Effects of sugar intake on body weight: a review

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Summary

Weight reduction programmes are mainly focused on reducing intake of fat and sugar. In this review we have evaluated whether the replacement of dietary (added) sugar by low-energy sweeteners or complex carbohydrates contributes to weight reduction. In two experimental studies, no short-term differences in weight loss were observed after use of aspartame as compared to sugar in obese subjects following a controlled energy-restricted diet. However, consumption of aspartame was associated with improved weight maintenance after a year. In two short-term studies in which energy intake was not restricted, substitution of sucrose by artificial sweeteners, investigated mostly in beverages, resulted in lower energy intake and lower body weight. Similarly, two short-term studies, comparing the effect of sucrose and starch on weight loss in obese subjects did not find differences when the total energy intake was equal and reduced. An *ad libitum* diet with complex carbohydrates resulted in lower energy intake compared to high-sugar diets. In two out of three studies, this was reflected in lower body weight in subjects consuming the complex carbohydrate diet. In conclusion, a limited number of relatively short-term studies suggest that replacing (added) sugar by low-energy sweeteners or by complex carbohydrates in an *ad libitum* diet might result in lower energy intake and reduced body weight. In the long term, this might be beneficial for weight maintenance. However, the number of studies is small and overall conclusions, in particular for the long term, cannot be drawn.

Keywords: Body weight, carbohydrates, sugar.

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Introduction

The prevalence of obesity is increasing around the world and it is a significant public health problem in many countries (1). An accurate energy balance (energy intake equals energy expenditure) is essential to maintain a stable body weight. In weight reduction programmes, dietary recommendations have been mainly focused on reducing intake of fat and sugar. In this review, we will not discuss fat, but carbohydrate intake. It is not quite clear whether the replacement of (added) sugar (meaning all simple carbohydrates [SCHOs]) by low-energy sweeteners or by complex carbohydrates (CCHOs), introduced as a tool to lower energy intake, truly contributes to weight reduction.

Replacing sugar by low-energy sweeteners may affect subjects' energy balance. Theoretically, energy intake will be lowered, while sweetness remains. However, the energy content of carbohydrates, fat and proteins, may have an impact on appetite and satiety as well (2). Therefore, consumption of products with sweeteners may lead to the adaptation of eating habits that compensate for the reduced energy intake. So, it may be possible that in the end the energy intake does not change when low-energy sweeteners are used.

In this review, published data from Medline (National Library of Medicine, Bethesda, MD), dated from 1980 onwards, on the role of sugars, CCHOs and sweeteners in human body-weight maintenance are evaluated [search words: simple or complex carbohydrate, sugar or sucrose, body weight, BMI (body mass index), sweeteners, obesity, energy intake and starch]. Only articles written in English were included, with a limitation up to 35 publications.

Studies were categorized into investigations reporting effects of dietary sugar relative to low-energy sweeteners, CCHOs and fat, on body weight. The regulation of food intake with respect to appetite, satiety and energy intake as well as adaptation of eating habits is briefly discussed.

Sugar vs. low-energy sweeteners

Few studies, which are summarized in Table 1, have investigated the effects of sugar replacement by sweeteners on body weight. Kanders *et al.* studied 59 obese men and women following an energy-restricted diet (4.2 MJ d^{-1} for women and 5 MJ d^{-1} for men) during a 12-week weight loss programme with 1-year follow-up (3,4). Subjects were either required to use aspartame-sweetened products or prohibited from using aspartame-sweetened products. Women who used aspartame-sweetened products lost more weight than non-users (7.5 kg vs. 5.8 kg), although differences were not statistically significant. The weight loss seen in the experimental group, after the active weight loss phase, compared to the control group might indicate that compliance of reduced energy intake was facilitated for subjects allowed to use low-energy sweetened products.

In a later study by the same group of investigators with obese women only, 163 subjects received an energy-restricted diet (4.2 MJ d^{-1}) during a 19-week weight loss programme (5). The women were again assigned to either consume or abstain from aspartame-containing products. After 19 weeks, the aspartame intake increased in the aspartame group and decreased in the non-aspartame group. Energy intake did not differ between the aspartame and non-aspartame groups. In both groups, women lost about 10% (9.9 kg) of body weight in the active weight loss phase, which was not different between the groups. In women who used the aspartame-sweetened products, intake of aspartame was positively correlated with loss of body weight during active weight loss. After 1-year weight maintenance, women who used aspartame-sweetened foods and beverages besides the 6.2 MJ weight maintenance diet regained significantly less weight (2.6 kg) than the non-aspartame users (5.4 kg) ($P < 0.05$). After the 2-year follow-up, the aspartame users still had a mean weight loss of 5.1 kg, whereas the non-aspartame users had regained all their weight lost. Both studies suggest that, although no short-term effects of aspartame consumption on body weight could be demonstrated, this high-intensity sweetener may be useful to maintain a reduced body weight during a weight control programme in the long term (3–5). Compliance to a weight maintenance programme seems to be facilitated with the use of low-energy sweeteners.

Because of the growing intake of soft drinks in our diet and the accompanying rise in obesity especially seen in children (6), the question arises whether there is a causal relationship. Recently, this discussion got a lot of attention and in the USA, can machines were even removed from school buildings. The evidence comes from different studies. In a 10-week supplementation study, subjects (on average 35 years) were supplemented with sucrose [3.4 MJ; 152 g sucrose per day = 28 energy percent (en%)] or artificial sweeteners (1.1 MJ; 0 g sucrose per day; aspartame, acesulfame K, cyclamate and saccharine), mostly as beverages in a further *ad libitum* diet (7). After 10 weeks, a decrease in body weight was seen in those consuming the artificially sweetened supplements (1 kg), in contrast to the increase in those supplemented with sucrose (1.6 kg) ($P < 0.001$). The main explanation for this difference in body weight was found to be the difference in energy intake coming from experimental fluids. DiMeglio and Mattes have already reported that compensation of energy intake is less accurate with energy intake from liquids vs. solid foods (8). Carbohydrate intake from liquids therefore promotes a positive energy balance, whereas carbohydrate intake from solid foods will be compensated for (8).

In a cross-over study, Tordoff and Alleva compared 3 weeks consumption of 1150 g soda sweetened with aspartame (3 kcal = 12.6 kJ) per day with 1150 g high-fructose corn syrup (530 kcal = 2.2 MJ) per day, and with no soda (control) in 30 men and women with a healthy body weight (9). After 3 weeks consumption of high-fructose corn syrup, body weight was significantly increased as compared to consumption of aspartame-sweetened soda and no soda. In both groups consuming experimental drinks, energy intake from the diet was lowered as compared to control [7.5 MJ for diet with the aspartame-sweetened soda; 7.3 MJ for diet with the high-fructose corn syrup (excluding 2.2 MJ from the soda); 8.5 MJ per day for the control diet]. When energy content of the high-fructose corn syrup was included, energy intake in this group was higher than that in the group using the aspartame-sweetened soda and the control group. The only difference in energy intake between the diets with the experimental drinks was the amount of energy from the high-fructose corn syrup (2.2 MJ), which may explain the difference in body weight between these groups. In both treatment groups, sugar intake from the diet was reduced as compared to the control group, probably because commonly used energy-containing drinks were replaced by experimental drinks (9). From this short-term study, it may be concluded that reducing total sugar intake by replacing consumption of large volumes of high-fructose-containing soda by aspartame-sweetened drinks may be favourable for body-weight control. This would only be favourable when there is no compensation for the reduced energy intake from other food products.

In a long-term observational study (19 months), Ludwig and colleagues reported a positive relation between intake of sugar-sweetened drinks and prevalence of childhood obesity (6). The beverage intake (of 57% of the participating

Table 1 Experimental studies investigating effects of sugar relative to sweeteners in relation to body weight

Reference	Subjects	Period	Design	Experimental groups	Products	Results (Body weight)
Kanders *et al.* 1988 (3)	59 obese subjects (13 ♂ and 46 ♀)	12 weeks	Parallel	I: Energy-restricted diet: 4.2 MJ for ♀ and 5 MJ for ♂ + aspartame-containing products II: Energy-restricted diet: 4.2 MJ for ♀ and 5 MJ for ♂ + no aspartame-containing products Both combined with an exercise programme	I: Milk products, drinks, sweeteners	I: ↓ 7.4 kg (7.5%) ♀ and 10.4 kg (9.5%) ♂ II: ↓ 5.8 kg (5.8%) ♀ and 12.2 kg (11.7%) ♂ No difference between the groups
Blackburn *et al.* 1997 (5)	163 obese women	19 weeks; 1-year weight maintenance; 2-year follow-up	Parallel	I: Energy-restricted diet (4.2 MJ) + aspartame-containing products II: Energy-restricted diet (4.2 MJ) + no aspartame-containing products Both combined with an exercise programme	I: Milk products, drinks, sweeteners II: Sugar, honey	I: ↓ 9.9 kg ($P < 0.0001$) II: ↓ 9.8 kg ($P < 0.0001$) No difference between the groups; better weight maintenance for the aspartame group ($P < 0.05$), regain 2.6 kg vs. 5.4 kg
Raben *et al.* 2002 (7)	41 obese subjects (6 ♂ and 35 ♀)	10 weeks	Parallel	I: *Ad libitum* diet with artificial sweeteners-containing products (1.1 MJ) II: *Ad libitum* diet with sucrose-containing products (3.4 MJ)	I + II: Drinks and solid foods (yoghurt, marmalade, ice cream, stewed fruits)	I: ↓ 1 kg II: ↑ 1.6 kg Significant difference between the groups ($P < 0.001$)
Tordoff & Alleva 1990 (9)	30 healthy-weight subjects (21 ♂ and 9 ♀)	3 × 3 weeks	Cross-over	I: 1150 g aspartame-sweetened soda (12.6 kJ) II: 1150 g high-fructose corn syrup (2.2 MJ) III: No aspartame-sweetened soda (control)	I: Soda II: Syrup	I: ↓ 0.11 kg ♀ 0.35 kg ♂ II: ↑ 0.61 kg ♀ 0.64 kg ♂ III: ↓ 0.36 kg ♀ 0.12 kg ♂ Significant difference between groups ($P < 0.01$)

children) as well as BMI had increased during the 19-month observation period. Although the study was observational in nature and causality is not proven, the results are consistent with the above-mentioned mechanism that consumption of sugar-sweetened drinks could lead to obesity because of imprecise and incomplete compensation for energy consumed in liquid form (6). Overweight individuals, who want to prevent weight gain, may want to choose beverages containing low-energy sweeteners rather than sucrose (7).

Few epidemiological studies have investigated the relationship between use of sweeteners and BMI. In a Spanish cross-sectional study with 2450 men and women, intake of cyclamate, an artificial sweetener, was negatively correlated with BMI (10). Previous prospective studies with women showed a positive association between use of artificial sweeteners (saccharine and/or cyclamate) and BMI at start of the study (11,12). After 1-year follow-up, weight gain was higher in the group of users than in the group of non-users. From these studies, it may be concluded that long-term usage of sweeteners (1 year) does not result in reduction of body weight. However, the latter study was designed to study cancer incidence and not obesity. Body weight was not measured but recalled, which was not checked at all, although body weight is known to be affected, especially for cancer. But the fact that affected the data the most is that women who changed their eating habits, including use of sweeteners, were excluded from the analysis. This could be the reason for the lack of weight loss. Moreover, the authors had already mentioned that sweetener use might have prevented weight gain (12). In another prospective cohort study, a positive association was found between use of saccharine and body-weight changes both at the start of the study and after 4-year follow-up (13). However, these epidemiological studies are based on observations, therefore, no causal relations can be made. It might be possible that subjects who are concerned about their weight were already using low-energy sweeteners to prevent weight gain.

Thus, results of experimental and epidemiological studies on the relationship between use of sweeteners and BMI are not univocal. At present, use of low-energy sweeteners does not seem to result in weight loss *per se*, but might be useful for weight maintenance in healthy-weight subjects.

Sugar vs. complex carbohydrates

Several intervention studies investigating the effects of dietary sugar relative to CCHOs on body weight are described (Table 2).

Energy-restricted diets

In a recent study by West and de Looy, 68 obese subjects (34 men and 34 women) received a low-fat (33 en%), energy-restricted low-sucrose diet (5 en% sucrose) or an energy-restricted sucrose-containing diet (10 en% sucrose) (14). The deficit in energy of 2.51 MJ d^{-1} resulted in a reported energy intake of 5.6 ± 1.5 MJ for the low-sucrose diet and 5.9 ± 1.6 MJ d^{-1} for the sucrose-containing diet (14). Diets only differed in source of carbohydrates (sucrose vs. starch). After a period of 8 weeks, body weight had declined in both groups: 3.0 kg in the group with a sugar-containing diet and 2.2 kg in the group with a low-sugar diet, which was significantly different from baseline but not significantly different between both groups (14). Based on the low reported intakes and the known energy deficit, it was calculated that the groups should have lost about 6.9 kg in 8 weeks. This means that most probably under-reporting took place, and that the subjects did not fully comply with the reduced energy diet. In another study by Surwit *et al.*, 42 obese women followed an energy-restricted low-fat diet (11 en% fat, 19 en% protein and 71 en% carbohydrates) of 4.6 MJ d^{-1}. Within the diet, two variations of carbohydrate were made: one diet with 43 en% sucrose (sugar-containing diet) and another with 4 en% sucrose (low-sugar diet) (15). As before, the diets differed only in the source of carbohydrates (sugar vs. starch). After 6 weeks, body weight decreased by 7.0 kg for the sugar-containing diet and by 7.4 kg for the low-sugar diet, which was not significantly different between both groups as well. Both studies illustrate that weight loss is a consequence of the energy deficit, regardless of the type of macronutrient, let alone within the type of macronutrient (SCHO vs. CCHO).

Ad libitum diets

The CARMEN study, a European multicentre study, investigated differences between an *ad libitum* low-fat high-SCHO diet and a low-fat high-CCHO diet vs. a control diet in relation to body weight in 316 obese adults (16). After 6 months, body weight was lowered by 1.7 kg in the SCHO group and by 2.6 kg in the CCHO group as compared to the control group. Differences in body-weight changes between the treatment groups did not reach significance, despite the significantly higher energy intake in the SCHO group (10.4 MJ d^{-1}) as compared to the CCHO group (9.3 MJ d^{-1}). Compared to the control group, the changes in body weight between the treatment groups were significantly different.

As a part of the CARMEN study, Poppitt and co-workers investigated the same design and diet as well in another subgroup of 39 overweight subjects (12 men and 27 women) with symptoms of the metabolic syndrome (17). Six-month *ad libitum* diet intervention resulted in decreases in body weight in both the SCHO group (−1.3 kg) and the CCHO group (−5.3 kg) as compared to the control group. In this low-fat diet with a difference in carbohydrate

Table 2 Experimental studies investigating effects of sugar relative to complex carbohydrates in relation to body weight

Reference	Subjects	Period	Design	Experimental groups	Products	Results (Body weight)
West & de Looy 2001 (14)	68 obese subjects (34 ♂ and 34 ♀)	8 weeks	Parallel	I: Energy deficit of 2.51 MJ – sugar-containing (10 en% sucrose) diet II: Energy deficit of 2.51 MJ – low-sugar (5 en% sucrose) diet	I: Sweet foods	I: ↓ 3.0 kg II: ↓ 2.2 kg No difference between the groups (not significant)
Surwit *et al.* 1997 (15)	42 obese women	6 weeks	Parallel	I: Energy restricted (4.6 MJ), low-fat, sugar-containing (43 en% sucrose) diet II: Energy restricted (4.6 MJ), low-fat, low-sugar (4 en% sucrose) diet		I: ↓ 7.0 kg II: ↓ 7.4 kg No difference between the groups (not significant)
Saris *et al.* 2000 (16)	316 obese subjects (155 ♂ and 161 ♀)	6 months	Parallel	I: *Ad libitum* low-fat, high-sugar diet (10.4 MJ) II: *Ad libitum* low-fat, high-complex carbohydrates (9.3 MJ) III: *Ad libitum* normal diet (10.3 MJ)	I + II: About 65% of the food products were provided in a laboratory shop	I: ↓ 0.9 kg II: ↓ 1.8 kg III: ↑ 0.8 kg No difference between groups I and II; significant difference between groups I and III ($P < 0.05$), II and III ($P < 0.001$)
Poppitt *et al.* 2002 (17)	39 overweight subjects with symptoms of the metabolic syndrome (12 ♂ and 27 ♀)	6 months	Parallel	I: *Ad libitum* low-fat, high-sugar diet (10.4 MJ) II: *Ad libitum* low-fat, high-complex carbohydrates (9.3 MJ) III: *Ad libitum* normal diet	I + II: About 60% of the food products were provided in a laboratory shop	I: ↓ 0.3 kg II: ↓ 4.3 kg III: ↑ 1 kg Significant difference between groups I and II ($P < 0.01$), II and III ($P < 0.01$)
Raben *et al.* 1997 (18)	40 women with healthy body weight	14 days	Cross-over	I: *Ad libitum* high-starch diet (9.1 MJ) II: *Ad libitum* high-sucrose diet (10.3 MJ) III: *Ad libitum* high-fat diet (10.2 MJ)	I + II + III: Food products were provided	I: ↓ 0.7 kg II: ↑ 0.2 kg III: ↓ 0.3 kg Significant difference between groups I and II ($P < 0.05$)

source, but not limited in energy intake, weight gain was prevented in overweight subjects with characteristics of the metabolic syndrome. Most of the weight loss was found when fat was replaced by CCHOs. As was seen in the CARMEN trial, both studies showed that a diet high in CCHO is favourable for weight loss.

In a cross-over trial of a group of 40 women with a healthy body weight, body weight decreased by 0.7 kg after 14 d of a high-starch diet with an *ad libitum* energy intake (18). This weight loss differed significantly from the stable body weight after a high-sucrose diet (increase of 0.2 kg) ($P < 0.05$). The difference may result from a higher energy intake in the high-sucrose group (on average 10.3 MJ d^{-1}) as compared to the high-starch group (9.1 MJ d^{-1}). This spontaneous reduction in energy intake of a diet rich in starch and dietary fibre is consistent with other studies, in which the type of diet is suggested to facilitate compliance to lower energy intake.

Glycaemic index

The variation in SCHO and CCHO present in a diet or meal, with respect to type of carbohydrate as well as amount, will affect the blood glucose response caused by the time necessary for digestion and absorption. Glycaemic index (GI) is defined as the incremental area under the blood glucose response curve after consumption of carbohydrates. In general, high-GI foods have a high-SCHO content and are rapidly digested. Products have a higher GI when they have (1) a higher refined carbohydrate content, (2) a high glucose and/or starch content relative to lactose, sucrose and fructose, or (3) a low soluble fibre content, and (4) when their texture is soft, overcooked, highly processed or over-ripened (19). The GI of a carbohydrate-rich diet not only affects glucose, insulin and lipid response of food (20), but also affects appetite, energy intake and body weight. Consumption of low-GI food increases satiety and reduces hunger as compared to products with high GI (19). Summarizing data from six cross-over studies suggested that consumption of high-GI carbohydrates promotes a short-time increase in energy intake as compared to lower-GI carbohydrates (21). However, others have found a lower energy intake and a higher weight loss after a carbohydrate-rich diet with high GI for 2 weeks, as compared to a low-GI diet (22). Recently, the pros and cons of GI on appetite, food intake, energy expenditure and body weight was thoroughly reviewed by Raben (23). Numerous studies showed conflicting results for the items mentioned, and therefore Raben concluded that at present there was no evidence to state that low-GI foods were superior to high-GI foods with regard to long-term weight maintenance (23). So, although a low-GI diet is generally recommended, no definite conclusions on the effects of the GI on appetite and body-weight maintenance can be drawn.

Based on the studies described above, it was concluded that when energy intake was restricted, the source of carbohydrate does not seem to be important for body weight. Results of *ad libitum* energy intake studies revealed that, for both obese subjects and subjects with a healthy body weight, there were differences in weight loss for high-SCHO vs. high-CCHO diets. The decreased body weights in both SCHO- and CCHO-rich diets as compared to the control group may be explained by differences in energy intake, which are easier kept reduced in a high-CCHO diet.

Sugar vs. fat

To examine the effect of exchange of sugar vs. fat on body weight, a limited number of studies were reviewed (Table 3).

In a parallel intervention trial by Gatenby *et al.*, 49 healthy-weight women received instructions for a low-sugar diet, a low-fat diet or a control diet during 10 weeks (24). Subjects in the low-sugar and low-fat groups were instructed to reduce intake of sugar or fat by replacing full-sugar or full-fat items with low-sugar and low-fat products, respectively. At the start of the study, energy intake did not differ between the groups. After 10 weeks, the energy intake was lowered in all groups as compared to baseline (−1.37 MJ, −1.22 MJ and −1.15 MJ, for the low-sugar, low-fat and control groups, respectively, not significantly different between groups). A decrease which appeared to be a reflection of repeated record keeping was seen. In the reduced-fat group, the reported fat intake decreased from 37 to 33 en% ($P = 0.017$). A reduction of reported sucrose intake (but not total carbohydrate intake) was seen in the reduced-sugar group (a reduction of about 2.5 en%). None of the three groups showed changes in body weight because of these differences in macronutrient composition (24).

Raben *et al.* also found no differences in changes of body weight after 14 d on a high-sucrose diet or a high-fat diet in their cross-over study of 20 healthy-weight women using an *ad libitum* food intake (18). The energy intake was 10.2 MJ d^{-1} in the high-fat diet and 10.3 MJ d^{-1} in the high-sucrose diet, which did not differ significantly.

In a multicentre trial, the effect of consumption of full-fat or reduced-fat products was investigated in 241 healthy-weight subjects, known as the MSFAT study (25). In an open, randomized controlled trial, subjects consumed food products containing either a full-fat or a reduced-fat composition for 6 months. About 30–40% of the total daily energy intake was covered by the products provided. A significant increase in body weight of 1.1 kg was seen in the group consuming a full-fat diet, compared with a relatively stable weight in the reduced-fat group (+0.4 kg) ($P = 0.023$). The investigators concluded that a switch from full-fat to reduced-fat in an *ad libitum* diet could prevent body-weight gain. The reduced-fat products will help in a

Table 3 Experimental studies investigating effects of sugar relative to fat in relation to body weight

Reference	Subjects	Period	Design	Experimental groups	Products	Results (Body weight)
Gatenby *et al.* 1997 (24)	49 healthy-weight women	10 weeks	Parallel	I: Low-sugar diet (−1.37 MJ) II: Low-fat diet (−1.22 MJ) III: Control diet (−1.15 MJ)	I: List with low-sugar products II: List with reduced-fat products	No difference between the groups ($P = 0.563$)
Raben *et al.* 1997 (18)	40 healthy-weight women	14 days	Cross-over	I: *Ad libitum* high-starch diet (9.1 MJ) II: *Ad libitum* high-sucrose diet (10.3 MJ) III: *Ad libitum* high-fat diet (10.2 MJ)	I + II + III: Food products were provided	I: $\downarrow$ 0.7 kg II: $\uparrow$ 0.2 kg III: $\downarrow$ 0.3 kg Significant difference between groups I and II ($P < 0.05$); no difference between groups II and III (not significant)
Weststrate *et al.* 1998 (25)	220 healthy-weight subjects (111 ♂ and 109 ♀)	6 months	Parallel	I: *Ad libitum* reduced-fat diet II: *Ad libitum* full-fat diet	I + II: Food products were provided in a laboratory shop (covered 30–40% of the daily intake)	I: $\uparrow$ 0.4 kg II: $\uparrow$ 1.1 kg Significant increase in body weight in group II ($P = 0.023$)

population strategy aimed at preventing overweight and obesity (25).

Several observational studies found an inverse relationship between energy intake from fat and from sugar, but not between fat and starch intake (26). Thus, sugar intake may reduce intake of fat simultaneously and subsequently reduce the energy intake, because of the lower-energy density. On the contrary, a reduction of sugar intake may result in an increased fat intake. Furthermore, dietary sugar may increase acceptance of a low-fat diet, which may increase long-term compliance. In a recent study, compliance in a high-carbohydrate low-fat diet may be increased by sugar intake, which is preferable in reducing body weight (27).

In the studies described, energy intake and body weight did not differ between a low-fat and low-sugar diet (24,25), or a high-fat and high-sucrose diet (18). The macronutrient composition (fat or carbohydrates) does not affect body weight, but the total amount of the fat and carbohydrates eaten (amount of energy intake) does affect body weight.

Epidemiological studies indicate a possible inverse relationship between intake of total and extrinsic or added sugar and BMI in adults (28). In these studies, high-fat, high-sugar food products (snacks) were investigated. The negative relationship between sugar intake and BMI was observed in different studies (28–30). No negative association was found between the intake of intrinsic sugar or lactose and BMI, suggesting that the extrinsic sugar source may specifically play a role in body-weight maintenance. Besides the absolute sugar intake, the ratio between intake of fat and sugar may be important in body-weight regulation (28–31). Subjects with a higher dietary fat to extrinsic sugar ratio had a higher BMI (28). The indication that high-sugar intake is negatively correlated with BMI, especially in men as was found in two studies (29,30), is interesting for further study.

Control of food intake

Appetite, satiety and energy intake

Food intake is regulated for an important part by two processes: satiation and satiety. Satiation is related to meal termination after inhibition of hunger and appetite within meals, while satiety refers to inhibition of feelings of hunger and appetite following food consumption in the postprandial phase. Both short-term and long-term studies have investigated effects of sugar on satiation, satiety and energy intake.

Pre-load studies, which are often used to investigate short-term effects of sugar on feelings of hunger, satiety and energy intake on additional food intake, showed contradictory results. Several studies found that sweeteners (e.g. aspartame alone or combined with acesulfame-K, sucralose) as compared to sucrose did not have any effect on