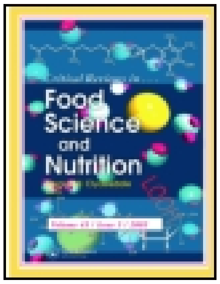

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SUGAR-FAT SEESAW: A SYSTEMATIC REVIEW OF THE EVIDENCE

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SUGAR–FAT SEESAW: A SYSTEMATIC REVIEW OF THE EVIDENCE

ABSTRACT

Further to reports of a reciprocal relationship between sugar and fat intakes this review aimed to provide an in-depth analysis and to determine the likely influence of this relationship on the achievement of population dietary guidelines. Using systematic methods, relevant literature was selected according to pre-set criteria.

A strong and consistent inverse association was found between total sugars and total fat intakes expressed as percentage energy. Fewer studies considered absolute intakes and these reported a positive relationship, which may be influenced by confounding with energy intakes. Evidence for an inverse relationship between percentage energy from fat and extrinsic sugars was weaker and less consistent than for fat and total sugars. Reciprocal relationships were also observed for sugar-saturated fat, sugar–protein, sugar–alcohol and sugar–starch expressed as percentage energy. Under-reporting of dietary intakes had no major influence on the findings.

This review confirms the existence of the sugar–fat seesaw on a percentage energy basis and concludes that it is most likely explained by a combination of mathematical and food compositional effects. This finding is relevant because dietary guidelines are expressed as percentage energy, and implies that at the population level multiple guidelines may be difficult to achieve in practice.

KEY WORDS

Dietary guidelines, sugars, sucrose, alcohol, protein, starch

INTRODUCTION

A reciprocal relationship between the intake of sugars and fat has been previously reported from observational data (Committee on Medical Aspects of Food Policy 1989; Gibney, Sigman et al. 1995), an association termed the ‘sugar–fat seesaw’. It has been hypothesised that in freely chosen diets, reducing intake of energy from both fat and sugars to comply with dietary guidelines may be difficult to achieve at the population level (Gibney 1990). Some data from intervention trials are consistent with this conclusion (West and De Looy 2001).

The reciprocal relationship between sugars and fat has been mainly observed when nutrient intake is expressed as percentage of dietary energy (% E) and it is unclear whether the relationship holds on the basis of absolute intakes of sugars and fat. It is also unclear whether the relationship is influenced by any particular type of dietary sugars, e.g. extrinsic sugars. Other limitations to the current state of knowledge are whether the relationship is applicable across the general population, if there is any evidence of a threshold effect, if the relationship is influenced by any particular type of fatty acid, if there is a relationship between sugars and other macronutrients, and if there is any influence of particular food groups. The current review aimed to systematically examine these issues to help determine whether, in practice, simultaneous population reductions in sugar and fat intakes are likely to be successful.

In this review 'total sugars' refers to all monosaccharides (glucose, fructose, galactose) and disaccharides (sucrose, maltose, lactose). 'Extrinsic sugars' refers to the terms 'added sugars', 'refined sugars', sucrose, sugar and non-milk extrinsic sugars (NMES). 'Intrinsic sugars' refers to the sugars present in unprocessed foodstuffs such as fruit and vegetables and those termed 'natural sugars'. 'Milk sugar' refers to lactose, and the term 'other sugars' invariably refers to a particular assessment of total sugars minus lactose. The lack of analytical data to determine intake of sugar sub-types means that the accuracy of such distinctions is poor.

METHODS

Research Question

This review addressed the following research question: "What is the evidence for an inverse relationship between dietary fat and sugars intake in populations freely selecting food and drink?" The scope of the review was observational studies of dietary intakes of healthy population groups (including children through to elderly people but excluding patient groups or people living in institutional care), from countries with cultural similarities to the UK (including the UK, Ireland, other European countries, USA and Australasia). The key relationships investigated were total sugars and total fat, sub-types of sugars and total fat, sugars (all types) and fatty acids, and sugars (all types) and other macronutrients. The review also explored potential threshold effects, and whether the relationships were particular to any population groups or were influenced by underreporting or by specific food groups. Eligible data from intervention studies were considered in a separate analysis. Potential mechanisms were also considered.

Data Sources and Literature Search Strategy

Medline, Embase and the Cochrane database of systematic reviews were searched for observational data and intervention studies using text terms with appropriate truncation and relevant indexing terms. The search was in the following form: 'Sugar terms' (e.g. sugars, sucrose) *and* fat *and* 'relationship terms' (e.g. seesaw, reciprocal). Dates of publication were restricted to 1985 onwards and only human studies in English language papers were eligible. Published government reports and reports of national survey data were included. The full list of search terms is detailed in Appendix 1. One author (1) carried out the database searches in June 2010 together with a hand/internet search. Reference lists of retrieved studies were also scrutinized. Unpublished data were not included in the review.

Study Selection and Quality

Inclusion and exclusion criteria (Online Table 1) were agreed by the authors prior to reviewing the search results. Since valuable data on sugar−fat intake relationships were known to have been published in abstracts and letters, including analyses based on good quality data sets, these sources of data were included in the review, recognising that they would not be accorded the same credibility as findings from full papers. To reduce confounding, eligible data were restricted to correlational analyses and analyses based on categorisation (e.g. quartiles, quintiles) of either sugars or fat intakes. Hence studies analysed according to clusters or dietary indices based on food groups, studies with total carbohydrate rather than sugar categorisation, and studies categorised on the basis of energy intake or energy density were excluded. Papers were also excluded if the fat or sugars intake data were not represented as total daily intakes (e.g. intake was only measured for certain meals or only for high-fat-sweetened food groups). Relevant intervention studies were considered separately and included those investigating dietary manipulation or advice to alter intake of sugars or fat, which was thus distinct from the primary research question relating to the free selection of food and drink. Though such studies may have been far smaller than many observational studies, they were important for understanding cause and effect, provided they were carefully controlled. Intervention studies that aimed to test manipulations in single foods or food groups, that did not allow subjects to freely select any final intake of macronutrients, or that followed a before-and-after design (with only one study group), were excluded.

One author (1) reviewed titles and abstracts from the search results and excluded clearly irrelevant records. Two investigators (1 and 3) each independently reviewed eligibility of 50% of the remaining potentially relevant records from the title, abstract and as necessary the full paper. To assess consistency of decisions 20% of records were cross-checked by both reviewers and good agreement was found. Discrepancies were resolved by discussion with the third author (2). One investigator (1) extracted the key data from the qualifying papers using predefined data fields. The data were analysed on the basis of statistical significance for sugar/fat intake relationships and were interpreted with regard to the study quality, and strength and consistency of the data. As proposed by Ryan (2007) quantitation of study quality was not considered feasible and was thus considered qualitatively within the tables and text by reference to the number of subjects, response rates and proportion of drop outs (where reported), method of statistical analysis, method of dietary intake assessment and assessment of under-reporting. For intervention studies other relevant quality markers included randomisation and length of follow-up.

SEARCH RESULTS

Papers reporting relationships between intakes of sugars and fat were potentially difficult to identify due to use of different terminologies. The search terms were thus deliberately comprehensive and identified a large number of potential records (2312). Initial screening identified 480 potentially relevant records, and of these 427 were excluded (Figure 1) resulting in a final list of 53 eligible papers. This included 16 for the total sugars analysis, 24 additional papers for the sugars sub-types and fatty acids analyses, and 12 reports of intervention studies (11 intervention studies overall).

Risk of Bias

Assessment of dietary intake is prone to random and systematic sources of error whatever the method of data collection (Miller, Abdel-Maksoud et al. 2008). The data are thus prone to a number of sources of bias including recall bias, responder bias, reporting bias and social approval bias (Miller, Abdel-Maksoud et al. 2008). Attrition bias may occur in prospective studies and interventions due to high participant dropout rates. Detection bias is possible in intervention studies due to the difficulty of blinding dietary studies. Reporting bias is possible where authors have only reported significant findings for sugar−fat intake relationships. Potentially there are many data sets for which sugar−fat intake relationships have not been

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explored, though this does not mean that such relationships did not exist. Publication bias is unlikely to be a key factor as investigation of the relationship was not always the primary focus of studies.

STUDY RESULTS AND DATA REVIEW

The eligible data addressed many relationships between sugars or sugar sub-types and fat, other macronutrients or alcohol, though not always on a consistent basis. The quality of the data was also variable. Most analyses were expressed as % E with fewer analyses for absolute intakes. Other analyses were based on a mixed comparison between % E or energy adjusted intake of one nutrient and absolute intake of the other. Most analyses were for total or extrinsic sugars and only a few addressed intrinsic or milk sugars *[Online Tables 2 & 3]*. Some intake relationships were investigated in only one or two studies and it was not possible to draw firm conclusions about all potential relationships (Table 1).

Associations Between Total Sugars and Total Fat Intakes

Percentage Energy Analyses

Studies that measured a correlation between total sugars and total fat intakes provided strong and consistent evidence for an inverse association when assessed on the basis of % E (Table 2). One result, published only as an abstract, provided an unrealistically high correlation coefficient (Baghurst 1988), hence the conclusion does not rely on this value. The evidence base included analyses of data from large surveys (Bolton Smith and Woodward 1994; Macdiarmid, Cade et al. 1995) and studies using 7-day weighed intakes (Macdiarmid, Cade et al. 1995; Ruxton, Kirk et al. 1996). The relationship held across all population groups studied including children, adolescents and adults. Data presented by fat or sugars categorisation (e.g. quartiles, quintiles) and expressed as % E (Table 3) also provided strong and consistent evidence for an inverse relationship between total sugars and total fat intakes, across all population groups studied (adults and children). The evidence included data from large surveys (Gibson 1993; Baghurst, Baghurst et al. 1994) and studies using a 7-day weighed dietary intake (Gibson 1993; Boulton and Magarey 1995).

Absolute Intake and Other Analyses

There were few analyses based on absolute intakes (Lenders, Hediger et al. 1994; Macdiarmid, Cade et al. 1995) and these reported a positive correlation (Tables 2 & 3). However, one study adjusted for energy intake and the association became inverse (Lenders, Hediger et al. 1994). In contrast, Rogers & Emmett (2002) commented that when using absolute nutrient intakes their results were extremely similar to the % E analysis, i.e. an inverse relationship, though the data were not reported in their paper.

The results of other analyses in which % E or energy adjusted intakes for fat or sugar were compared with absolute intakes of the other gave inconsistent results between studies (Table 3).

Associations Between Sugars Sub-Types and Total Fat

Extrinsic Sugars – Percentage Energy Analyses

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Studies that measured the correlation between extrinsic sugars and fat mostly showed statistically significant inverse associations on the basis of % E (Table 4). The evidence was weaker and less consistent than for total sugars and fat. Nevertheless an inverse relationship was observed in all population groups investigated, including children, adolescents and adults. Of three larger studies, two reported an inverse relationship (Bolton Smith and Woodward 1994; Gibson 1996) and one found no association (Drewnowski, Henderson et al. 1997). Studies in children, adolescents and adults analysed by sugar or fat categorisation also provided evidence for an inverse relationship between extrinsic sugars and fat on a % E basis (Table 5), though again the evidence was less consistent than for total sugars and fat. The exceptions included two studies (Haraldsdottir and Andersen 1994; Drewnowski, Henderson et al. 1997) that reported a lack of association in adults, and a larger study that reported an inverse association in men but not in women (Baghurst, Baghurst et al. 1994).

Extrinsic Sugars – Absolute Intake and Other Analyses

One study investigated the correlation between sucrose and total fat intake in adults on the basis of absolute intakes and reported a positive association (Table 4). The data were from a large survey (n=837) using the dietary history method (Drewnowski, Henderson et al. 1997). Additionally a positive association was reported between extrinsic sugars and fat on the basis of sucrose percentiles in both children and adults (Linseisen, Gedrich et al. 1998). However, when adjusted for energy intakes the relationship was inverse (Table 5).

The results of other analyses for extrinsic sugars and fat in which % E or energy adjusted intake of one nutrient was compared with absolute intake of the other were inconsistent. Most studies in children reported a non-significant association, while positive and inverse relationships were reported for adults (Table 5).

Intrinsic Sugars, Lactose or 'Other Sugars'

Fewer studies investigated correlations between intrinsic sugars and fat intakes (Table 4), one reporting an inverse association in women but not in men, and a positive relationship between total fat and lactose intakes in men and an inverse relationship in women (Bolton Smith and Woodward 1994). For analyses by sugars or fat categorisation (Table 5), one study investigated intakes of natural sugars and fat and reported an inverse association in men and women on a % E basis (Baghurst, Baghurst et al. 1994). A consistent inverse relationship was also reported for all age groups from 1 year upwards (Gibney, Sigman et al. 1995) based on a large analysis of intakes of total sugars excluding lactose and fat assessed by 3-day records. In this study the potential for a threshold effect was explored, and it was reported that a greater proportion of low-sugar consumers tended to consume above 30% energy from fat and more than 10% energy from saturated (SFA) and monounsaturated fatty acids (MUFA) than was consumed at higher levels of sugars intake.

No analyses addressed absolute intakes of intrinsic sugars, lactose or 'other sugars' and fat intakes. A small study in women, based on a 7-day diet history reported a lack of significant association for absolute intakes of fruit sugars and vegetable sugars with % E from fat (Flynn, Sugrue et al. 1996) and a study in children reported no association between fat intake and lactose (Räsänen and Ylönen 1992).

Hence overall, no firm conclusions can be drawn about the relationship between intrinsic sugars and fat intakes.

Associations Between Sugars Intakes and Fatty Acids

Analyses for Total Sugars and Fatty Acids

A study in children based on 24-hour dietary recall reported a strong inverse association with SFA on an energy adjusted basis (Table 6). In three further studies a consistent inverse association was reported for % E from total sugars and SFA in children, adolescents and women, though no statistical analysis was reported for the study in women (Flynn 1994). Overall this provides consistent evidence of an inverse association on the basis of % E between total sugars and SFA intakes. No studies addressed the relationships between total sugars and MUFA or polyunsaturated fatty acids (PUFA). There was insufficient evidence to address the relationship on the basis of absolute intakes. One study published only as an abstract (Flynn 1994), reported an inverse association between SFA and total sugars but no statistical analysis was provided.

Analyses for Extrinsic Sugars and Fatty Acids

The relationship between intakes of extrinsic sugars and SFA (with or without *trans* fatty acids) expressed as % E, was inconsistent and there was no clear pattern for different population groups (Table 6). In contrast associations on a % E basis for extrinsic sugars and both MUFA and PUFA showed consistently strong inverse associations across all population groups studied including children and adults.

No analyses addressed absolute intakes of extrinsic sugars and fatty acids. One large study in adults based on % E from added sugars and absolute intakes of fatty acids found a positive association for both SFA and MUFA and a negative association for PUFA in men and a non-significant association in women (Baghurst, Baghurst et al. 1992).

Associations Between Sugars and Other Macronutrients or Alcohol

Overall, on a % E basis (Table 7), the data support an inverse association between total or extrinsic sugars and protein. Based on fewer studies, the data also suggest an inverse association between total or extrinsic sugars and starch, and an inverse association between extrinsic sugars and fibre on a % E basis. There is also consistent evidence for an inverse association between extrinsic sugars and alcohol intakes.

Two studies found a positive association between total sugars and protein measured as absolute intakes (Table 8), which after adjusting for energy became inverse. Only one analysis considered absolute intakes of total sugars and total carbohydrate and reported a positive relationship.

Only one study investigated the relationship between intakes of intrinsic sugars and macronutrients other than fat (Bolton Smith and Woodward 1994) and reported (% E basis) a positive association with protein, a positive association with starch in men only, and an inverse association with alcohol (Table 7).

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Starch-Fat Relationship

The relationship between starch and fat is also of relevance but there was inconclusive evidence to support a starch–fat seesaw expressed as % E (data not shown), with some studies reporting no association (Gibney and Lee 1991; Baghurst, Baghurst et al. 1994; Flynn, Sugrue et al. 1996; Cullen, Nolan et al. 2004), an inverse association (Bolton Smith and Woodward 1994; Rogers and Emmett 2002) and one study reporting inconsistent findings in children (Boulton and Magarey 1995).

Under-Reporting and Threshold Effects

Most of the studies did not consider or did not exclude potential under-reporters of dietary intakes. In other studies the exclusion of under-reporters or subjects on weight loss diets had no significant effect on the results (Bolton Smith and Woodward 1994; Haraldsdottir and Andersen 1994; Macdiarmid, Cade et al. 1995; Flynn, Sugrue et al. 1996; Gibson 1996; Rogers and Emmett 2002; Alexy, Sichert et al. 2003; Cullen, Nolan et al. 2004). Few studies addressed the potential for threshold effects and there was no evidence that a threshold explained inconsistencies in the results.

Influence of Food Group

[Online Table 4]

A variety of measures were used to assess the contribution of food groups to sugar and fat intakes, including daily or weekly food intake, food intake adjusted for energy, grams sugars contributed by a particular food group, contribution of the food group to sugars intake, and servings of food per day, while one study also addressed the issue of using intakes only for consumers of the food as well as for all participants, which made it difficult to compare studies. Flynn et al (Flynn, Sugrue et al. 1996) identified non-fat confectionery and drinks as the most important food sources in terms of contribution to the reciprocal relationship between fat and sugar. The difference in sugars intakes between the low and high-fat groups was 53g per day of which 76% was contributed by added sugars and 23% by natural sugars (Flynn, Sugrue et al. 1996), the latter being derived from foods containing a much lower concentration of sugars compared with jam and table sugar. Overall, in studies supporting the existence of the sugar-fat seesaw, sugar intakes were positively associated and fat intakes were inversely associated with table sugars and preserves and other major sources of sugars.

Intervention Studies

Eligible intervention studies investigated the impact of dietary manipulation or dietary advice to alter sugar and/or fat intakes, though this was not always the primary aim of the study *[Online Table 5]*. Different study designs were used, ranging from studies investigating the addition of sugar to the usual diet to those investigating weight loss interventions. In all but one study results were on a % E basis and seven studies provided data as absolute intakes.

In studies that investigated reductions in sugars and/or fat, one study compared reduced-fat and reduced-sugar (RFRS) or reduced-fat with-sugar (RFwS) groups against control (Drummond and Kirk 1998; Drummond and Kirk 1999). Both intervention groups successfully reduced % E from fat at 6 weeks and 6 months (RFRS: 39% energy at baseline, 33.7% at 6m; RFwS: 40.2% energy at baseline, 32.2% at 6m). At 6 weeks % E from NMES was reduced in the RFRS group with no change in total sugar intake, but this reduction was not sustained at 6 months. In the RFwS group, % E intakes from total sugar and NMES were increased at 6 weeks but not at 6 months. Hence, while the RFRS group successfully reduced % E from fat they failed to maintain a reduced-sugars intake for the longer term, a finding consistent with the sugar−fat seesaw hypothesis. On a % E basis carbohydrate intakes were increased in both groups at 6 months, consistent with the aims of the dietary advice. On the basis of absolute intakes (Drummond and Kirk 1999) a fall in total sugar and NMES was observed in the RFRS group at 6wk with a fall only in NMES at 6 months (mean decrease 22.8g/day). There was no change in sugar or NMES in the RFwS group, and no change in absolute intakes of carbohydrate at 6 months in either group. Hence a fall in both fat and extrinsic sugars was sustained when measured as absolute intakes, which is inconsistent with the hypothesis. In a further study, both groups aimed to reduce fat intake but there was no significant change in either the reduced-fat high-carbohydrate group or the RFRS group on either a % E basis or absolute intakes (Drummond, Kirk et al. 2003). The RFRS group was successful in reducing % E from NMES and absolute intakes of total sugars and hence advice to reduce both fat and sugar resulted in a decrease in sugar only, which was consistent with the sugar-fat seesaw hypothesis. In a weight loss study (West and De Looy 2001) the nutritional aims of the low-fat sugar-containing (LFSC) diet were achieved with no change observed in sucrose intake and a fall in fat intake (by 6% of food energy). However, in the traditional weight loss diet group that aimed to reduce intake of both sucrose and fat (LFLS) only a reduction in sucrose was achieved (4.1% food energy) with no change in fat intake. Hence

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consistent with the sugar–fat seesaw hypothesis this study also demonstrated difficulty in achieving simultaneous reductions in both fat and sucrose on a % E basis.

In a study based on freely selected commercial low-fat or low-sugar foods (Gatenby, Aaron et al. 1997) fat intake was reduced significantly in the reduced-fat group (37% energy at baseline to 33% at 10 weeks) compared with controls and with the reduced-sugar group, but this was not related to any consistent directional change in sucrose intake. In the reduced-sugar group energy from fat rose by 2% compared with baseline. This suggested that the reduced-sugar group were successful in reducing energy from sugar and sucrose intake at the expense of a small rise in energy from fat, which was consistent with the sugar-fat seesaw hypothesis on a % E basis, though absolute intakes of fat may have been unchanged. In a study rigorously controlling dietary manipulation (Saris, Astrup et al. 2000) the reduced-fat high-complex carbohydrate group was successful in reducing % E from both fat and sugar. However the reduced-fat high-sugar intake group achieved a greater reduction in fat on a % E basis compared with the reduced-fat high-complex carbohydrate group, though not on the basis of absolute intakes.

In eligible studies that compared supplementary intake of sugar or sucrose against sweetener or fat, foods were provided for part or for the whole diet on an *ad libitum* basis. One study compared the incorporation of supplementary sucrose-sweetened or artificially-sweetened drinks and foods every day (Raben, Vasilaras et al. 2002). There was a significant increase in sucrose intake in the sucrose group (to 28% energy) and a fall in sucrose intake in the sweetener group on both a % E and absolute intake basis. In the sucrose group the increase in sucrose was accompanied by a fall in fat intake from 33 to 28% energy, but not when assessed by absolute intakes. There were no significant changes in fat intake in the sweetener group (34% energy) by either measurement basis. It was concluded that adding or replacing sugar from the diet was independent of fat intake. The changes were thus consistent with the sugar–fat seesaw hypothesis on a % E basis, but not on the basis of absolute intakes.

A well-designed study that compared supplementary sucrose-sweetened drinks (105g carbohydrate per day) with diet-drinks in normal weight women eating a low-fat diet reported a greater fall in fat intake in the sucrose group vs baseline than in the sweetener group, on both a % E and absolute intake basis (average fall of 6g per day). There was no change in carbohydrate intake in the sweetener group and an increase in the sucrose group (half the content of the sucrose supplement). Hence this study supported an inverse relationship between sucrose and fat intakes on both a % E basis and absolute intakes (Reid, Hammersley et al. 2007). In a dose-response study using a within-subject repeated-measures design (Mazlan, Horgan et al. 2006) snacks providing additional sugar resulted in a decrease in % E from fat and no change in absolute intakes when overall intake inclusive of the snacks was considered. When intake was assessed exclusive of the mandatory snacks, absolute intakes of fat were decreased in overweight subjects though not in lean subjects, and there was no change in % E from fat in either group. This demonstrated that, on a % E basis for total consumption, additional sugar resulted in a proportional decrease in energy from fat, but not on the basis of absolute intakes.

Overall on a % E basis the results of all but two studies (Burke, Milligan et al. 1998; Saris, Astrup et al. 2000) showed some consistency with the sugar–fat seesaw (Table 9), while on the

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basis of absolute intakes 3 studies supported (Naismith and Rhodes 1995; Drummond, Kirk et al. 2003; Reid, Hammersley et al. 2007) and 4 studies did not support the seesaw (Drummond and Kirk 1999; Saris, Astrup et al. 2000; Raben, Vasilaras et al. 2002; Drummond, Kirk et al. 2003; Mazlan, Horgan et al. 2006)

DISCUSSION

Following reports from observational data of a reciprocal relationship between sugars and fat intakes it has been suggested that in freely chosen diets, it may not be feasible at the population level to reduce intake of energy from both sugars and fat to comply with dietary guidelines. This reciprocal relationship has been mainly observed when intake of sugars and fat are expressed on a % E basis. The aim of this review was to explore more fully the relationship between the intake of sugars and fat and to determine if a reciprocal relationship also holds on the basis of absolute intakes of sugars and fat and whether the relationship is influenced by any particular type of dietary sugars or fatty acids.

The summary of results (Table 1) demonstrated a consistent inverse association between intakes of total sugars and fat expressed as % E across all population groups. The evidence also supported an inverse relationship for extrinsic sugars though the evidence was less consistent than for total sugars, which may be explained by the challenge of accurately measuring intakes of extrinsic sugars compared with total sugars. Fewer studies analysed these relationships on the basis of absolute intakes and generally indicated a positive correlation between fat and total or extrinsic sugars. This may be a reflection of higher food consumption in general as the association became inverse when adjusted for energy intake and as the relationship also applied to protein. There was evidence of an inverse relationship between total sugars and SFA measured as % E but the data were inconsistent for extrinsic sugars and SFA measured on this basis. An inverse association was found between extrinsic sugars and MUFA and PUFA expressed as % E. In studies reporting an inverse association between sugars and fat there was also a consistent inverse association for both total and extrinsic sugars with protein intake measured as % E. This association was positive when expressed as absolute intakes but was inverse when adjusted for energy intake. Fewer studies addressed the relationships between intakes of sugars and starch or fibre, but there was evidence for inverse associations between intakes of total or extrinsic sugars and starch and between extrinsic sugars and fibre. Alcohol intake was inversely associated with sugars intake, whatever the basis of intake.

Under-reporting of dietary energy is a potential issue when investigating sugar–fat intake associations because it may reflect selective reporting of sugars or high-fat high-sugar foods. However there was no clear evidence from the studies reviewed that under-reporting explained or influenced the findings. Studies that analysed results with and without under-reporters invariably recorded no impact of under-reporters on the results (Haraldsdottir and Andersen 1994; Gibson 1996; Tonstad and Sivertsen 1997; Rogers and Emmett 2002; Alexy, Sichert et al. 2003).

Owing to the variety of different measures used to investigate the contribution of food groups to sugar and fat intakes comparison of results was difficult. However, the overall results generally indicated a positive relationship between total and extrinsic sugars with confectionery and sweetened drinks, table sugar and preserves, but did not find any strong evidence that high-sugar high-fat foods explained sugar–fat intake relationships. Hence the fact that many high-fat foods are low in sugars and vice versa undoubtedly contributes to the seesaw.

Intervention studies are valuable in fully understanding the relationships between intakes of fats and sugars, and different study designs allow for different considerations. Highly controlled studies using a restricted range of foods are able to reduce confounding and investigate true nutritional effects. In contrast free-living studies are more relevant to real life situations and the influence of usual consumer behaviour. Adequate monitoring of dietary compliance is an important consideration and the interpretation of some studies may be limited by poor dietary compliance. Intervention studies reporting data expressed as % E were mostly consistent with the observational data and supported an inverse relationship between fat and sugars. In studies that measured changes in sugar and fat intakes on the basis of absolute intakes three studies were consistent with an inverse sugar–fat relationship and four were not.

Few studies considered the potential for a threshold effect and where this was considered the results were conflicting. It was reported that a greater proportion of low-sugar consumers tended to consume above 30% energy from fat than did higher sugar consumers (Gibney, Sigman et al. 1995), but in a French study it was suggested that the lack of association observed for sucrose and fat on a % E basis may have been explained by the lower contribution of energy from added sucrose in the French diet compared with American and British diets (Drewnowski, Henderson et al. 1997). A further analysis (Mela 1997) of intervention data (Gatenby, Aaron et al. 1997) concluded that in subjects with an initially low-fat intake, the use of reduced-sugar foods significantly increased % E from fat compared with baseline, whereas subjects with a higher initial fat intake showed no significant change. Also, high sucrose consumers using reduced-sugar foods increased their % E from fat (Mela 1997) (data not shown in Mela's paper) whereas for the overall reduced-sugar group the increase in energy from fat was only 2%. Hence the potential for a threshold effect warrants further investigation, on the basis of both % E and absolute intakes.

The concept of the sugar–fat seesaw has been much debated. The two key outcomes from this review, (1) of an inverse relationship between % E from sugars and fat from observational studies that is generally supported by intervention studies, and (2) indications from observational studies of a positive association on the basis of absolute intakes that may be confounded by energy intake and inconsistent findings from intervention studies, raise the question how these findings can be explained. While absolute intakes may be important at the individual level, intakes on a % E basis form the basis of dietary guidelines and are important at the population level to account for differing energy requirements. Some authors have suggested (Macdiarmid, Cade et al. 1995) or concluded (Mazlan, Horgan et al. 2006) that the seesaw may be a mathematical effect, arising as a function of expressing intakes as % E. However, if the relationship were entirely explained by a mathematical effect, a starch–fat seesaw on the basis of % E may equally be expected, yet this review found inconclusive evidence to support such a relationship. In nutritional terms the existence of any reciprocal relationships, as suggested by this review not only for sugar–fat, but also for sugar–protein, sugar–alcohol, sugar–starch and sugar–fibre, is likely to reflect food composition. The fact that key sources of sugar energy are low in energy from fat (e.g. soft drinks, table sugar) and that many sources of fat are low in sugar (e.g. oils, butter and fat-spreads, cheese, meat products) undoubtedly contributes to the inverse relationship between sugar and fat such that a mathematical effect is unlikely to be the sole explanation. If the sugar–fat seesaw is at least partly explained by food composition this implies that, with appropriate food selection, it is of course possible for individuals to eat less fat and less sugars concurrently. However, the intervention data demonstrate that consumers find this difficult to achieve in practice suggesting that consumer behaviour and influences of palatability and satiety are also important considerations in the achievement of multiple dietary guidelines.

A positive relationship between sugar and fat measured as absolute intakes potentially supports an alternative proposal that high-fat high-sugar foods are highly palatable such that sugar acts as a vehicle for dietary fat. However, evidence to support this hypothesis is weak since the positive relationship for absolute intakes reported in this review is based on limited observational data and the finding was subject to confounding since the relationship no longer held when adjusted for energy intake. Also, results of absolute intake data from intervention studies were equivocal. High-sugar intakes may be a marker of higher energy intakes on account of more active lifestyles, and the positive correlation may be partly explained by sugars, fat and protein (on a g/day basis) being positively related to energy intake. There was no evidence from food group analysis to suggest that high-sugar high-fat foods explained the hypothesis (Flynn, Sugrue et al. 1996). No evidence was available to assess the relationship between extrinsic sugars and SFA intakes on an absolute basis, and there was no evidence of a positive relationship for extrinsic sugars and SFA measured as % E. Stubbs et al have also concluded that there is little evidence that sugar acts as a vehicle for dietary fat and that the area warrants further investigation in intervention trials (Stubbs, Mazlan et al. 2001).

It has further been suggested that increased sugar intake levers fat energy out of the diet (Gibney 1990). Few observational studies addressed whether a low % E from fat was inversely associated with absolute intake of sugars. One study found an inverse association with extrinsic sugars in women (Flynn, Sugrue et al. 1996), but two other studies found no evidence for an association in children when considering total sugars (Nicklas, Webber et al. 1992) or extrinsic sugars (Nicklas, Webber et al. 1992; Räsänen and Ylönen 1992). However, this question can only be confirmed from well-designed and controlled intervention studies. Evidence from one carefully controlled intervention study, where energy density, palatability, taste, texture and appearance of the intervention foods were equalised across treatments, did not find evidence that sugar displaces absolute intake of fat in the diet (Mazlan, Horgan et al. 2006). While rigorously controlled interventions can help tease out nutritional from mathematical effects they do not allow for the influence of usual consumer behaviour in real-life eating situations.

In summary results of interventions allowing the free selection of foods demonstrate that it is difficult to reduce concurrently % E of sugar and fat over time. This finding is important because dietary guidelines for fat and sugars are generally expressed as % E. It implies that multiple guidelines may not be easily compatible and that prioritising guidelines may be constructive.

Strengths and Limitations

Strengths of this review include the large number of studies that were eligible for the analysis, including studies with high numbers of participants and using weighed dietary intake assessment. Data from eligible intervention studies included a range of different study designs, and there was low discrepancy between the reviewers. A wide range of potential relationships have been considered, resulting in a broad examination of the dietary sugar−fat seesaw hypothesis.

Limitations of the review include the challenge of searching for relevant data in studies where investigation of potential sugar−fat relationships may not have been the primary endpoint. Although a number of diverse search terms were used in a serious attempt to capture all the potentially relevant studies it is possible that some data may have been missed. There are also a number of limitations relating to the quality of the published data. Though many large studies were eligible for the review, some of the smaller studies may have been underpowered such that small differences did not reach statistical significance. For studies in which investigation of the sugar−fat relationship was not the primary purpose statistical analysis of the relationship was not always provided and there was insufficient evidence from such studies to support or refute the hypothesis. Validity of the relationship between sugar and fat in the diet relies on the accuracy of dietary intake data and all methods of data collection have inherent limitations that can lead to bias such that they may not accurately reflect true intakes. A further limitation relates to adequate classification of different sub-types of sugars. One analysis that included total, extrinsic and intrinsic sugars and lactose, provided a full description of the assumptions and estimations on

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which intake of the sugars sub-types was calculated (Bolton Smith and Woodward 1994), but such details were not provided in all study reports. Hence the data from which dietary intakes of sugars sub-types are calculated are not very robust, affecting the validity of comparisons between studies. Finally, there are potentially many existing data sets for which sugar–fat intake relationships and relationships with other macronutrients have not been explored. Such analyses would provide further useful information, on the basis of % E and absolute intakes expressed on a constant energy basis.

CONCLUSIONS

In summary this review confirms the existence of a sugar–fat seesaw on a % E basis and suggests that conforming to % E guidelines for both sugars and fats is challenging. The implication is that population guidelines to reduce both fat and sugar intakes may be difficult to achieve in practice and more studies investigating aspects of consumer behaviour that may influence the relationship are warranted.

Notwithstanding the limitations of dietary intake data, including assessment of different sugar types, the eligible data in this review demonstrate a strong and consistent inverse association between sugars and fat intakes when expressed as % E, in both observational and intervention studies. Overall the results suggest that this may be partly explained by mathematical and nutritional effects since major sources of sugar are not high in fat, and vice versa. Based on a smaller number of studies, the evidence suggests a positive relationship on the basis of absolute intakes, though this appears to be confounded by energy intake. The finding that the sugar–fat seesaw only holds when nutrients are expressed on a % E or energy adjusted basis is nevertheless highly relevant because population dietary guidelines are formulated on a % E basis. The finding is also consistent with the conclusions of Gibson and Ashwell (Gibson and Ashwell 2011) that it may be unrealistic to expect individuals to attain guidelines conceived as population intakes rather than individual targets.

Further work is needed to enable accurate determination of intakes of sub-types of sugars. More *ad libitum* intervention studies, designed to measure the effect on energy and macronutrient intake of altering fat or sugar intakes, are needed to understand consumer behaviour in practice and the factors influencing this. Measuring satiety and palatability scores within such studies, and palatability of low-fat low-sugar diets *per se*, would help to determine potential drivers of the inverse relationship and to explore reasons for the observed difficulty in sustaining reductions in energy intake from both fat and sugar over time. Studies that quantify the relationship, i.e. determine unit change in fat for a given change in sugar would contribute to further understanding of sugar–fat intake relationships. Further investigation of the relative strength of other potential reciprocal relationships such as sugar–protein, sugar–alcohol and fat–starch is warranted to understand more about possible mechanisms.

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APPENDIX 1: Search Terms

Sugar$1/ sucrose / sugar sweetened beverage$1 / soft drink$1	*And*	Fat	*And*	Seesaw / See saw
Sugar$1/ sucrose / sugar sweetened beverage$1 / soft drink$1	*And*	Fat	*And*	Reciprocal$2
Sugar$1/ sucrose / sugar sweetened beverage$1 / soft drink$1	*And*	Fat	*And*	Relation$4 / Interrelation$4
Sugar$1/ sucrose / sugar sweetened beverage$1 / soft drink$1	*And*	Fat	*And*	Ratio$1
Sugar$1/ sucrose / sugar sweetened beverage$1 / soft drink$1	*And*	Fat	*And*	Vehicle
Sugar$1/ sucrose / sugar sweetened beverage$1 / soft drink$1	*And*	Fat	*And*	Negative$2 / Inverse$2
Sugar$1/ sucrose / sugar sweetened beverage$1 / soft drink$1	*And*	Fat	*And*	Positive$2
Sugar$1/ sucrose / sugar sweetened beverage$1 / soft drink$1	*And*	Fat	*And*	Intake$1 / Consumption

$x= Wildcard + no. of following letters

The searches were applied to ‘whole document’.

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SUPPLEMENTARY TABLES FOR ONLINE PUBLICATION

ONLINE Table 1: Inclusion and Exclusion Criteria

	Inclusion	Exclusion
	OBSERVATIONAL STUDIES	
A	Published papers, government reports, case-control studies, letters, reviews and comments that provide dietary survey or	Recommendations, guidelines, statements, animal studies, *in vitro* studies and any other publications that do not

	other observational data in humans for fat and sugar(s) intakes for the whole diet published in English language	provide dietary intake data for fat and sugars, or that only provide such data for part of the diet (e.g. breakfast, main meal, selected food groups), or published in foreign languages
B	Studies in countries with a similar food culture and/or nutritional needs compared with the UK (e.g. Europe, Australia/New Zealand, North America)	Studies in countries with a different food culture and/or nutritional needs compared with the UK (e.g. Eastern countries, African countries)
C	Studies with healthy free-living human populations of any age, to include data in smokers or those carrying common risk factors (type 2 diabetes, hypertension, hypercholesterolaemia and obesity)	Study populations other than healthy free-living human subjects (e.g. hospitalised patients, chronically ill patients and people living in institutions)
	Primary analysis:	
D (i)	Papers that categorise and analyse total sugars vs total fat intakes (or vice versa), on the basis of absolute intakes or as percentage energy, or that provide a correlational analysis between sugars and fat intakes	Papers that do not refer to categorisation and analysis of sugars vs fat, that analyse categorisation of sugars or fat against parameters such as age, gender, time points or population sub-groups, or that categorise intake by dietary clusters or indices
	Secondary analyses:	
D (ii)	Papers that refer to categorisation and analysis of sugars sub-types (e.g. sucrose, added sugars, NMES) vs total fat intakes (or vice versa), expressed as absolute intakes or percentage energy	Papers that do not refer to categorisation and analysis of sugars sub-types vs total fat intakes (or vice versa), expressed as absolute intakes or percentage energy
D (iii)	Papers that refer to categorisation and analysis of sugars intakes (total or any sub-type) vs fatty acids (or vice versa), expressed as absolute intakes or percentage energy	Papers that do not refer to categorisation and analysis of sugars intakes (total or any sub-type) vs fatty acids (or vice versa), expressed as absolute intakes or percentage energy
	INTERVENTION STUDIES	
E	Randomised, human intervention trials with a control or second test group that test dietary manipulation or advice to alter sugars and/or fat intake (expressed as absolute intakes or percentage energy) on reciprocal intake of fat and/or sugars with	Non-randomised trials, before and after studies that test other dietary manipulations or advice than altering sugars and/or fat intake, that do not report reciprocal effect on fat and/or sugar sintakes, that tightly control overall

potential to achieve any final level of intake, and that have eliminated subjects with pre-existing therapy e.g. modified diet for medical reasons, appetite suppressants, weight loss drugs that could affect appetite and food selection	macronutrient intake, or that have not eliminated subjects with pre-existing therapy, or non-human studies.

NMES – non milk extrinsic sugars

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ONLINE Table 2: Characteristics of eligible papers for primary analysis – total sugars and total fat

Reference and publication type*	Population group	Number subjects (records used)	Sugars/Fat categorisation (measurement)*Or* CC (measurement)	Reciprocal fat/sugars (measurement)	Dietary intake assessment method	UR status
(Baghurst 1988) Abstract	Adults (randomly selected from electoral roll)	*c.* 3000	CC: fat and total sugars (% total energy)		Not stated	Not considered
(Baghurst, Baghurst et al. 1994)	Adults (18+ y) (randomly selected from electoral roll)	3209 (Response rate 67%)	Fat: quintiles (% total energy)	Simple sugars (% total energy)	Self-completed, quantitative FFQ	Not considered
(Bolton Smith and Woodward 1994)	Adults (25-64 y)	11,626	CC: fat and total sugars (% total energy)		FFQ	Participants on weight loss diets excluded (8.5% study population)
(Boulton and Magarey 1995)	Children (3m – 8 y) (randomly selected by birth order)	140	Fat: 3 groups (% energy)	Sugars (% energy)	3-, 4-, and 7-day weighed Records	Not considered
(Cullen, Nolan et al. 2004)	Adults (controls) (16-75y; mean	87 (nos matched to	Fat: tertiles (% total energy)	Sugars (% total	3-day diary	URs excluded (n=32)

	35.9±14.6)	cases)		energy)		
(Farris, Nicklas et al. 1998)	Children (10 y)	568	Total sugars: quartiles (g/1000kcal)	Fat (% energy and g/1000kcal)	24-hr recall	Not considered
(Flynn, Sugrue et al. 1996)	Women (20-55; mean 35y)	83 (77% response rate)	Fat: quartiles (% total energy)	Sugars (% total energy)	7-day diet history	Participants on slimming diets excluded but presence of URs not ruled out
(Gibney and Lee 1991)	Adults (Mean men 34.2±9.6, women 32.6±11.1, [from 50 randomly selected families)**	97	Fat: quartiles (% food energy and g/day)	Total sugars (g/10MJ)	1 wk diet history interview*	Not considered
(Gibson 1993)	Children (10-11 & 14-15y)	2705 (75% response rate)	Total sugars: tertiles (g/day and % energy)	Fat (% energy)	7 consecutive day weighed intake	Not excluded
(Lenders, Hediger et al. 1994)	Pregnant adolescents (13-19y)	337 (selected from 425 if delivered live singleton and had complete	Total sugars at and above, or below 90th %ile (g/day); Total sugars at	Fat (g/day)	24-hr dietary recall	Not considered

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		records	and above, or below 90th %ile adjusted for energy (g/day)			
(Macdiarmid, Cade et al. 1995) Letter to the Editor	Adults (16-64y)	2197 (70% response rate)	CC: fat and sugars (% food energy and g/day)		7-day weighed intake	Excluded URs (EI:BMR = <1.2), & those on weight loss diets or unwell (n=1240)
(Nicklas, Webber et al. 1992)	Children (10y; mean 10.6y)	871	Fat: 4 groups (% energy)	Total sugars (g/day)	24-hour dietary recall	Not considered
(Payne and Belton 1992)	Children (2-5y)	207 (675 randomly selected, 205 accepted (response rate 33%), 153 completed & 54 repeated 12m later)	CC: Fat and sugars (% energy)		7-day weighed intake	Not considered
(Rogers and Emmett 2002)	Children (1.5 & 3.5y)	1026 1.5y (77% response rate); 863 3.5y (69% response	Fat: quartiles (% energy)	Sugars (% energy)	3-day unweighed food record (2 weekdays and 1 weekend day, not necessarily	Data analysed with and without URs (EI <120% BMR)

		rate)		consecutive)	
(Ruxton, Kirk et al. 1996; Ziegler, Nelson et al. 2001)	Children (7-8y)	136 (58% response rate, 86% completion)	CC: Fat and total sugars (% energy)	7-day weighed inventory	Energy intakes close to predicted; URs not excluded
(Ziegler, Nelson et al. 2001)	Male & female figure skaters (mean 18y (m),16y (f))	161	CC: Sugars and fat (% total energy†)	3-day food records (2 non-consecutive weekdays and 1 weekend day)	Low energy reporters not excluded

CC: correlation coefficients; EI: energy intake: BMR: basal metabolic rate

*Peer reviewed research paper unless otherwise indicated; ** From (Gibney 1989); † Alcohol not consumed

NB For studies in children it is assumed that alcohol is not consumed and that food energy ≡ total energy

ONLINE Table 3: Characteristics of eligible papers for secondary analysis – sugars sub- type and total fat

Reference and publication type*	**Population group**	**Number subjects (records used)**	**Sugars/Fat categorisation (measurement) *Or* Correlation coefficient (CC) (measurement)**	**Reciprocal fat/sugar type (measurement)**	**Dietary intake assessment method**	**Under-reporter (UR) status**
(Alexy, Sichert et al. 2003)	Children & adolescents (2 -18y)	849 ('Low' dropout rate)	Added sugars: quintiles (% energy¶)	Fat (% energy¶)	3-day weighed dietary records	Not excluded - data analysis of females without implausible records similar to total records
(Baghurst 1988) Abstract	Adults (randomly selected from electoral roll)	*c.* 3000	CC: total fat vs natural sugars; total fat vs refined sugars (% total energy)		Not stated	Not considered
(Baghurst, Baghurst et al. 1992)	Adults (18+y) (randomly selected from electoral roll)	*c.* 1850 (66% response rate)	Added sugars: deciles (% total energy)	Fat (% total energy); Fat (g/day)	FFQ (quantified, postal)	Not considered
(Baghurst, Baghurst et al. 1994)	Adults (18+ y) (randomly selected	3209 (Respons e rate	Fat: quintiles (% total energy)	Natural sugars (% total energy); Added sugars (%	Self-completed, quantified	Not considered

	from electoral roll)	67%)		total energy)	FFQ	
(Bolton Smith and Woodward 1994)	Adults (25-64 y)	11,626	CC: extrinsic sugars and total fat; intrinsic sugars and total fat; lactose and total fat		FFQ	Participants on weight loss diets excluded (8.5% study population)
(Cade and Booth 1990)	Adults (35-54y)	2340 (85% response rate)	Above/below NACNE† guideline: 12% total energy from refined sugars (% total energy)	Fat (g/day)	24-hr Dietary Record or 24 hr recall of previous day	Not considered for main analysis
(Committee on Medical Aspects of Food Policy 1989) Unpublished data within consensus report	Adults (age not stated)	217	NMES: tertiles (g/1000kcal)	Fat (g/1000kcal); Fat (g/day)	Not stated	No details available
(Drewnowski, Henderson et al. 1997)	Adults (18 - 97y)	837 (response rate 62%)	Added sucrose: deciles (g/1000kcal/day) CC: sucrose and fat (% total energy	Fat (% total energy); Fat (g/day)	Dietary history (up to 6-mo) (by interview)	Not considered

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			and g/day)			
(Erkkola, Kronberg et al. 2009)	Children at risk of diabetes type 1 (3y)	471 (59% response rate)	Added sucrose: quartiles (% energy)	Fat (% energy)	3-day food record (2 consecutive week days, one weekend day)	URs not excluded
(Flynn, Sugrue et al. 1996)	Women (20-55; mean 35y)	83 (77% response rate)	Fat quartiles (% total energy)	Fruit sugars (g/day); Vegetable sugars (g/day); Breads and cereals sugars (g/day); Milk sugars (g/day); Total added sugars (g/day)	7-day diet history	Participants on slimming diets excluded but presence of URs not ruled out
(Garemo, Lenner et al. 2007)	Children (4 y)	132 (86% completion rate)	CC: sucrose and total fat (% energy)		7-day food record (4 days + 3 days)	URs considered - exclusions not necessary
(Gibney 1987) Abstract	Adults (35-44y)	60	Fat: 3 groups (% food energy)	Sugars‡ (% food energy)	7-day weighed intake	Not considered
Gibney,	Adults (35-	60	Fat 3 groups (%	Sugars minus	7-day	Not considered

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Moloney et al. 1989)	44y)		food energy); Fat above/below 120g/day	lactose (g/day)	weighed intake	
(Gibney, Sigman et al. 1995)	Adults and children (1+ y)	8296 (26% to 38% response rate)	Total sugars minus lactose: 3 groups (g/1000kcal)	Fat (g/1000kcal)	3-day records	Not considered
(Gibson 1996)	Adults (18-64 y)	2197 (70% response rate)	NMES: quintiles (% food energy) CC: NME sugars and fat (% food energy)	Fat (% food energy)	7-day weighed dietary records	Data analysed with and without dieters, unwell and low energy reporters
(Gibson 1997)	Children (1.5-4.5y)	1675 (80% response rate)	NMES: quintiles (% energy)	Fat (% energy)	4-day weighed records	URs not observed
(Haraldsdottir and Andersen 1994)	Adults (23-27y)	132 (from 303 randomly sampled with 33% drop out (= 203), and 35% drop out	Fat: tertiles (% total energy) CC: fat and refined sugars (% energy)	Refined/industrial sugars (% total energy)	7-consecutive day food records	Data analysed with and without URs (EI/BMR<1.10)
(Kranz, Smiciklas-	Children (2-5y)	5437	Added sugars: 5 groups (% energy)	Fat (% total energy)	2 days records	Diets reported by proxy & prone to

Wright et al. 2005)					intake by household and phone interviews	incomplete or biased information
(Lewis, Park et al. 1992)	Children & adults (4+y)	27,942 (response rate 61%)	Added sugars: quartiles (with 3 groups) (g/kg body wt) Added sugars: quartiles (with 3 groups) (% energy)	Fat (% total energy)	3 days data collection	Low-sugars group excluded as group overall had low energy intakes - data confounded by dieters
(Linseisen, Gedrich et al. 1998)	Children & adults (4+y)	15,838	Sucrose percentiles (g/day, energy unadjusted & energy adjusted)	Fat (g/day)	7-day dietary records	Data not corrected for underreporting
(Nicklas, Webber et al. 1992)	Children (10y; mean 10.6y)	871	Fat: 4 groups (% energy)	Sucrose (g/day) Lactose (g/day)	24-hour dietary recall	Not considered
(Parnell, Wilson et al. 2008)	Children 5-14y (3049) & Adults 15+(4379)	7428 (from 7911 surveyed)	Fat: quartiles (% total energy)	Sucrose (% total energy)	24-hour dietary recall	Not possible to account for URs in a meaningful way
(Räsänen and Ylönen 1992)	Children(1-2y)	46 (of random sample of 100)	Fat: 4 groups (% total energy)	Sucrose (g/day) Lactose (g/day)	3 consecutive day food records	Not considered

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(Rasmussen, Lyhne et al. 1998)	Children (7-10y)	377 (all ages 65% response rate)	Added sugars: quintiles (% energy)	Fat (g/day)	7-day food records	Not considered
(Rogers and Emmett 2002)	Young children (1.5 & 3.5y)	1026 1.5y (77% response rate); 863 3.5y (69% response rate)	Fat: quartiles (% energy)	NMES (% energy)	3-day unweighed food record (2 weekdays and 1 weekend day, not necessarily consecutive)	Data analysed with and without URs (EI <120% BMR)
(Ruottinen, Niinikoski et al. 2008)	Children (13m – 9y)	543 (from 1062 with returned records)	Sucrose: 3 groups (% energy)	Fat (% energy) Fat (g/day)	3 & 4-day food records	URs not excluded – under-reporting of sugar unlikely as fat was main focus of study
(Tonstad and Sivertsen 1997)	Children (8-12y)	174	Fat: quartiles (% energy)	'Sugar' (assumed to be added sugars) (% energy)	Quantitative FFQ/Interview	Not excluded as found similar results after exclusion of subjects below cut off for energy intake and estimated BMR
(Ylönen, Virtanen et al. 1996)	Children (1-7y)	77 (86% response	Fat: 4 groups (% energy)	Sucrose (% energy)	3-day estimated food	Not considered

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		rate)			records (2 weekdays and 1 weekend day)	
(Flynn 1994) Abstract	Women	83	Saturated fat: quartiles (% total energy)	Total sugars (% energy) NMES (% energy) Total sugars (g/day) NMES (g/day	Diet history method	Not considered
(Matthys, De et al. 2006)	Adolescents	341	Saturated fat: tertiles (% energy)	Total sugars (% energy)	7-day estimated food record	Data analysed with and without URs (EI/BMR<1.10)

CC: correlation coefficients; EI: energy intake: BMR: basal metabolic rate; NMES: Non-milk extrinsic sugars

*Peer reviewed research paper unless otherwise indicated

¶ Not stated if total or food energy

† National Advisory Committee on Nutrition Education

‡ Assumed to be sugars minus lactose

NB For studies in children only, it is assumed that food energy = total energy

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ONLINE Table 4: Sugars/fat relationship and intake of food groups

Reference	Sugars categorisation	Sugars/fat relationship	Association with sugars categorisation						
			Energy intake	**Fruit, vegetables and juices**	**Dairy products**	**Table sugar, preserves**	**Sweet bakery & desserts**	**Confectionery**	**Beverages - sweetened & alcoholic**
Inverse sugar–fat association: total sugars									
(Farris, Nicklas et al. 1998)	Total sugars quartiles (g/1000kcal)	Inverse fat % energy and fat g/1000kcal	Children: NS	Children (g food): NS	Children (g food): Positive (milk), Inverse (cheese)	Not assessed	Children (g food): NS desserts	Children (g food): Positive	Children (g food): Positive
(Gibson 1993; Burke, McCarthy et al. 2007)	Total sugars tertiles (g/day)	Inverse sugars (% energy & g/day) vs fat (% energy) except for older girls for sugars	Children: Positive	Children (% sugars intake): Inverse (fruit, veg, soups); NS (fruit juices)	Children (% sugars intake): Inverse (milk, yogurt)	Children (% sugars intake): Positive	Children (% sugars intake): Inverse (buns & pastries, biscuits); NS (cakes, puddings/fr	Children (% sugars intake): Positive	Children (% sugars intake): Inverse association

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		(g/day)					uit pies)		
Inverse sugar–fat association: extrinsic sugars									
(Baghurst, Baghurst et al. 1992)	Added sugars deciles (% energy)	Inverse for fat (% energy), positive for fat (g/day)	Adults: Positive	Not assessed	Adults (g food /day): Inverse (milk)	Adults (g food /day): Positive	Adults (g food /day): Positive	Adults (g food /day): Positive	Adults (g/day): Positive (soft drinks); Negative (beer)
(Erkkola, Kronberg et al. 2009)	Added sucrose quartiles (% energy)	Inverse fat (% energy)	Children: NS	Children (g food/day): Positive (juice drinks, fruit soups); Inverse (vegetables)	Children (g food/day): Positive (yogurt, ice-cream, milk desserts); Inverse (skimmed milk, cheese)	Not assessed	Children (g food/day): Positive	Children (g food/day): Positive	Not assessed
(Gibson 1997)	NMES quintiles (% energy)	Inverse fat (% energy)	Boys: positive; Girls: NS	Children (g food/wk): positive fruit juice); inverse (vegetables)	Children (g food/wk): Inverse (milk)	Not assessed	Not assessed	Children (g food/wk): Positive	Children (g food/wk): Positive
(Kranz,	Added	Inverse fat	Children 2-	Children	Children	Not	Not	Not	Not assessed

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Smiciklas-Wright et al. 2005)	sugars: 5 groupings (% energy)	(% energy)	3y: Positive; 4-5y No association	(servings food group/day): Inverse (fruit & vegetables)	(servings food group/day): Inverse	assessed	assessed	assessed	
(Lewis, Park et al. 1992)	Added sugars g/kg body wt	Children & adults: Trend for high added sugar consumers to have lower % energy from fat than moderate consumers	All ages: positive	All ages (servings/day): no association (fruits & vegetables)	All ages (servings/day): No association (milk)	Not assessed	Not assessed	All ages (servings/day): positive	All ages (servings/day): no association alcoholic beverages; positive association other beverages

Reference	**Fat categorisation**	**Sugar/fat relationship**	**Association with fat categorisation**							
			Energy intake	**Fruit, vegetables and juices**	**Dairy products**	**Table sugar, preserves**	**Sweet bakery and desserts**	**Breakfast cereals**	**Confectionery**	**Beverages - sweetened & alcoholic**
Inverse sugar–fat association: total sugars										
(Baghurst	Total fat (%	Inverse	Adults:	Adults	Adults	Not	Not	Not	Not	Not

1988)	energy)	simple carbohydrates (% total energy)	Positive	(diets high in): Inverse	(diets high in): Positive	assessed	assessed	assessed	assessed	assessed
(Baghurst, Baghurst et al. 1994)	Fat quintiles (% energy)	Inverse association simple sugars (% energy)	Adults: Positive	Adults: higher intake in low-fat grp vs high-fat grp per unit energy	Adults: lower intake in low-fat grp vs high-fat grp per unit energy		Adults: lower intake in low-fat grp vs high-fat grp per unit energy	Adults: higher intake in low-fat grp vs high-fat grp per unit energy	Adults: lower intake in low-fat grp vs high-fat grp per unit energy	Adults: higher intake in low-fat grp vs high-fat grp per unit energy
(Flynn, Sugrue et al. 1996)	Fat quartiles (% energy)	Inverse sugars (% energy)	Women: NS	Women (g sugars from food): No association	Women (g sugars from food): No association	Not assessed	Not assessed	Women (g sugars from food): No association	Women (g sugars from food): inverse (non-fat containing)	Women (g sugars from food): No association
(Gibney and Lee 1991)	Fat quartiles (% food energy)	Inverse total sugars per (g/10MJ)	Adults: Inverse	g food/10MJ /day): Women positive (fruit), inverse	Adults: (g food/10MJ/day): positive (cheese), butter); men no	Adults (g food/10MJ/day): inverse	Adults: (g food/10MJ/day): positive	Not assessed	Adults: (g food/10MJ/day): positive	Not assessed

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				(vegetables);Men: positive (vegetables) no association (fruit)	association (milk), women positive (milk);					
(Rogers and Emmett 2002)	Fat quartiles (% energy)	Inverse sugar (% energy)	Children: Positive	Children (g food/MJ): inverse	Children (g food/MJ): Positive association (whole milk, cheese)	Children (g food/MJ): inverse	Children (g food/MJ): inverse	Children (g food/MJ): inverse	Children (g food/MJ): No association	Children (g food/MJ): inverse (sweetened drinks), no association (diet drinks)
Gibney and Lee 1991)	Fat quartiles (g/day)	Men: no association Women inverse total sugars per (g/10MJ)	Women: positive	Women (g food/10MJ/day): inverse (fruits & vegetables)	Women (g food/10MJ/day): inverse (milk)	Women (g food/10MJ/day): inverse	Women (g food/10MJ/day): positive	Not assessed	Women (g food/10MJ/day): positive	Not assessed
Inverse sugar–fat association: sugar sub-type(s)										
(Gibney	Fat: low,	Adults:	Adults:	Adults (g	Adults (g	Adults (g	Adults (g	Not	Not	Not

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1987)	moderate high (% food energy)	Inverse sugars minus lactose (% food energy)	positive	food/day) : Positive (fruit, vegetables)	food/day) : Positive (cheese)	food/day) : inverse	food/day) : positive (cakes)	assessed	assessed	assessed
(Gibney, Moloney et al. 1989)	Fat 3 groupings (% food energy)	Men: Inverse g sugars minus lactose/day Women: No association	Men: No association	Men (g food/day) : positive (fruit)	Men (g food/day) : positive (butter, milk)	Men (g food/day) : inverse	Men (g food/day) : No association	Not assessed	Men (g food/day): inverse	Not assessed
Gibney, Moloney et al. 1989)	Fat <120, >120 (g/day)	Men: Inverse g sugars minus lactose/day	Men: positive	Men (g food/day) : inverse (fruit)	Men (g food/day) : positive (butter, milk)	Men (g food/day) : inverse	Men (g food/day) : positive (biscuits and cakes)	Not assessed	Men (g food/day): positive	Not assessed
(Ylönen, Virtanen et al. 1996)	Fat: 4 groupings (% energy)	Inverse sucrose (% energy)	No overall association (kcal/kg body wt);	Children (amount consumed): inverse (fruits,	Children (amount consumed): no association	Children (amount consumed): no association	Not assessed	Children (amount consumed): no association	Children (amount consumed): no association	Children (amount consumed): no association

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	positive (kcal)	fruit juices)	(sweeten ed milk)	(sucrose)	(cereal products)		(sweeten ed soft drinks)

NMES: Non-milk extrinsic sugars

ONLINE Table 5: Characteristics of eligible intervention studies

Reference	Study type	Population group	Number subject s	Intervention	Duration of trial	Dietary intake assessment method	Under-reporters (URs) considered
(Burke, Milligan et al. 1998)	Randomised controlled intervention study	Children 11y	800 (or 898 invited to participa te)	Nutrition program that aimed to reduce fat, sugars and salt, and increase fibre intakes	20wk interventi on and 6-month follow-up	2-day dietary records (mid-week)	Not considered
(Drummond and Kirk 1998; Drummond and Kirk 1999)	Randomised controlled intervention study	Men 46.3±3.7y	74 (after exclusio n of under-reporter s and incompl ete data sets)	RFRS: Advice to reduce fat and sucrose replacing with complex carbohydrate RFwS: advice to reduce fat intake replacing with complex carbohydrate and sucrose Control – no advice	7-day baseline; 6 month interventi on	Baseline: 7-day unweighed inventory; 2wk, 4wk, 6wk and 6 months: 4-day food diaries	Excluded subjects reporting energy intake below 1.10 X BMR for baseline dietary record

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(Drummond, Kirk et al. 2003)	Randomised, parallel group intervention study	Men 40+y	25	RF – advice to reduce high-fat foods and substitute with high carbohydrate foods RFRS: Advice to reduce fat and sugars	1wk baseline, 8 wk intervention	Baseline: 7-day unweighed diet diary 4wk, 8wk: 4-day diet diaries	From 30 recruited 5 excluded as URs (EI<1.1 X BMR)
(Gatenby, Aaron et al. 1997)	Controlled intervention trial (assume randomised)	Women, 34.3y	49 (after exclusion of under-reporters)	Reduced-Fat Group – advice to replace full-fat items with reduced-fat alternatives; Reduced-Sugar Group – advice to replace sugar-containing foods with reduced–sugar foods Control	2-wk baseline; 10-wk intervention	Baseline (0) and at 2, 4, 7 and 10wk of intervention: 4-day weighed diet records	URs excluded if baseline energy intake/estimated BMR <1.10, or <1.14 for wks 2-10 with weight loss <0.5kg
(Mazlan, Horgan et al. 2006)	Randomised within-subject repeated-measures, counterbalanced design	Lean and overweight men, 27-68 y	12	Each subject studied 3 times, consuming either high-fat or high-sugar snacks providing 3.0MJ/day, 1.5MJ/day or 0MJ/day. Energy density was equalised across treatments	3 x 7-day treatments with 5-day washouts	Food provided: 3-day rotating menu; self-selected and ad libitum	Not relevant
(Naismith and Rhodes 1995)	Cross-over trial (assume randomised)	Men 19-30y	14	3-day run in; Period 1: Diet rich in sugar for 10 days Period 2: Sugar replaced with sweetener for 10 days In 4 subjects intervention periods reversed	3-day run in; 2 X 10 wk intervention	Food provided: 5-day repeating menu; self-selected and ad libitum	Not relevant

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(Raben, Vasilaras et al. 2002)	Randomised, parallel group Intervention study; artificial sweetener group interpreted as control for purposes of this review	Overweight men (6) & women (35) 20-50y	41 (of 42 enrolled)	Daily consumption of supplementary sucrose-sweetened (high-sugar group) or artificially-sweetened drinks/foods (sweetener group)	10-wk intervention period	Baseline, wk5 and wk10: 7-day weighed dietary records	Not considered
(Reid, Hammersley et al. 2007)	Factorial design study	Women currently watching or not watching their weight, 20-55y	133 (from 161 recruited)	2x2x2 design for daily consumption of supplementary sucrose-sweetened drinks vs drinks with sweetener, drinks labelled as containing sugar or “diet” (50% incorrectly,) and subjects weight watching vs not watching	7-day baseline; 4-wk intervention	7-day food diary for each of the 5-wks of the study	Not considered
(Saris, Astrup et al. 2000)	Randomised controlled multi-centre intervention, weight loss study	Adults moderately obese, 20-55y	316 (from 398 recruited)	LFHS: aim to reduce fat by 10% energy, and for ratio of 1.5 for simple to complex carbohydrate LFHC: aim to reduce fat by 10% energy, and for ratio of 0.5 for simple to complex carbohydrate Vs Control	5 wk run in, 6m intervention	3-day or 7-day weighed intake Foods purchased from laboratory shop from a choice of 100-150 specified items and additional	Not considered

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						foods from supermarket	
(Vandongen, Jenner et al. 1995)	Randomised controlled intervention study	Children 10-12y	1147	Subjects allocated to health program: fitness, fitness + school nutrition, school based nutrition, school + home nutrition, home-based nutrition OR control. Nutritional intervention aimed to achieve ≤33% energy from fat and ≤12% energy from sugar	9m	Baseline and 9m: 2-day food records	Not considered
(West and De Looy 2001)	Randomised , weight loss trial; Traditional low calorie diet assumed as control	Overweight Women (34) and men (34), 39.5y	68 (dropout rate: 27% of the men and 29% of the women)	LFSC: low-fat weight-reducing diet *c.* 10% energy sucrose LFLS: traditional low-fat weight-reducing diet ≤5% energy added sucrose (Control);	2-day baseline; 8wk interventi on	Baseline, 2, 4, and 8wk: 2-day unweighed diet inventory	Validity of intakes confirmed by comparing energy intakes with 24h energy expenditure predicted by BMRX1.4

RFRS: Reduced-fat and reduced-sugar; RFwS: Reduced-fat with-sugar; LFCS: Low-fat containing-sugar; LFLS: Low-fat low-sugar; LFHS: Low-fat high-sugar; LFHC: Low-fat high-complex carbohydrate

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Table 1: Overview of results of observational studies

Analysis	Percentage Energy			Absolute Intake			Mixed Measurement Comparison		
	Inverse	NS	Positive	Inverse	NS	Positive	Inverse	NS	Positive
Total sugars vs fat									
Correlation coefficient	6					1			
Sugars/fat categorisation	7					1	2	1	
Extrinsic sugars vs fat									
Correlation coefficient	5	2				1			
Sugars/fat categorisation	11	4				1	3	3	2
Intrinsic sugars vs fat									
Correlation coefficient	2	1							
Sugar/fat categorisation	1							1	
Milk sugar vs fat									
Correlation coefficient	1		1						
Sugars/fat categorisation								2	
‘Other sugars’ type vs fat									
Sugars/fat categorisation	1								
Fatty acids vs sugars categorisation									
Saturated/Total sugars	3								
Saturated/Extrinsic	2	2	1						1
Monounsaturated/Extrinsic	5								1
Polyunsaturated/Extrinsic	5						1		
Macronutrients other than fat vs sugars categorisation (for studies showing inverse sugars/fat relationship)									
Protein/Total sugars	2					2	2	1	

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Protein/Extrinsic sugars	7				1	3	2	
Protein/Intrinsic sugars			1					
Protein/Other sugars						1		
Carbohydrate/Total sugars			1		1			1
Carbohydrate/Extrinsic			6		2		1	4
Carbohydrate/Other sugars								1
Starch or CC/ Total sugars	2							
Starch or CC/Extrinsic	2				1	1	1	
Starch or CC/Intrinsic		1	1					
Fibre/Total sugars		1						
Fibre/Extrinsic sugars	3					1		
Fibre/Other sugars						1	1	1
Alcohol vs sugars categorisation (for studies showing inverse sugars/fat relationship)								
Alcohol/Total sugars	1							
Alcohol/Extrinsic sugars	3	1		1		4		
Alcohol/Intrinsic sugars	1							

NS: Non significant; CC: complex carbohydrate; (1): value is number of studies in category

Table 2: Correlation coefficients for total sugars and total fat intakes

Reference	Analysis	Correlation coefficient (r) for population group (P value):

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Measurement: % energy		
(Baghurst 1988)	Fat vs simple carbohydrates (% total energy)	Adults: -0.97 (No statistical analysis)*
(Bolton Smith and Woodward 1994)	Total sugars vs fat (% total energy)	Men: -0.34 P<0.001 Women: -0.39 P<0.001
(Macdiarmid, Cade et al. 1995)	Fat vs sugars (% food energy)	Adults: -0.57 P<0.001
(Payne and Belton 1992)	Total sugars vs fat (% total energy)	Children: -0.63 P<0.001
(Ruxton, Kirk et al. 1996)	Fat vs total sugars (% total energy)	Children: -0.65 P<0.001
(Ziegler, Nelson et al. 2001)	Sugars vs fat (% total energy) (alcohol not consumed)	Male adolescents: -0.54 P<0.01 Female adolescents: -0.41 P<0.01
Measurement: g/day		
(Macdiarmid, Cade et al. 1995)	Fat vs sugars (g/day)	Adults: 0.37 P<0.001

- Conclusions do not rely on this value, which is unrealistically high

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- **Table 3: Association between fat or total sugars categorisation and total sugars or fat intakes**

Reference	Fat/total sugars categorisation	Total sugars/fat measurement	Method of statistical analysis	Association for population group
Measurement: % energy				
(Baghurst, Baghurst et al. 1994)	Fat quintile (% total energy)	Sugars (% total energy)	Chi squared test on one dietary factor for linear trend	Adults: Inverse P<0.001
(Boulton and Magarey 1995)	Fat: 3 groupings (% energy)	Sugars (% energy)	ANOVA	Children: Inverse P< 0.0001
(Cullen, Nolan et al. 2004)	Fat tertile (% total energy)	Sugars (% total energy)	Two-way ANOVA	Adults: Inverse P<0.001
(Farris, Nicklas et al. 1998)	Sugars quartiles (g/1000kcal)	Fat (% energy)	ANOVA; Coefficients of sums of squares for trend analysis	Children: Inverse P<0.0001
		Fat (g/1000kcal)		Children: Inverse P<0.0001
(Flynn, Sugrue et al. 1996)	Fat quartile (% total energy)	Sugars (% total energy)	Student t test	Women: Inverse P< 0.0001
(Gibney and Lee 1991)	Fat quartiles (% food	Sugars (g/10MJ food	N/A	No statistical analysis - data

	energy)	energy)		suggest an inverse relationship
(Gibson 1993)	Sugars tertile (% energy)	Fat (% energy)	ANOVA & multiple range test	Children: Inverse P<0.001
(Rogers and Emmett 2002)	Fat quartile (% energy)	Sugars (% energy)	One-way ANOVA	Children: Inverse P<0.001
Measurement: g/day				
(Lenders, Hediger et al. 1994)	Sugars above/below 90th percentile (g/day)	Fat (g/day)	Students T Test	Adolescents: Positive P<0.001
(Lenders, Hediger et al. 1994)	Sugars above/below 90th percentile (g/day) adjusted for energy	Fat (g/day)	Students T Test	Adolescents: Inverse P<0.001
Other measurement				
(Gibney and Lee 1991)	Fat quartiles (g/day)	Sugars (g/10MJ food energy)	N/A	No statistical analysis - data suggest an inverse relationship in women and no relationship in men
(Gibson 1993)	Sugars tertiles (g/day)	Fat (% energy)	ANOVA & multiple range test	Boys & girls 10-11y: Inverse P<0.001 Boys 14-15y:

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			range test	Inverse P<0.001 Girls 14-15y: NS
(Nicklas, Webber et al. 1992)	Fat: 4 groupings (% energy)	Sugars (g/day)	Pairwise comparisons	Children: NS

Table 4: Correlation coefficients for sugars sub-type and total fat intakes

Reference	Analysis	Correlation coefficient
Measurement: % energy		
(Baghurst 1988)	Total fat (% total energy) vs natural sugars (% total energy)	Adults: *c.* r= -0.97*
	Total fat (% total energy) vs refined sugars (% total energy	Adults: r= <-0.97* (No statistical analysis)
(Bolton Smith and Woodward 1994)	Extrinsic sugars vs fat (% total energy)	Men :-0.36 P<0.001 Women:-0.29 P<0.001
	Intrinsic sugars vs fat (% total energy)	Men: NS Women: -0.20 P<0.001
	Lactose vs total fat (% total energy)	Men: 0.15 P<0.001 Women: r<-0.10

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(Drewnowski, Henderson et al. 1997)	Sucrose (% energy) vs total fat (% energy)	Adults: r = -0.01 NS
(Garemo, Lenner et al. 2007)	Sucrose (% energy) vs total fat (% energy)	Children: r = -0.35 P<0.0001
(Haraldsdottir and Andersen 1994)	Refined/industrial mono/disaccharides (% energy) vs fat (% energy)	Men: -0.30 P<0.05 Women: 0.04 NS
(Gibson 1996)	Fat (% food energy) vs extrinsic sugars (% food energy)	Men: -0.43 P<0.001 Women: -0.45 P<0.001 Men most reliable records: -0.44 P<0.001 Women most reliable records:-0.53 P<0.001
Measurement: g/day		
(Drewnowski, Henderson et al. 1997)	Sucrose (g/day) vs total fat (g/day)	Adults: r = 0.51 P<0.001

- Conclusions do not rely on these values, which are unrealistically high
-
-
-
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- **Table 5: Association between sugars sub-type or total fat categorisation and intake of total fat or sugars sub-type**

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Reference	Fat/sugar type categorisation	Sugar type or fat measurement	Method of statistical analysis	Association for population group
Measurement: % energy				
(Alexy, Sichert et al. 2003)	Added sugars quintiles (% energy)	Total fat (% energy)	Mixed linear model (PROC MIXED)	Children & adolescents: Inverse P<0.0001
(Baghurst, Baghurst et al. 1992)	Added sugars deciles (% total energy)	Total fat (% total energy)	Chi squared test	Men & women: Inverse P<0.001
(Baghurst, Baghurst et al. 1994)	Fat quintile (% total energy)	Natural sugars (% total energy)	Chi squared test on one dietary factor for linear trend	Men: Inverse P<0.001 Women: Inverse P<0.001
		Added sugars (% total energy)		Men: Inverse P<0.01 Women: NS
(Drewnowski, Henderson et al. 1997)	Added sucrose deciles (g/1000kcal/day)	Fat (% total energy)	Stepwise regression analyses	Adults: NS
(Erkkola, Kronberg et al. 2009)	Added sucrose quartiles (% energy)	Total fat (% energy)	One-way ANOVA	Children: Inverse P<0.001

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(Gibney 1987)	Fat: 3 groupings (% food energy)	Sugars (minus lactose) (% food energy)	N/A	Adults: Inverse (no statistical analysis provided)
(Gibney, Sigman et al. 1995)	Total sugars minus lactose: 3 groupings (g/1000kcal)	Fat (g/1000kcal)	One-way analysis of variance and series of Student-Newman-Keuls range tests	1y to 51+y: Inverse P<0.05
(Gibson 1996)	NMES quintiles (% energy)	Fat (% energy)	Multiple Range Test	Adults: Inverse P<0.05
(Gibson 1997)	NMES quintiles (% energy)	Fat (% energy)	One-way ANOVA & Bonferroni test	Children: Inverse P<0.0001
(Haraldsdottir and Andersen 1994)	Fat tertiles (% total energy)	Refined/industrial sugars (% total energy)	T test	Adults: NS
(Kranz, Smiciklas-Wright et al. 2005)	Added sugars: 5 groupings (% energy)	Fat (% energy)	Non parametric test for trend (z score)	Children: Inverse P<0.001
(Lewis, Park et al. 1992)	Added sugars tertiles (% total	Fat (% total energy)	Bonferroni test	Children & adults: Trend

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	energy)			for high added sugar consumers to have lower % energy from fat (No statistical analysis provided)
(Parnell, Wilson et al. 2008)	Fat quartiles (% total energy)	Sucrose (% total energy)	Linear regression	Children, Men & Women: Inverse P<0.001
(Rogers and Emmett 2002)	Fat quartiles (% energy)	NMES (% energy)	One-way ANOVA	Children: Inverse P<0.001
(Ruottinen, Niinikoski et al. 2008)	Sucrose: 3 groupings (% energy)	Fat (% energy)	ANOVA, F test	Children: NS
(Tonstad and Sivertsen 1997)	Fat quartiles (% energy)	“Sugar” (% energy) *assume not total sugars*	Unpaired t test & ANOVA	Children: Inverse P<0.0001
(Ylönen, Virtanen et al. 1996)	Fat: 4 groupings (% energy)	Sucrose (% energy)	One-way ANOVA & Bonferroni test	Children: Inverse P<0.001
Measurement: g/day				
(Linseisen,	Sucrose intake	Fat (g/day)	Multiple	Children &

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Gedrich et al. 1998)	(not energy adjusted) (g/day)		regression analysis	adults: Positive P<0.001
(Linseisen, Gedrich et al. 1998)	Sucrose intake (energy adjusted) (g/day) vs fat (g/day)	Fat (g/day)	Multiple regression analysis	Children & adults: Inverse P<0.001
(Gibney 1989)	Fat above/below 120g/day	Sugars excluding lactose (g/day)	N/A	Men: Inverse (No statistical analyses provided)
Other measurements				
(Baghurst, Baghurst et al. 1992)	Added sugars deciles (% total energy)	Total fat (g/day)	Chi squared test	Men: Positive P<0.05 Women: Positive P<0.01
(Cade and Booth 1990)	Refined sugars above/below 12% total energy	Fat (g/day)	SPSS	Men: Inverse P<0.05 Women: NS
(Drewnowski, Henderson et al. 1997)	Added sucrose deciles (g/1000kcal/day)	Fat (g/day)	Stepwise regression analyses	Adults: Positive P<0.0001
(Flynn, Sugrue et al. 1996)	Fat quartiles (% total energy)	Fruit sugars (g/day) Vegetable	Mann Whitney U-test	Women: NS Women: NS

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		sugars (g/day)		Women: NS
		Breads and cereals sugars (g/day)		Women: NS
		Milk sugars (g/day)		Women: Inverse P =0.009
		Total added sugars (g/day)		
(Gibney 1989)	Fat 3 groups (% food energy)	Sugars excluding lactose (g/day)	N/A	Men: Inverse Women: No change (No statistical analyses provided)
(Lewis, Park et al. 1992)	Added sugars tertiles (g/kg body wt)	Fat (% total energy)	Bonferroni test	Children & adults: Trend for high added sugar consumers to have lower % energy from fat (No statistical analysis provided)
(Nicklas, Webber et al. 1992)	Fat: 4 groups (% energy)	Sucrose (g/day	Pairwise comparisons	Children: NS
		Lactose (g/day)		Children: NS

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(Räsänen and Ylönen 1992)	Fat: 4 groupings (% total energy)	Sucrose (g/day Lactose (g/day)	One-way ANOVA & Bonferroni test	Children: NS Children: NS
(Ruottinen, Niinikoski et al. 2008)	Sucrose: 3 groupings (% energy)	Fat (g/day)	ANOVA, F test	Children: NS (data not provided)

Table 6: Association between sugars categorisation (any type) and fatty acid intake

Reference	Sugar type categorisation	Method of statistical analysis	Association with fatty acid (% energy or energy adjusted basis) for population group		
			Saturated/*Trans*[¶]	Monounsaturated	Polyunsaturated
(Farris, Nicklas et al. 1998)	Total sugars quartiles (g/1000kcal)	Analysis of variance; Coefficients of sums of squares for trend analysis	Children (g/1000kcal): Inverse P = 0.0001; Negative Linear trend P<0.0001 &		

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			negative quadratic trend P<0.05		
(Baghurst, Baghurst et al. 1992)	Added sugars deciles (% total energy)	Chi squared test	Men & Women: NS	Men & Women: Negative linear trend P<0.001	Men & Women: Negative linear trend P<0.001
(Erkkola, Kronberg et al. 2009)	Added sucrose quartiles (% energy)	One-way ANOVA	Children (Saturated + Trans): NS	Children: Inverse P<0.001	Children: Inverse P<0.001
(Gibson 1996)	NMES quintiles (% food energy)	Pearson Correlation Coefficient	Men & women: Inverse P<0.001 ***Trans fatty acids*** men: NS; women: inverse P<0.01	Men & women: Inverse P<0.001	Men & women: Inverse P<0.001
(Gibson 1996)	NMES quintiles (% food energy)	Pearson Correlation Coefficient	*Most reliable records* Men: Inverse P<0.01; Women: Inverse P<0.001 ***Trans fatty acids*** men: NS; women: inverse P<0.05	*Most reliable records* Men & women: Inverse P<0.001	*Most reliable records* Men & women: Inverse P<0.001
(Gibson 1996)	NMES quintiles (% food energy)	Multiple Range Test	Men & women: Inverse P<0.05 Trans fatty acids - Men & women: NS	Men & women: Inverse P<0.05	Men & women: Inverse P<0.05

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(Linseisen, Gedrich et al. 1998)	Sucrose percentiles (g/day) energy adjusted)	Multiple regression analysis model: unpaired T test	**g/day (energy adjusted)** Children & adults: Inverse P<0.001	**g/day (energy adjusted)** Children & adults: Inverse P<0.001	**g/day (energy adjusted)** Children & adults: Inverse P<0.001
(Ruottinen, Niinikoski et al. 2008)	Sucrose Low/medium/high (% energy)	ANOVA, F test	Children: Positive P =0.009	Children: Inverse P =0.03	Children: Inverse P =0.0001
Gibney, Sigman et al. 1995)	Total sugars minus lactose 3 groupings (g/1000 kcal of total energy)	One-way analysis of variance and series of Student-Newman-Keuls range tests	**g/1000kcal (of total energy)** Children & adults: Inverse P≤0.05		

			Association with fatty acid (g/day) for population group		
			Saturated	**Monounsaturated**	**Polyunsaturated**
(Baghurst, Baghurst et al. 1992)	Added sugars deciles (% total energy)	Chi squared test	Men & Women: Positive linear trend P<0.001	Men & Women: Positive linear trend P<0.05	Men: Negative linear trend P<0.01; Women: NS

	Saturated fat categorisation (% energy)	**Method of statistical analysis**	**Association with sugar/s intake for population group**			
			Total sugars (% energy)	**NMES (% energy)**	**Total sugars (g/day)**	**NMES (g/day)**
(Flynn 1994)	Quartiles (% total energy)	No statistical analysis	Women: Inverse	Women: Inverse	Women: Inverse	Women: Inverse

(Matthys, De et al. 2006)	Tertiles (% energy)	Mann-Whitney U test	Adolescents: Inverse P =0.000
(Ruxton, Kirk et al. 1996)	Correlation coefficient: total sugars (% energy) vs saturated fat (% energy)	Pearson's correlation coefficient	Children: Inverse r = -0.24 P<0.01

¶ Where indicated; NMES: non-milk extrinsic sugars

Table 7: Association between sugars categorisation (any type) and intake of macronutrients (other than fat) and alcohol (% energy)

Reference	Sugars classification	Statistical Test	Energy intake	Protein (% energy)	Carbohydrate (% energy)	Carbohydrate type (% energy)	Alcohol (% energy)

Total sugars							
(Bolton Smith and Woodward 1994)	Total sugars (% total energy)	Spearman rank correlation coefficients (two-tailed significance levels)	Men: Positive P<0.001 Women: Positive r<0.10	Men & Women: Inverse P<0.001		***Starch*** Men & Women: Inverse P<0.001	Men & Women: Inverse P<0.001
(Farris, Nicklas et al. 1998)	Total sugars quartiles (g/1000kcal)	Analysis of variance; Coefficients of sums of squares for trend analysis	Children: NS	Children Inverse P=0.0001 ***(g/1000kcal):*** Inverse P=0.0001 (Significant linear trend (<0.0001)	Children Positive P=0.0001 ***(g/1000kcal):*** Positive P=0.0001 (Significant linear trend P<0.0001)	Children ***Dietary Fibre*** NS ***Starch (g/1000kcal):*** Inverse P=0.001 (Significant linear trend P<0.0001)	
Extrinsic sugars							
(Baghurst, Baghurst et al. 1992)	Added sugars deciles (% total energy)	Chi squared test	Men & Women: Positive linear trend P<0.001	Men & Women: Negative linear trend P<0.001	Men & Women: Positive linear trend P<0.001	***Complex Carbohydrate*** Men & Women: Negative linear trend P<0.001	Men & Women: Negative linear trend P<0.001
(Bolton Smith and Woodward 1994)	Extrinsic sugars (% total energy)	Spearman rank correlation coefficients	Men & Women: Positive P<0.001	Men & Women: Inverse		***Starch*** Inverse P<0.001	Men: NS Wome

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		(two-tailed significance levels)	P<0.001	P<0.001			n: inverse P<0.00 1
(Committee on Medical Aspects of Food Policy 1989)	NMES tertiles (g/1000kcal)	Method not provided	Men & Women: NS	g/1000kcal Men & Women: Inverse P<0.01	g/1000kcal Men & Women: Positive P<0.001		g/1000 kcal Men & Wome n: NS
(Erkkola, Kronberg et al. 2009)	Added sucrose quartiles (% energy)	One-way ANOVA	Children: NS	Children: Inverse P<0.001	Children: Positive P<0.001	***Fibre*** Children: Inverse P<0.001	
(Kranz, Smiciklas-Wright et al. 2005)	Added sugars: 5 groupings (% energy)	Non parametric test for trend (z score)	Children 2-3y: Positive P=0.01; 4-5y: NS	Children: Inverse <0.001	Children: Positive <0.001	***Fibre*** Children: Inverse <0.001	
(Lewis, Park et al. 1992)	Added sugars tertiles (% total energy)	Bonferroni test	Children & adults: Positive P<0.01 for low vs moderate consumers		Children & adults: Positive trend (No statistical analysis)		
(Ruottinen,	Sucrose: 3	Repeated	Children: NS	Children:	Children:	***Dietary Fibre***	

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Niinikoski et al. 2008)	groupings (% energy)	measures ANOVA F test		Inverse (P<0.001)	Positive (P<0.001)	Children: Inverse (P<0.001)	
Intrinsic sugars							
(Bolton Smith and Woodward 1994)	Intrinsic sugars (% total energy)	Spearman rank correlation coefficients (two-tailed significance levels)	Men & Women: Inverse P<0.001	Men & Women: Positive P<0.001		***Starch*** Men: Positive P<0.001 Women; NS	Men: Inverse P<0.001 Women: Inverse r<0.10

NMES: Non-milk extrinsic sugars

Table 8: Association between sugars categorisation (any type) and intake of energy, macronutrients (other than fat) and alcohol (g/day)

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Reference	Sugars categorisation	Method of statistical analysis	Energy	Protein (g/day)	Carbohydrate (g/day)	Carbohydrate type (g/day)	Alcohol (g/day)
Total sugars							
(Lenders, Hediger et al. 1994)	Total sugars Low/High (g/day)	Students T Test	Adolescents: Positive P<0.001	Adolescents: Positive P<0.001	Adolescents: Positive P<0.001		
(Gibson 1993)	Total sugars tertiles (g/day)	ANOVA & multiple range test	Children: Positive P<0.001	Children: Positive P<0.001			
(Gibson 1993)	Total sugars tertiles (% food energy)	ANOVA & multiple range test	Children: Positive P<0.001 boys & girls 10-11y; P<0.05 boys 14-15 & P<0.01 girls 14-15y	Children: Inverse P<0.001 boys 10-11y; P<0.05 girls 10-11y; NS boys & girls 14-15y			
(Lenders, Hediger et al. 1994)	Total sugars low/high (g/day) adjusted for dietary energy	Least-squares-means values		Adolescents: Inverse P<0.001	Adolescents: Positive P<0.001		
Extrinsic sugars							
(Lewis, Park et al. 1992)	Added sugars tertiles (g/kg	Bonferroni test	Children & adults: Positive		Children & adults:		

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	body wt)		P<0.01		Positive trend (No statistical analysis)		
(Linseisen, Gedrich et al. 1998)	Sucrose percentiles (g/day) energy unadjusted	Multiple regression analysis model: unpaired T test	Children & adults: Positive P<0.001	Children & adults: Positive P<0.001	Children & adults: Positive P<0.001	***Polysaccharides*** Children & adults: Positive P<0.001	Inverse P<0.001
(Baghurst, Baghurst et al. 1992)	Added sugars deciles (% total energy)	Chi squared test	Men & Women: Positive linear trend P<0.001	Men & Women: NS	Men & Women: Positive linear trend P<0.001	***Complex Carbohydrate*** Men & Women: NS	Men & Women: Negative linear trend P<0.001
(Committee on Medical Aspects of Food Policy 1989)	NMES tertiles (g /1000kcal)	Method not provided	Men & Women: NS	Men: NS; Women: Inverse P<0.05	Men: NS; Women: Positive P<0.001		Men: NS; Women: Inverse P<0.05
(Drewnowski, Henderson et al. 1997)	Sucrose deciles (g /1000kcal of total energy)	Stepwise regression analyses	Men & Women: Positive P<0.0001				Men & Women: Inverse P<0.0001
(Linseisen, Gedrich et al. 1998)	Sucrose percentiles (g/day) energy adjusted)	Total sugar Low/High (g/day)		Children & adults: Inverse P<0.001	Children & adults: Positive P<0.001	**Polysaccharides** Children & adults: Inverse P<0.001	Inverse P<0.001

(Rasmussen, Lyhne et al. 1998)	Added sugars quintiles (% energy)	No statistical analysis provided	Children: Constant across quintiles	Children: Inverse	Children: Positive	***Fibre*** Children: Inverse
Other sugars measurement						
(Gibney, Sigman et al. 1995)	Total sugars minus lactose, 3 groupings (g/1000kcal total energy)	One-way analysis of variance and series of Student-Newman-Keuls range tests		Children & adults: Inverse P≤0.05	Children & adults: Positive P≤0.05	***Fibre*** Negative & positive P<0.05 or NS with age

NMES: Non-milk extrinsic sugars

Table 9: Summary of results of intervention studies

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Reference	Change in intake of fat and/or sugars	Change in energy intake
(Burke, Milligan et al. 1998)	**% Energy** No significant changes at end of intervention or follow-up	
(Drummond and Kirk 1998; Drummond and Kirk 1999);	**% Food Energy** 6wk vs baseline: RFRS: Reduction in fat P<0.05; NS change in total sugars; reduction in NMES P<0.05. RFwS: Reduction in fat P<0.05; Increase in total sugars P<0.05; NS change in NMES; Control: NS changes in fat, total sugars or NMES 6m vs baseline: RFRS: Reduction in fat P<0.05; NS change in total sugars or NMES; RFwS: Reduction in fat P<0.05; NS change in total sugars or NMES; Control: NS changes in fat, total sugars or NMES **Absolute Intakes** 6wk vs baseline: RFRS: Reduction in fat P<0.05; Reduction in total sugars and NMES P<0.05. RFwS: Reduction in fat P<0.05; NS change in total sugars or NMES. Control: NS changes in fat, total sugars or NMES 6m vs baseline: RFRS: Reduction in fat P<0.05; No significant change in total sugars; Reduction in NMES P<0.05 RFwS: Reduction in fat P<0.05; No significant change in total sugars or NMES; Control: NS changes in fat, total sugars or NMES	**Total energy:** 6wk vs baseline: RFRS: Reduction P<0.05 RFwS: Reduction P<0.05 Control: NS change 6 months vs baseline: RFRS: Reduction P<0.05 RFwS: NS change Control: NS change
(Drummond, Kirk et al. 2003)	**% Energy** RF: No significant change in fat or NMES RFRS: No significant change in fat; decrease in NMES P<0.02	RF: No significant change RFRS: No significant change

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	Absolute Intakes RF: No significant change in fat or NMES RFRS: No significant change in fat; decrease in sugars P<0.05	
(Gatenby, Aaron et al. 1997)	**% Energy** 10wk vs baseline: RF group: Reduction in fat P =0.017; RF, RS & Control groups: Reduced total sugars intake vs baseline P = 0.001 with no between group differences RS group: Increase in fat P<0.05; Reduction in sucrose vs control and vs RF group (P<0.05) Control group: Increase in fat (P<0.05)	Significant time effect for reduction in energy intake in RF, RS and Control groups (P<0.001); No group effects
(Mazlan, Horgan et al. 2006)	**% Energy inclusive of mandatory snacks** Sugar increments: Decrease in fat (P<0.001) **% Energy exclusive of mandatory snacks** Sugar increments: No change in fat **Kcal inclusive of mandatory snacks** Sugar increments: No change in fat **Kcal exclusive of mandatory snacks** Sugar increments: No change in fat	**Kcal inclusive of mandatory snacks** Sugar increments: Increase P<0.016 **Kcal exclusive of mandatory snacks** Sugar increments: No change
(Naismith and Rhodes 1995)	Displacement of sugar with sweetener: increased fat kcal P<0.001 Replacement of sweetener with sugar: NS change in fat kcal	Displacement of sugar with sweetener: decrease in energy P<0.02 Replacement of sweetener with sugar: increase in energy P<0.05
(Raben, Vasilaras et	10wk vs baseline:	

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al. 2002)	**% Energy** High sucrose group: Increase in sucrose P<0.0001 vs sweetener group, P<0.05 vs baseline; Decrease in fat P<0.01 vs sweetener group, P<0.05 vs baseline Sweetener group: Decrease in sucrose P<0.0001 vs sucrose group, P<0.05 vs baseline; NS change in fat **Absolute Intakes** High sucrose group: Increase in sucrose P<0.0001 vs sweetener group, P<0.05 bs baseline; NS change in fat; Sweetener group: Decrease in sucrose P<0.0001 vs sucrose grp, P<0.05 vs baseline; NS change in fat	High sucrose group: Increase P<0.0001 vs sweetener group, P<0.05 vs baseline; Sweetener group: NS change
(Reid, Hammersley et al. 2007)	4wk vs baseline: **% Energy** Sucrose drinks: Decrease in fat P<0.001 Drinks with sweetener: Decrease in fat P<0.001 Greater decrease in fat in group receiving sucrose drinks P<0.001 **g/day** Sucrose drinks: decrease in fat intake Drinks with sweetener: no change	4wk vs baseline: Sucrose drinks: Increase P<0.001 of approximately half the energy value of the supplementary drinks Drinks with sweetener: Decrease P<0.05
(Saris, Astrup et al. 2000)	**% Energy** LFHS: Decrease in fat P<0.05 and increase in sugars P<0.0001 vs LFHC group; P<0.001 for decrease in fat and increase in sugars vs control LFHC: Decrease in fat P<0.001 and sugars P<0.01 vs control **g/day** LFHS: Decrease in fat P<0.001 vs control; increase in sugars P<0.001 vs LFHC group and control LFHC: Decrease in fat P<0.001 and sugars P<0.01 vs control	LFHS: Decrease LFHC: Decrease Control: No significant change

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(Vandongen, Jenner et al. 1995)	**% Energy** 9m vs baseline: Boys: Change in sugars vs change in total fat: r= -0.5261 P<0.0001 Girls: Change in sugars vs change in total fat: r= -0.5437 P<0.0001	9m vs baseline Boys & Girls: NS change
(West and De Looy 2001)	**% Total Energy** 8wk vs baseline: LFSC: Non-significant change in sucrose; reduction in fat (P<0.05) LFLS: Reduction in sucrose (P<0.001); non-significant change in fat	**Total energy** Reduced in LFLS and LFSC groups with no significant difference between groups

NS: Non significant; NMES: non-milk extrinsic sugars; RFRS: Reduced-fat and reduced-sugar; RFwS: Reduced-fat with-sugar; LFSC: Low-fat sugar-containing; LFLS: Low-fat low-sugar; LFHS: Low-fat high-sugar; LFHC: Low-fat high-complex carbohydrate

FIGURES

Figure 1: Search results and study selection

Searches identified 2312 records: 2289 (from databases) + 8 (from hand/internet searching) + 1 (direct contact with author) + 14 (from reference lists)

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Initial screening

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Excluded 1832 clearly irrelevant records

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Potentially relevant records: 480

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Screening

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Excluded:

- 135 (non-human or foreign language studies or studies without data for whole diet)
- 7 (studies in countries without cultural similarities to the UK)
- 10 (studies in patient groups)
- 241 (data without categorisation/analysis by sugar/fat intake)
- 34 (Non-qualifying intervention studies)

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Eligible records: 53

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