Evidence Update

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SUGAR AND THE HEART

This umbrella review provides a snapshot of the evidence in relation to sugar and heart health

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Executive Summary

General nutrition advice has consistently recommended limiting sugar intake for health. Similarly, the Heart Foundation recommends using only small amounts of sugar and choosing ready-prepared foods low in sugar as one part of a healthy dietary pattern.

While limiting sugar is considered important for general health, evidence on the specific impact of sugar on heart disease has been less conclusive. This evidence snapshot reviews the current evidence for sugar and/or sugar-sweetened beverages (soft drinks or drinks with sugar added), and their impact directly on heart disease and risk factors for it.

Within the limitations of the current evidence base, this umbrella review of the literature found:

- There remains insufficient and currently inconclusive evidence on which to draw conclusions on the direct influence of sugar on heart disease itself. However, there is a small body of cohort evidence that sugar-sweetened beverages are associated with increased risk of heart disease.
- There is evidence for an effect of sugar and sugar-sweetened beverages on body weight, which is a risk factor for heart disease.
- There is evidence of an association between sugar (at high intakes) or sugar-sweetened beverages and other risk factors for heart disease such as raised triglyceride, lipids, blood pressure or type 2 diabetes.
- When substituted iso-energetically, sugar does not appear to impact on body weight. However, added sugar can lead to overconsumption of energy, which is associated with increases in body weight. Evidence is stronger for the role of sugar-sweetened beverages.
- When reducing saturated fat in the diet, replacing it with refined (including sugary) carbohydrates does not have any benefits for heart health.

Thus, evidence supports advice to limit intakes of added sugar as one part of an eating pattern that supports health and heart health.

The Heart Foundation recommends that:

- High intakes of sugar and sugary drinks may adversely impact on risk factors for heart disease, and should be avoided.
- Small amounts of added sugar (less than 10% total energy) are unlikely to be harmful in the context of a healthy diet.
- Foods or drinks that are high in added sugar with little nutritional value are best kept for special occasions only. This includes sugary drinks, lollies, cakes, biscuits, or similar foods and drinks.
- Reducing added sugar intake (including sugary drinks) can help reduce body weight.
- There are naturally occurring sugars in nutritious foods like fruit and plain milk, which we encourage people to eat as part of a healthy dietary pattern.

Background

Dietary guidelines in many countries recommend limiting the amount of free or added sugar consumed. This is generally based on concerns that added sugar increases energy density of the diet with little nutritional value, displaces foods with higher nutritional value, has a potential impact on body weight, and increases risk of dental erosion or dental cavities.

The Heart Foundation of New Zealand's position on sugar (1999) has been that, in excess, refined carbohydrates (which include sugar) may influence obesity, diabetes and other risk factors for cardiovascular disease; and recommends people use only small amounts of highly sweetened foods or drinks such as sugar confectionery, cakes, biscuits, soft drinks and chocolate.

Specifically, the Heart Foundation of New Zealand recommends to:

> *"Drink plenty of fluids each day, particularly water, and limit sugar-sweetened drinks and alcohol"*
>
> *"Use only small amounts of total fats and oils, sugar and salt when cooking and preparing meals, snacks or drinks. Choose ready-prepared foods low in these ingredients."*

Further, dietary patterns that support heart health for people at risk of cardiovascular disease are those where "*…the dietary intake of refined sugar and flour products is low…"*. [Heart Foundation position paper on dietary patterns, 1999]

This paper is an evidence snapshot of current research on sugar and heart health to update the 1999 position statement. It is an umbrella review of the literature. A full review will be conducted when the Heart Foundation's Carbohydrate Position Statement is updated.

Introduction

Sugars are a form of carbohydrate. During digestion, all carbohydrates are broken down into their smallest unit, which are monosaccharides. Table sugar, or sucrose, is broken down into the monosaccharides glucose and fructose. Under normal circumstances, glucose is the primary source of energy for the brain and central nervous system. The rate glucose is released into the bloodstream is measured by the Glycaemic Index (GI). Table sugar has a moderate GI of 68, whereas pure glucose has the highest GI of 100.

Humans are born with an innate preference for sweet tastes - in nature sweet foods are generally safe to eat. However, where this preference for sweetness was once obtained from foods like fruit and berries, it is now more typically from sugar added to food and beverages. Where nature made sugar hard to get, the modern food environment makes it extremely easy to get.[1]

What is a sugar?

The term 'sugars' covers a range of mono- and di-saccharides. Table sugar (sucrose) is a disaccharide, made up of two monosaccharides: glucose and fructose. Other common sugars are lactose, found in milk, and galactose.

Free sugars are classified as all monosaccharides and disaccharides added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups and fruit juices.

Added sugars are sugars and syrups added to foods during processing or preparation.

Sugar sweetened beverages (SSBs) are drinks with any form of added sugar, such as soft drinks, cordials, sports drinks or energy drinks.

Sugars have become ubiquitous in the food supply, occurring naturally in many foods as well as being added by food manufacturers. While a healthy diet contains naturally occurring sugars from nutrient-dense foods such as fruit and vegetables, milk and milk products, and grains, added sugars are not necessary for health. However, in today's food environment eliminating added sugar entirely would greatly limit available food choices and could impact on palatability of the diet. It should be noted that some added sugar in the diet has been associated with a more well-balanced dietary pattern, provided energy needs are met.[2 3] Evidence suggests added sugar intakes below 5% and above 20% of energy could negatively impact on micronutrient intakes[3], especially if the diet is also low in energy[4]. A high intake of sugar does not have any advantages in terms of micronutrient intakes[5] however eliminating it entirely from the diet could also potentially compromise nutrient intakes.

New Zealand Context

New Zealanders' median intake of total sugars in the 2008/09 Adult National Nutrition Survey was 120g for males and 96g for females (Table 1). This is a small decrease on the 1997 National Nutrition Survey (131g for males and 99g for females).[6] Sucrose (table sugar) contributed a median of 55g for males and 42g for females. This equates to 10-13 teaspoons of table sugar. Fructose contributed 22g for males and 18g for females.[7] Median sugar intake was highest in the 19-30 year age group, followed by the 15-18 year age group.

There was little difference in median total sugar intake by ethnic group. Māori males consumed a median of 124g and females 103g. Pacific males consumed a median of 113g total sugars and females 98g. There was also little difference in sugar intake by deprivation quintile.

The intakes given above are medians; at the 90th percentile the total population intake of sugars was 175g per day.

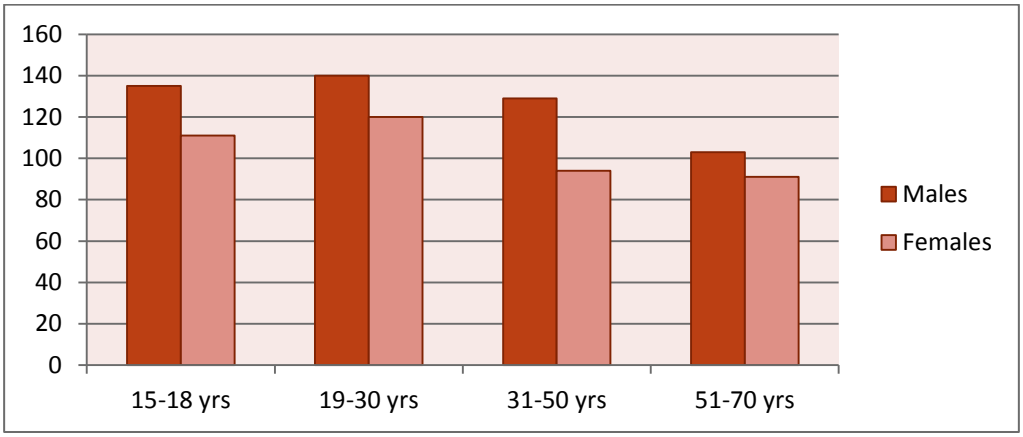


Table 1: Median intake of total sugars (g), by age group and sex

Total sugar was calculated as providing 19% to 24% of median energy intakes by age group and sex. Percentage energy from total sugar was highest for 15-30 year old females, and lowest for 31-70 year old men.

Sources of total sugar, sucrose and fructose

The main contributors to sugar intake in the Adult National Nutrition Survey are shown in Table 2.[6]

Total sugar	Sucrose	Fructose
Fruit (18%)	Sugar and sweets (23%)	Fruit (29%)
Non-alcoholic beverages (17%)	Non-alcoholic beverages (16%)	Non-alcoholic beverages (18%)
Sugar and sweets (15%)	Fruit (16%)	Vegetables (13%)
Milk (10%)	Cakes and muffins (7%)	Sugar and sweets (7%)
	Dairy products (6%)	Alcoholic beverages (5%)
	Biscuits (5%)	

Table 2: Sources of sugar

Soft drinks and energy drinks are included in the non-alcoholic beverages category. Intake of these was highest in the 15-18 and 19-30 year age group. For the total population, soft drinks and energy drinks were self-reported as being consumed three or more times each week by nearly a quarter of the adult population and consumed daily by 7%.[7] There were ethnic differences in soft drink intakes. Forty-two percent of Māori males and 29% of Māori females drank soft drinks or energy drinks three or more times each week.[8] Forty-five percent of Pacific males and 32% of Pacific females drank soft drinks or energy drinks three or more times a week.[9]

New Zealand Food and Nutrition Guidelines

New Zealand's Food & Nutrition Guidelines recommend that adults:[10]

- Prepare foods or choose pre-prepared foods, drinks and snacks … with little added sugar; limit your intake of high-sugar foods

And for children:[11]

- Prepare foods or choose pre-prepared foods, snacks and drinks that are … low in sugar, especially added sugar.*
- Drink plenty of water during the day. Include reduced or low-fat milk every day. Limit drinks such as fruit juice, cordial, fruit drink, fizzy drinks (including diet drinks), sports drinks and sports water [and energy drinks].

New Zealand's Nutrient Reference Values do not make any specific recommendations in relation to sugar. However, the acceptable macronutrient reference range to lower chronic disease risk recommends a carbohydrate intake of 45% to 65% total energy, predominantly from low energy density and/or low glycaemic index foods.[12]

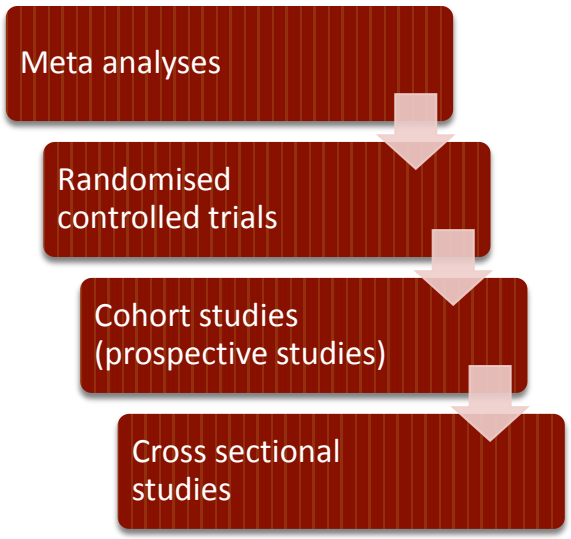
* The term 'added sugar' does not include sugar from fruit juice and concentrate, but it is included in the definition of 'free sugars'. Some products add fruit concentrates as a sweetener, claiming they are low in added sugar despite being high in free sugars.

Evidence Snapshot

Nature of evidence used

Due to the scale and conflicting nature of the research on sugars, much of the evidence in this paper has been drawn from reviews and meta-analyses (an umbrella review). It is important to note that there are strong methodological limitations with many of the individual studies included in these reviews.

Figure 1: Hierarchy of evidence



The bulk of research has been observational studies (cross-sectional and cohort studies), with some experimental or randomised controlled trial (RCT) evidence. Cross-sectional studies cannot establish causality or a temporal sequence because measures are taken at only one point in time. They are highly prone to confounding, recall bias, and reverse causation (eg. someone changes their diet because of weight gain or onset of disease, rather than the other way around). In nutrition studies, they also suffer from inherent limitations in dietary assessment methods.

Cohort studies can also suffer from issues of residual confounding, limitations in dietary assessment, often a lack of repeat measures over the course of the study, and are not entirely immune to reverse causation. The most robust evidence, and the only type of study that can show a causal relationship, are RCTs.

In general, many of the published studies on sugar or sugar-sweetened beverages (SSBs) have suffered from small sample sizes and short durations of follow up. There was also wide variation in how sugar and sugar-sweetened beverages were defined and measured.

Study results also varied according to funding source.[13] Industry funded intervention studies were four to eight times more likely to have favourable conclusions (and none had unfavourable conclusions)[14] or had significantly smaller associations than non-industry funded.[15] Allison (2009) notes that research in this area appears to have been extensively influenced by biases, whether through industry funding or authors, reviewers and editors own biases.[13]

As well as issues with the individual studies, the quality of the reviews on SSBs and health outcomes has been assessed.[16] Seventeen reviews (including four meta-analyses) were identified and assessed using the AMSTAR quality assessment tool. Overall, reviews scored poorly with a mean score of 4.4 out of 11. Only half of the reviews scored positively for considering scientific quality when conclusions were reported.

While this evidence snapshot is primarily interested in the effect of sugar *per se*, much of the evidence relates to sugar in the form of sugar-sweetened beverages (SSBs). SSBs are an easier aspect of sugar intake to study as they are an easily defined food type for measurement and allow effects to be more easily separated from other nutrients. However, it is also plausible they could have a different effect to sugar consumed as part of a food.

The remainder of this evidence snapshot considers firstly the key reports in relation to sugar and heart disease or risk factors for it, followed by evidence directly in relation to heart disease, and then individual risk factors. It finishes with a section on fructose, as this is topical at present.

Key reports

There have been a number of key reports which summarise the evidence on sugar and SSBs and make recommendations on intake.

The WHO/FAO Expert Consultation on diet, nutrition and prevention of chronic disease (2003) found probable evidence that SSBs and fruit juices increased risk of obesity and dental erosion.[17] They also found convincing evidence that obesity increases risk of cardiovascular disease, type 2 diabetes and some cancers. However, there was no direct evidence upon which to assess the impact of sugar on cardiovascular disease, type 2 diabetes, or cancer. Thus, at the time of the report, there was evidence of an effect on a risk factor for cardiovascular disease (obesity), but not directly on cardiovascular disease itself. The WHO/FAO recommendation was, and continues to be, that free sugars[†] are kept to <10% of energy intake (~50g/day). This recommendation was reiterated in a 2007 scientific update by FAO/WHO on carbohydrates and human nutrition.[18]

The WHO/FAO Expert Consultation's view was that free sugars provided energy but little nutritional value and restricting their intake would contribute to a reduced risk of weight gain. They referred to acute and short-term studies that showed increased energy intake when energy density of the diet was increased (whether from fat or sugar), and also the reverse – that limiting free sugars reduced total energy intake and induced weight loss.

The American Heart Association has recently revised their recommendations on sugar and heart disease, and for the first time have made a specific recommendation for American women and men to consume no more than 100-150 calories (420-630kJ or ~26-40g sugar) from added sugars in a day.[2] This is less than half the current intake of the average American.[19] The recommendation was based on what was viewed as an increasingly robust evidence base that added sugar, especially sugar-sweetened beverages (SSBs), increased risk of overweight, dyslipidaemia, and high blood pressure.[20] The recommendation was quantified as half of the US dietary guideline for discretionary calorie allowance (at that time).[20]

[†] Free sugars are classified as all monosaccharides and disaccharides added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups and fruit juices.

The European Food Safety Authority reports that a number of European Union States recommend less than 10% of total energy as added sugars, but others do not make a specific recommendation.[21] In their review of the evidence for labelling purposes, the EFSA concluded there is some evidence that SSBs might contribute to weight gain, and some evidence that high intakes (>20% total energy) of sugars may increase triglycerides and cholesterol and adversely impact on glucose and insulin response.[21] The literature review the EFSA report was based on was criticised for being selective and not considering study quality or using a hierarchy of evidence.

In the United States, the Institute of Medicine recommended <25% total energy as sugars, based on reduced micronutrient intake by some people at higher sugar intakes.[22] It is important to note the recommendation was not based on that level being acceptable to eat, but rather compromised micronutrient intakes over that level of intake.

The 2010 US Dietary Guidelines recommend significantly reducing intakes of foods containing added sugars, amongst other things, as they contain few nutrients and contribute excess calories.[23] The Dietary Guidelines Advisory Committee (DGAC) found limited evidence that intake of SSBs is linked to higher energy intakes in adults; a moderate body of epidemiological evidence suggesting SSBs are associated with increased body weight in adults; and a moderate body of evidence that iso-energetically sugar is no more likely to cause weight gain than other sources of energy. They also noted that dietary patterns low in energy density have low sugar contents, and that a low energy density diet improves weight loss and is linked to a lower risk of type 2 diabetes.[23 24]

Similarly, in relation to SSBs, the World Cancer Research Fund and American Institute for Cancer Research (2007) determined that sugary drinks have an independent effect on body weight by promoting excess energy intakes.[25] They judged that high-energy dense foods, in particular sugary drinks and fast foods are probably a cause of weight gain, overweight and obesity.

Sugar and cardiovascular disease

Sugar

Data on a direct link between added sugar and heart disease (rather than risk factors) is limited and therefore inconclusive. A review of carbohydrates by the German Nutrition Society found that due to the small number of studies, evidence of an association between mono- or disaccharides or SSBs and risk of heart diseases was insufficient.[‡]

[‡] A grading of 'insufficient' means a few study results indicate an association between a factor and a disease, but they are not sufficient to establish the relationship. This means the relation between the nutritional factor and the disease has not yet or has rarely been investigated, or the studies available are inconsistent with a majority of studies without risk relations and nearly equally as strong opposite results.

If we look at refined carbohydrates as a whole (which includes sugar), the evidence is more compelling. The FAO/WHO Expert Consultation on fats and fatty acids determined there is probable evidence that replacing saturated fat with largely refined carbohydrates has no benefit on coronary heart disease and may even increase the risk of coronary heart disease and favour development of metabolic syndrome.[26]

Sugar sweetened beverages

Recent epidemiological evidence suggests an association between SSBs and CVD. The Nurses' Health Study, a prospective study with 88,000 women over 24 years, found that after adjustment for unhealthy lifestyle factors, women who drank two or more SSBs a day had a 35% greater relative risk of coronary heart disease compared with infrequent consumers. Adjustment for other potential mediating factors such as BMI and energy intake reduced the risk down to 21%, but retained statistical significance.[27]

In the Health Professionals Study, men consuming 355mL of SSB per day had a 19% increased relative risk of cardiovascular disease, and statistically significant adverse changes in HDL, trigylcerides and C-reactive protein, after adjustment for multiple lifestyle factors.[28]

The Framingham Heart Study, a prospective cohort study, found drinking one or more SSBs per day (350ml) was associated with a range of risk factors for cardiovascular disease. This included a 44% increase in odds of developing metabolic syndrome (that is, metabolic syndrome developed in 18% of participants drinking less than one soft drink/day compared with 22% drinking more than one soft drink/day); 25% increase in odds of impaired fasting glucose; 31% greater odds of obesity; 32% greater odds of low HDL; 25% higher odds of hypertriglyceridaemia; and 18% greater odds of higher blood pressure.[29 30]

SUMMARY: CVD

- Due to lack of data, evidence for a direct association between sugar and heart disease is inconclusive. However, replacing saturated fat with refined carbohydrates has no benefit for heart health.
- Prospective studies suggest one to two serves of SSBs per day may be associated with increased risk of heart disease and risk factors for it.

Sugar and Lipids

The FAO/WHO scientific update on carbohydrates emphasises the importance of carbohydrate quality for cardiovascular health.[18 31] Specifically, it states that:

> *Failure to emphasize the need for carbohydrate to be derived principally from wholegrain cereals, fruits, vegetables and legumes may result in increased lipoprotein-mediated risk of cardiovascular disease, especially in overweight and obese individuals who are insulin resistant.*

Similarly, the FAO/WHO expert consultation on fats concluded there was probable evidence that replacing saturated fat with refined carbohydrates (including sugar) had no benefit on heart disease and could potentially increase risk.[32]

The American Heart Association advises that a diet with more than 20% of energy from sugars (glucose, fructose, sucrose) is linked with raised fasting triglycerides. The effects may be more marked in men, sedentary and overweight people, in metabolic syndrome, and in people eating low-fibre diets.[2]

While the American Heart Association review on sugars concluded that sugar intake is associated with raised triglyceride levels, they felt the effect on cholesterol was unclear.[2] The review by the German Nutrition Society also found insufficient evidence for an effect of increased intake of mono- or disaccharides on total, LDL or HDL cholesterol, due to inconsistent study results.[33] However they found sufficient evidence for the impact of fructose on plasma triglycerides, but not for other mono- or disaccharides (see fructose section of this snapshot).

On the other hand, the European Food Safety Authority found some evidence for sugars increasing both triglycerides and cholesterol at intakes greater than 20% of total energy.[21] This finding was based on seven small, short term studies and two longer term (six month) studies. However, many of the studies did not control for changes in body weight or diet (such as fat intake).

Addendum 2014: A systematic review and meta-analysis of RCTs by Te Morenga et al found that dietary sugars influence both blood pressure and lipids independent of their effect on body weight. High compared with low sugar intakes was associated with increased triglycerides, total and LDL cholesterol and a very small increase in HDL cholesterol.[34]

SUMMARY: LIPIDS

- A sugar intake over 20% of total energy is associated with raised triglycerides.
- There is evidence that high versus low sugar intakes are associated with increased triglycerides and lipids.

Sugar and blood pressure

Sugar

There is growing evidence on the potential impact of added sugars on blood pressure in humans, however results remain inconsistent,[2] and there are an insufficient number of RCTs to establish an effect.[35]

Addendum 2014: A systematic review and meta-analysis of RCTs by Te Morenga et al found that dietary sugars influence blood pressure independent of their effect on body weight. High compared with low sugar intakes was associated with increased blood pressure especially in studies of longer duration (over eight weeks). In these studies, those with high sugar intakes had 6.9mmHg higher systolic blood pressure and 5.6mmHg higher diastolic blood pressure.[34]

Sugar-sweetened beverages

The PREMIER study was a three-arm randomised trial in the US with 810 participants who were pre-hypertensive or hypertensive. It compared the impact of two behavioural interventions on blood pressure. A prospective analysis of the data found reducing intake of SSBs by one serving a day (355mL) was associated with 1.8mmHg reduction in systolic blood pressure and a 1.1mmHg reduction in diastolic blood pressure over an 18-month period.[36] The reduction in blood pressure was mediated by weight loss. Adjusting for weight loss more than halved this reduction, although it retained statistical significance.

In the Framingham Heart Study, consumption of more than one SSB per day was associated with 18% greater odds of experiencing higher blood pressure.[29 30]

A cross-sectional analysis of 2696 people from the UK and US in the INTERMAP study found SSB intake related directly to blood pressure. Each additional serving (355mL) of SSB per day was associated with 1.1mmHg higher SBP and 0.4mmHg higher DBP, after adjusting for weight and height.[37]

SUMMARY: BLOOD PRESSURE

- Added (free) sugar in liquid or solid form can influence blood pressure.

Sugar and body weight

There are five main ways it has been proposed that sugar contributes to weight gain:

- Energy density
- Lack of fibre
- High palatability, leading to excess consumption
- Possible unique effects of fructose
- Frequent consumption as a liquid rather than food, thus little satiating effect.[38]

It has also been proposed that SSBs could lead to lower thermogenesis and thereby create positive energy balance.[39]

The most recent and robust systematic review and meta-analyses on the impact of sugar on body weight was conducted by Te Morenga *et al* for the World Health Organization.[40] It looked at the effect of increasing or decreasing sugar intake (added sugar and SSBs) on body weight in adults and in children. It found that increasing intake of dietary sugars was associated with a 0.75kg weight increase in adults (95% CI 0.30 to 1.19; P=0.001). In sub-group analysis, a significantly greater weight increase was seen in the two studies that lasted longer than eight weeks (2.73kg, 95% CI 1.68 to 3.78).

Conversely, reducing intake of dietary sugar was associated with a 0.8kg reduction in weight in adults (95% CI -1.21 to -0.39; P<0.001). Excluding three studies (out of five) with a high risk of bias showed a similar weight reduction, but lost statistical significance. Only including studies which achieved a clinically significant difference in sugar intake between intervention and control groups increased the reduction in weight to 1.22kg.[40]

The effect on body weight from reducing dietary sugars was not evident in children, and this is likely due to poor compliance. Three out of the five studies did not manage to achieve clinically significant differences in intake of sugar between the intervention and control groups. However, in cohort studies, higher intakes of dietary sugar were associated with increased risk of being overweight (OR 1.55; 95% CI 1.32 to 1.82).[40]

In studies that exchanged carbohydrates or other macronutrients with dietary sugars of an equal calorie level and where energy intakes were strictly controlled, there was no effect on body weight.[40] Thus, the effect of dietary sugar on body weight appears to be due to increased consumption of energy rather than a specific effect of sugar. Excess energy intake from any source, without compensation by increased energy expenditure, will contribute to weight gain.[20] Portion size is also important in relation to energy intake, with portions sizes of SSBs and sugary foods now much larger than they once were.[41 42]

The effect of drinking SSBs on energy intake was investigated by Vartanian *et al* (2007), who conducted a meta-analysis of 88 studies.[15] Cross-sectional and prospective studies showed increased soft drink consumption was related to increased energy intake (effect size r= 0.16, P<0.001) (a small-medium effect size). That is, people did not appear to compensate for the energy consumed in SSBs by reducing energy intake elsewhere. The effect size was stronger in longitudinal studies (medium effect size r=0.24, P<0.001).

Short-term experimental studies (up to a day) showed mixed results as to whether people compensated for energy from SSBs. However, the four longer-term experimental studies of three to 10 weeks all found a failure to compensate for extra energy consumed from SSBs, leading to an increased energy intake.[15] This is supported in other research, which suggests that the effect of SSBs on body weight is due to a failure to compensate for the extra energy consumed, rather than because sugar is more obesogenic than other forms of energy.[43-45]

The review and meta-analyses by Te Morenga *et al* strengthens earlier advice by the WHO in relation to sugars and SSBs. WHO's advice was that solid foods high in free sugars are usually energy dense, and there was some evidence from intervention studies that reducing these foods could lead to weight loss.[18] In relation to SSBs, WHO classified it is as probable that there was an association between SSBs and body weight.[17]

The US 2010 Dietary Guidelines Advisory Committee graded the evidence as strong that greater intake of SSBs is associated with increased adiposity in children.[23] Similarly, the Australian Dietary Guidelines review found consumption of SSBs was associated with increased risk of weight gain in adults and children.[46] Despite what

they considered a poor evidence base, they also concluded that "a reduction in sugar consumption prevents increases in measures of body weight and/or body fat". Limitations were that studies were generally industry-funded, small, and short-term RCTS or intervention studies, and none measured long-term impact on body weight. It was also difficult to separate out changes in total energy consumption from changes in sugar consumption, and inconsistencies between studies were explained by varied energy intakes between groups.[46]

It should be noted that Te Morenga *et al* conducted sensitivity analyses on their data and despite potential bias in some studies and significant heterogeneity in one meta-analysis, the "sensitivity analyses showed that the trends were consistent and associations remained after these studies were excluded".

Taken together the evidence strongly suggests that sugar and SSBs can contribute to weight gain, and that reducing their intake reduces weight.[§]

SUMMARY: BODY WEIGHT

- When substituted iso-energetically, sugar does not appear to impact on body weight.
- However, dietary sugar appears to lead to overconsumption of energy, which is associated with increases in body weight.

Sugar and Metabolic Syndrome or Type 2 diabetes

Sugar-sweetened beverages

Epidemiological evidence suggests a positive association between consumption of SSBs and increased incidence of metabolic syndrome.[38] Malik et al (2010) analysed evidence from 11 prospective cohort studies on SSB consumption and risk of metabolic syndrome and type 2 diabetes. Consuming 1-2 servings of SSBs/day compared with none to 1 serving/month, was associated with a 20% greater risk of developing metabolic syndrome and a 26% greater risk of developing type 2

[§] There have been numerous reviews conducted on SSBs and body weight, mostly narrative reviews, with varied conclusions drawn from a similar evidence base. Differences in interpretation are often due to valid concerns about quality of the evidence. Conclusions on the impact of SSBs on body weight have ranged from no association in children,[47] inconclusive,[43 48] weak,[49] potential concern[50], possible[51 52] or probable,[51] through to supportive or clearly suggestive of an association,[39 44] sufficient,[53] strong,[54 55] consistent, or clear evidence[45 56]. Combining the individual studies identified in reviews by Taylor (2005), Malik (2006) and Vartanian (2007) showed 26 out of 42 studies had a statistically significant positive association between SSBs and weight gain, and no studies showed a negative association.[53] In prospective cohort studies, more consistent and positive results emerged from longer studies.[39] Few of the reviews explained or appeared to consider the limitations of individual studies in their findings.

diabetes. Looking at individual studies, longer and larger studies tended to show stronger associations.[57]

The German Nutrition Society review found probable evidence of an association between regular consumption of SSBs and increased risk of type 2 diabetes, based on prospective cohort studies and a meta-analysis.[33] It also found possible evidence of an association between SSBs and metabolic syndrome.

This effect may be through a variety of mechanisms, including weight gain from increased consumption of SSBs and their high glycaemic load.[57] Despite sugar having a moderate GI, when consumed in SSBs it has a high glycaemic load due to the amount of sugar in the volumes typically consumed. A study by Shulze et al suggested around half the effect of SSBs on type 2 diabetes was mediated through weight gain.[58]

Some, but not all, studies also suggest a high intake of SSBs or sugary foods is associated with acute inflammation and oxidative stress.[2] However, further long-term studies are required to confirm this.

Sugar

A review of 21 intervention, prospective and cross-sectional studies by Laville and Nazare (2009) found studies failed to demonstrate a relationship between total sugars and glycaemic control or risk of type 2 diabetes, and a lack of evidence on sucrose's effect on diabetes. They also found discrepancies between studies on the long-term effect of fructose on risk of type 2 diabetes.[59]

A review by Ruxton *et al* which only considered better quality studies on sugar and metabolic syndrome concluded that any negative effects of sugar on metabolic parameters were likely to be restricted to triglycerides and non-essential fatty acids, could be transitory, and were influenced by weight changes and lipids at baseline. Better quality studies in 'at risk' groups mostly reported no association between sugar and lipid abnormalities, and the few studies on insulin sensitivity reported no significant impact of sugar.[50] The studies Ruxton *et al* considered were mostly hypo-caloric interventions designed to achieve weight loss, which limits their relevance to the development of population level recommendations.

The German Nutrition Society review of carbohydrates and health found that due to varying results, evidence of an association between intake of mono- or disaccharides, or specifically glucose or fructose, and risk of type 2 diabetes was insufficient.[33] They also found it probable that there is no association between sucrose intake and type 2 diabetes, based on observational studies.

Aller et al notes divergent findings when looking at observational studies alone to when experimental studies are included.[35] It also possible there is a difference between glucose and fructose, as it has been proposed that fructose may be more detrimental in relation to development of insulin resistance.[35]

SUMMARY: TYPE 2 DIABETES

- There is a probable association between SSB intake and increased risk of type 2 diabetes
- Evidence does not suggest an effect of sugars on risk of metabolic syndrome and type 2 diabetes

Fructose

In recent years, there has been growing interest in the specific role of fructose in obesity and obesity-related diseases. This interest has arisen because fructose intakes in the US have increased over the same time period that obesity rates have increased. Fructose is naturally found in fruit and honey, and is one of the mono-saccharides in table sugar and in high fructose corn syrup (HFCS). HFCS added to food and beverages has been largely held responsible for the increase in fructose intakes in the US. In New Zealand, table sugar is used as the main sweetener added to manufactured foods.

Although its name implies it is high in fructose (either 43% or 55%), HFCS has a similar fructose content to sugar (50%), but unlike sucrose it is available as free fructose. However, even in sucrose-sweetened drinks, the level of free fructose increases over time due to hydrolysation.[60] Fructose is sweeter than sucrose, allowing less to be used in a product for an equivalent sweetness. It is metabolised in a different way to glucose, primarily in the liver, and does not require insulin to enter body cells, which means it can be more readily converted to fat.[21 61 62] It can also increase triglyceride and VLDL production in the liver.[61 62]

Fructose metabolism has been studied extensively in animal models, however, only human trials are considered here. Dose, form and study length all impact on results. That is, doses of fructose used in studies are often unrealistically high, in a form not usually consumed (eg. a bolus of fructose or as crystalline fructose), and acute effects differ from longer-term effects. Energy content of the usual diet is often not controlled, and effects may differ between males and females, or whether a person has diabetes.

Blood pressure

It is thought that fructose can increase serum uric acid levels, reduce endothelial nitric oxide, and thereby increase blood pressure.[45 63 64] A recent RCT in Spanish men found very high doses (200g) of fructose raised blood pressure and induced features of metabolic syndrome. Taking medication to lower uric acid levels prevented the increase in blood pressure.[65] However, a meta-analysis of 21 studies by Wang (2012) could not find evidence for an impact of fructose on serum uric acid when iso-energetically exchanged for other carbohydrates in controlled feeding trials at normal levels of intake. When very high doses of fructose were hyper-energetically supplemented (213-219g/day) they did increase serum uric acid compared with controls.[66] These levels of fructose intake are far higher than consumed in New Zealand. The latest New Zealand Adult National Nutrition Survey found the 90th percentile of fructose intake was 35g per day.[7]

Sievenpiper (2012) conducted a meta-analysis of 15 studies on the impact of fructose on blood pressure when iso-energetically exchanged for other carbohydrates. Included studies needed to last longer than seven days. When fructose replaced other carbohydrates there was a statistically significant decrease in diastolic (-1.54mmHg) and mean arterial pressure (-1.16mmHg), but no statistically significant effect on systolic blood pressure (-1.1mmHg).[67] Similarly, when Sievenpiper et al (2012) looked at the impact of fructose on body weight, no effect was seen in comparison to other carbohydrate sources. Not surprisingly, when fructose was added hyper-energetically at high doses (+104 to 250g/day) it did lead to a mean 0.53kg weight gain. However, the poor quality of studies, short duration, and methodological limitations limited robustness of conclusions.[68]

Fruit is also a common source of fructose, however, it should be noted that any potential adverse impacts of other forms of fructose should not be extrapolated to it. Johnson argues that fructose in fruit does not have negative effects due to the level of antioxidants and flavanols in fruit which block the hypertensive effect, and the uric acid lowering effect of ascorbate through increased renal excretion.[69]

Lipids

A systematic review by Dolan *et al* considered fructose intake by a normal healthy population at intakes up to the 95th percentile in the United States (136g/day).[70] Dolan found differing results between short and long-term studies. In short-term studies, ingestion of 30–100 g/day fructose (either in a liquid bolus or in a meal) slightly increased triglycerides in comparison to sucrose, glucose, or starch after approximately three hours. However, long-term studies did not show evidence of an increase in triglycerides after ingestion of up to 133-136 g/day fructose, provided excess energy was not consumed. Longer term studies tended to be of higher quality. They supported the conclusion that fructose does not cause biologically relevant changes in triglycerides (or body weight) when consumed at these levels, in comparison to other sugars. This has been supported in reviews by Rizkalla (2010)[71] and Tappy (2010)[72].

Other reviews and meta-analyses have come to similar conclusions, and suggest that in the long-term fructose intakes of less than 100g per day do not have any statistically significant effect on *fasting* triglyceride levels, with a dose-dependent increase over that level. For *postprandial* triglycerides, dose-dependent increases were seen at intakes over 50g fructose.[33 73 74] Schaefer (2009) found statistically significant increases in fasting triglycerides and LDL cholesterol with fructose intakes of 20-25% total energy or more.[75]

Diabetes

Sievenpiper (2009) assessed the impact on lipids in people with type 2 diabetes. Although 16 trials were included, this only represented 236 subjects. An iso-energetic switch to fructose from carbohydrate raised triglycerides and lowered total cholesterol, with no effect on LDL or HDL. However, results were only consistent when there was a dose-threshold of >60g day, follow up was for less than four weeks, crystalline fructose was used, or participants had switched to fructose from starch.[76]

Body weight

It has been proposed that there are two mechanisms through which fructose might elicit less satiety than other sugars or starches. It has a far lower GI than glucose (and it is proposed postprandial glycaemia may impact on mechanisms controlling satiety), and there is less suppression of ghrelin and less increase in leptin with fructose rather than glucose.[61 72] However, a review by Moran (2009) comparing the effect of preloads of glucose, sucrose and/or fructose on satiety found effects were related to factors other than the type of sugar. These other factors were timing of the preload in relation to the meal, whether it was in a pure state or mixed with other ingredients, and the volume given.[77] Overall, long-term studies have not supported an effect of fructose at intakes up to 100g/day on increased food intake or body weight, when consumed instead of glucose or sucrose.[70] Alongside this, Aller *et al* (2011) reported six studies that all show fructose increases energy expenditure compared to glucose and starch.[35]

SUMMARY: FRUCTOSE

- At fructose intakes typical in New Zealand, evidence does not suggest an adverse effect on lipids or body weight.

Form of sugar

The form in which sugar is consumed could impact on its biological effect. For example, sugar consumed in a beverage could have a different metabolic effect to sugar consumed as part of a food, or to naturally occurring sugars. It has been proposed that SSBs may have a particularly detrimental impact on body weight because sugar is consumed as a liquid rather than as a solid. This implies it is the form of sugar that is detrimental rather than the energy content, although this is not universally supported.[78] Certainly, there is evidence of weaker dietary compensation with energy in a beverage compared to solid form.[79-81] This means that when people consume sugar in a drink, they do not compensate for the increased energy intake by reducing intake at subsequent meals. A recent randomised four-arm crossover trial compared oral preloads of solids and liquids.[78] Liquids elicited greater levels of postprandial hunger and less fullness, more rapid gastric emptying, and attenuated hormone responses more than solids.

Conversely, Van Baak and Astrup reviewed the effect of sugar in solids versus liquids. They found a small number of acute RCTs related to satiety and compensation of energy intake. Results were equivocal and insufficient to draw conclusions. Thus, they did not find support for the hypothesis that liquid sugar is more detrimental for body weight than solid forms of sugar.[52] Similarly, in her review, Bachmann (2006) was not convinced by arguments either for or against a relationship between liquid foods and satiety, due to conflicting evidence.[48]

SUMMARY: SUGAR FORM

- Sugar may be more detrimental in fluid form (as a SSB) due to weaker energy compensation, but evidence is inconsistent.

Public health significance of sugar-sweetened beverages

While it is important to consider a whole dietary pattern, SSBs do have a number of features that create an opportunity for public health intervention:[82]

- They are an easily defined category
- They contribute excess energy to the diet
- There is more evidence for SSBs and excess weight than for many other foodstuffs
- They provide no nutritional benefit [other than helping meet fluid intakes]
- Reducing intakes could have a measurable impact on body weight without any negative dietary consequences.

Furthermore, in New Zealand they are consumed in higher quantities among Māori and Pacific peoples, who experience a greater rate of nutrition-related disease, making SSBs an appropriate target to improve health equity.

Conclusion

In summary, the evidence in relation to sugar and heart disease (or risk factors for it) is generally poor quality or limited, and often inconsistent. Evidence is stronger for the impact of sugar-sweetened beverages. Based on current evidence, there is no reason to avoid added sugar altogether. However, there is rationale for avoiding high intakes, especially in sugary drinks because:

- Studies suggest potential for an effect on risk factors for cardiovascular disease, if not on CVD itself. There is some evidence for an impact of SSBs on heart disease, blood pressure, and type 2 diabetes and stronger evidence for an impact on body weight. There is evidence for an impact of fructose on triglycerides at very high intakes.
- Reducing saturated fat intakes remains a priority for heart health, but if it is replaced with refined carbohydrates (including sugar) there is no benefit for heart health.
- Reducing energy intake supports body weight management,[83] and added sugars have no particular nutritional value other than adding energy.

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