simple vs complex carbohydrates on body weight and blood lipids: the CARMEN study. The Carbohydrate Ratio Management in European National diets. *Int J Obes Relat Metab Disord* **24**, 1310–1318.
52 Institute of Medicine Food and Nutrition Board (2000) *Dietary Reference Intakes: Applications in Dietary Assessment*. Washington, DC: National Academies Press.
53 Kaplan RJ (2004) Proportion of the US population whose intakes of added sugars exceed the suggested maximum in the dietary reference intakes. *Am J Clin Nutr* **80**, 524–525.
54 Barr SI & Johnson RK (2005) Effect of added sugars on dietary quality. *J Nutr* **135**, 1336–1337.
55 Forshee RA & Storey ML (2005) Reply to Barr and Johnson. *J Nutr* **135**, 1337.
56 Emmett P, Rogers I & Symes C (2000) Food and nutrient intakes of a population sample of 3-year-old children in the South West of England in 1996. *Public Health Nutr* **5**, 55–64.
57 Kant AK & Schatzkin A (1994) Consumption of energy-dense, nutrient-poor foods by the US population: effect on nutrient profiles. *J Am Coll Nutr* **13**, 285–291.
58 Sutherland LA (2004) Soft drinks and obesity. *J Pediatr* **144**, 554.
59 Allport JH (2004) Soft drinks and obesity. *J Pediatr* **144**, 554–557.
60 Institute of Medicine Food and Nutrition Board (2003) *Dietary Reference Intakes: Applications in Dietary Planning*. Washington, DC: National Academies Press.
61 Mackerras D & Rutishauser I (2005) 24 Hour national dietary survey data: how do we interpret them most effectively? *Public Health Nutr* **8**, 657–665.
62 Hannon EM, Kiely M, Harrington KE, Robson PJ, Strain JJ & Flynn A (2001) The North/South Ireland Food Consumption Survey: mineral intakes in 18-64-year-old adults. *Public Health Nutr* **4**, 1081–1088.

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