

Dietary intake of fruit and vegetables and management of body weight

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Dietary intake of fruit and vegetables and management of body weight

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1. Introduction

In 2002, there were more than 1 billion overweight people worldwide and over 300 million of these were obese (1). This problem is not limited to developed countries as evidenced by some of the following prevalence rates of obesity (taken from 1). A survey carried out during 1991-1994 in the urban region of Cairo, Egypt, (in a general population over 20 years of age) found that 56.0% of men and 45% of women were obese (body mass index (BMI) ≥ 30). In Saudi Arabia, 26.4% of men and 44.0% of women in a nationally representative survey of adults over 30 years of age (in 1995–2000) were found to be obese; equivalent to 35.6% of the population. In a survey conducted from 1998 to 2000, Kuwait was found to have a slightly lower prevalence of obesity; 21.5% in men and 22.8% in women. A study from India reported that 25.4% of men and 35.8% of women, over 20 years of age, were overweight (BMI ≥ 25) in 2000. In a report from Japan, 26.8% of men and 21.3% of women were overweight (BMI ≥ 25). The highest percentage of obesity was found in the population in Japan aged between 60 and 69 years, with 30.7% for men and 31.0% for women from a nationally representative survey of adults carried out in 2000. In 1999 in Mongolia, the prevalence of overweight people (BMI ≥ 25) for the population over 20 years of age was 52.0%; 44.0% for men and 57.0% for women. China has some of the lowest reported prevalence rates of obesity (BMI ≥ 27) with 1.7 - 2.9% for men and 4.3% for women in the population aged 20 to 45 years. Thailand is reported to have a prevalence of a BMI ≥ 25 in 18.8% of men and 28.6% of women aged 13 to 59 years. A study from Italy, carried out in 1998, reported 18.0% of men and 22.0% of women (aged 35–74 years) to be obese in a nationally-representative sample. South Africa was found to have very different prevalence rates by sex; 9.3% of men and 30.1% of women (more than 15 years of

age) were reported obese in a survey carried out in 1998. In Ghana, the prevalence of overweight women ($BMI \geq 25$) aged 15–49 was found to be 16.1%, reaching 21.7% in the group aged 35–39 years old. In a study conducted in Germany in 1998, 20.3% of the population, aged 18–79 years, were reported to be obese.

Given this global prevalence of persons who are overweight and obese, effective dietary strategies are needed for both losing weight and maintaining a healthy body weight. Most strategies emphasize the macronutrient composition of the diet, and many researchers have investigated the effects of macronutrient content on satiety (the effects of a food or a meal after eating has ended), food intake, and body weight. Given the research focus on macronutrients, this review examines the influence of particular food groups on intake and body weight, and evaluates whether laboratory and clinical interventions, as well as epidemiologic investigations, have shown that consumption of fruit and vegetables affects satiety, food intake, and body weight.

Because many studies mention fruit and vegetable consumption, five criteria were established for including them in this review:

- they must be studies in adults or children that can be regarded as either interventions or epidemiological investigations related to fruit and vegetables and weight management;
- they must not report on an intervention limited to an exclusively vegetarian diet;
- they must provide specific data on intake of fruit or vegetables;
- they must report the effects of the intervention on satiety, energy intake, body weight, or BMI;
- they must be published in a peer-reviewed journal.

There was no limitation of the types of participants in the studies, as all studies of free-living persons of both sexes were included. Animal studies were not included as none were identified which met the criteria. Only papers reported in English were considered. Peer-reviewed journal articles published between January 1966 and July 2003 which included an investigation of fruit and vegetable intake and body weight in adults and children and that

reported a test for significance are included. Articles were identified by searching MEDLINE, PubMed and Web of Science using the following keywords: energy balance, treatment of obesity, weight control, weight loss, weight reduction, energy density, satiety, fruit and vegetable consumption, orosensory factors, water incorporated into food, volume of food, glycaemic (glycemic) index, energy balance, vegetarian diets, dietary fibre (fibre), hunger, time-calorie displacement, metabolizable energy, caloric ratio, weight and BMI. Additional articles were collected by examining the reference lists in the original research articles. Although every effort was made to be comprehensive, studies may have been overlooked because the relevant measures were secondary outcomes that would not be identified in a literature search.

Firstly, the review considers in manner in which fruit and vegetables affect regulation of energy intake, and secondly, intervention and epidemiologic studies that have tested the effects of these foods on intake regulation and body weight. Although little research has addressed directly the effects of fruits and vegetables on these variables, a number of studies have done so indirectly.

2. How fruit and vegetables could affect energy regulation

Before reviewing the interventions related to the effects of fruit and vegetables on food intake, satiety, and body weight, the basic research on the components of these foods which could affect these variables is summarized.

2.1 Energy density

Energy density is defined as the energy content in a given weight of a food (kcal/g or kJ/g). Water is the component of food that has the biggest impact on energy density, as it adds weight to food without increasing calories, and therefore decreases energy density (2). Fibre also reduces energy density, but its influence is small compared to that of water, because most foods have more water than fibre. Conversely, fat, the most energy-dense

nutrient (9 kcal/g versus 4 kcal/g for carbohydrate and protein), increases energy density. Most fruits and vegetables are low in energy density because of their high water and low fat content. Addition of fruit and vegetables to the diet reduces overall energy density, increasing the amount of food that can be consumed for a given level of calories.

Reducing the energy density of foods affects satiety. To study satiety, a fixed amount of a defined food (a preload) is consumed and then, over an interval of time after the preload, hunger and fullness are rated and food intake is measured. Research has shown that increasing the water content of a preload, thereby decreasing its energy density, while keeping the macronutrient and energy content constant, increased satiety and decreased energy intake at a subsequent meal (3, 4). Thus, fruit and vegetables could enhance satiety through their high water content and low energy density (5-7).

The energy density of foods also affects satiation, or the processes involved in the termination of a meal. Satiation is studied by measuring intake when foods are freely available. Several studies have shown that lowering the energy density of the available foods enhanced satiation (5-9). Participants in these studies tended to eat a similar weight of food over a day, so that when energy density was decreased, energy intake was reduced simultaneously. Adding fruit and vegetables to the diet can reduce its overall energy density and allow consumption of satisfying portions while reducing calorie intake; this strategy could play an important role in weight management.

2.2 Fibre content

Plants contribute both soluble and insoluble fibres to the diet. Solubility describes the extent to which the fibre dissolves in water to form a gel. Insoluble fibres (lignin, cellulose, hemicellulose), which are found in plant cell walls and in high concentrations in plant skins, are contained in many fruits and vegetables, as are soluble fibres (pectin, gums, mucilages). Many studies have been conducted on the effects of dietary fibre on satiety, energy intake, and body weight, and this literature has recently been evaluated in several comprehensive reviews (10, 11). Although some inconsistencies between studies have been

reported, many have shown that increasing consumption of both soluble and insoluble fibre increases satiety, reduces hunger, and decreases energy intake. For example, in their analysis of combined data from published studies, Howarth et al. (10) found that consuming an additional 14 g/day of fibre for more than two days was associated with a 10% decrease in energy intake and a loss of 1.9 kg over 3.8 months. Thus, the increase in fibre intake associated with increased consumption of fruit and vegetables could help reduce energy intake and body weight.

2.3 Glycaemic response

The type and amount of carbohydrates in fruits and vegetables may affect satiety and food intake (12). As carbohydrates are digested they are converted to glucose; the rate of this conversion process can be measured by assessing plasma glucose concentrations over time (the glycaemic response). The glycaemic response during the two hours following consumption of an amount of a food containing 50 g carbohydrate is used to compare foods and for creating an “index” for them. A food with a high glycaemic index (GI) causes a rapid but short-lived rise in blood glucose concentration, while a food with a low GI causes a slower, more sustained rise. Foods with a low GI have been proposed to be more satiating than those with a high GI, but a robust relationship between GI and satiety, food intake, and body weight has not been found (13,14).

The GI of fruit and vegetables varies widely; it is relatively high for potatoes, carrots and bananas and low for apples and beans. If the GI is related to satiety, systematic differences would be expected between various fruits and vegetables and satiety, but no consistent relationship has been shown. Indeed, in one study comparing satiety following consumption of a variety of foods, boiled potatoes, which have a high GI and thus might be predicted to have low satiety value, were found to be the most satiating food tested, and this effect was related to their low energy density (15). The glycaemic response to consumption of fruits and vegetables will be considered further in this review where data are available.

In summary, basic research on satiety and satiation suggests that increased consumption of fruit and vegetables could help to reduce energy intake, promote satiety, and aid weight management. These effects could be due to the high water and fibre content and low energy density of these foods. In the next sections, studies that directly test the effects of fruits and vegetables on satiety, satiation, and body weight will be reviewed.

3. Effects of fruits and vegetables on satiety

Studies retrieved from the literature search and which tested the effects of fruit or vegetables on satiety are summarized in Table 1. The most direct test is to have participants ingest the food as a preload and then rate their hunger and satiety using a validated assessment scale. Ideally, subsequent energy intake should also be measured to determine whether ratings are related to food intake, but this outcome has rarely been measured in studies of fruit and vegetables.

3.1 Vegetables

Gustafsson et al. conducted a series of experiments to assess the influence of vegetables on satiety (16-19). The authors found that none of the vegetables affected ratings of satiety compared with the control lunch, and they speculated that the amounts of vegetables added were too small to have an effect. In further studies, larger amounts of either cut or minced spinach (150 and 250 g, containing 4.3 and 7.2 g fibre) were added to meals with equal calories, and it was found that satiety increased with spinach content and ratings of satiety were correlated positively with the dietary fibre content, the water content, and the total weight of the meal (18).

In another study, greater effects on satiety were seen as more carrots (100, 200, and 300 g with 2.9, 5.8, and 8.7 g fibre, respectively) were added to isocaloric meals (17). The investigators also compared how raw and cooked carrots affected satiety, using different crops. With the first crop, but not with the second, the raw carrots enhanced satiety more

than cooked carrots. The results were, however, confounded by the fact that the water content of the raw and cooked vegetables differed in one crop but not in the other. Thus, differences in satiety may have been related to the energy density rather than to cooking.

These studies suggest that adding spinach or carrots, and perhaps some other vegetables, to a meal can enhance satiety. Significant effects were not seen when the amounts added were less than 200 g. This could indicate that smaller amounts are ineffective, but it may also reflect the small numbers of subjects (10 per experiment) and therefore a lack of statistical power to detect differences. The effects on satiety could have related to the fibre or water content of the vegetables or to the reduction in energy density, but the studies do not provide sufficient information to assess the relative importance of these factors.

Other studies have shown that the addition of fibre of vegetable origin to meals can enhance satiety. For example, the addition of either bean flakes (20) or pea fibre (21) enhanced ratings of satiety, thus supporting a role for the fibre content of vegetables in the enhancement of satiety. Because the glycaemic response was not consistently related to satiety, no conclusions can be drawn about its role in mediating the effects of fruit and vegetables.

3.2 Fruit

Few studies have been conducted on the effects of fruit on satiety. In one, 38 foods were given as preloads (each as 240 kcal) and the effects on satiety ratings and food intake were compared (15). The properties of the foods found to be related to satiety were the serving weight, which varied because of differences in energy density, and the protein, fibre, and water content. Fruits were the most satiating of the foods tested.

Several studies have considered how the physical form of fruit affects ratings of hunger and satiety after consumption (Table 1). In one study, comparisons were made of test meals of different forms of apples, each containing 60 g of sugar. Whole apples (2.9% fibre) were associated with higher satiety ratings than was fibre-disrupted apple purée,

which was more satiating than fibre-free apple juice. The authors attributed the differential satiety to the fibre content of the foods and to effects on glucose homeostasis (22). The finding that whole fruit provides more satiety than juice was confirmed in a study comparing whole oranges (2.5% fibre) to orange juice (fibre-free) and whole grapes (1.3% fibre) to grape juice (fibre-free) (23). Increased ratings of satiety were associated with the higher fibre content of the whole fruit, but plasma insulin and glucose concentrations were not related to satiety. In summary, the few studies available indicate that fruit can enhance satiety, especially when consumed whole.

3.3 Form of the food

While it seems likely that the higher fibre content of whole fruit compared to that of juice partly explains its greater effects on satiety, other possibilities should be considered. For example, beverages may affect the regulation of energy intake differently from solid foods. Hunger and thirst are controlled by separate mechanisms; it has not been established whether fruit juice affects hunger or thirst mechanisms or both and whether the fibre content will influence such responses.

Although fibre-free juice has been found to have low satiety value, some foods are more satiating with higher amounts of liquids (such as soups) than in solid form. One study found that cooking 10 ounces of water with a casserole of vegetables, rice, and chicken to make a soup led to enhanced satiety, and a significant reduction in energy intake at lunch afterwards (4). In two other studies, investigators found that incorporating water into a vegetable-rich meal was more satiating than drinking water with the meal (25, 26). These findings show that the water content of foods affects satiety, and reinforce the suggestion that the high water content of fruits and vegetables could enhance satiety.

In summary, studies directly testing the effects of fruit and vegetables on satiety confirm findings from more basic research, i.e., that the high fibre and water content and low energy density of these foods may promote satiety as measured by ratings of hunger and fullness. The plasma glucose response was not consistently related to ratings of satiety.

4. Effects of fruits and vegetables on satiation

Satiation is assessed by measuring the amount eaten when food is freely available. A reduction in energy intake may indicate that a food is highly satiating. It has been argued that foods low in energy density, such as vegetables, affect satiation and reduce energy intake because their palatability is low compared to foods high in energy density (29). While it is difficult to match the palatability of foods that vary widely in energy density, such as chocolate and broccoli, substantial reductions in the energy density of dishes or meals can be achieved without a loss of palatability, as shown by the studies reviewed below. In the few studies that have been conducted on satiation, a reduction in energy density by adding fruits and vegetables to the diet was associated with a spontaneous decrease in energy intake when palatability was controlled (Table 2).

In a study by Bell et al., women were provided with all of their meals in the laboratory over two days (8). During lunch, dinner, and for an evening snack, they were served a main entrée to be consumed ad lib that was varied in energy density (0.8, 1.1, and 1.3 kcal/g) but not in macronutrient content. The entrées were mixed dishes such as pasta salads and casseroles. The energy density of the dishes was reduced by adding a variety of fresh and frozen vegetables; for example, an additional 29 to 48 g/100 g was added to the higher energy density dishes to make the lower energy density versions. Even with this large increase in the proportion of vegetables, participants rated the three dishes as equally palatable, and they consumed a similar amount of food by weight across the three levels of energy density. Thus, daily energy intake was reduced from 1800 kcal/day in the highest-energy-density condition to 1376 kcal/day in the lowest-energy-density condition. There were no differences across conditions in ratings of hunger or fullness before or after meals, or over the two days (8).

In the study by Bell and colleagues, the proportion of fat in the experimental diets was low (16%) (8). Bell and Rolls conducted another study to test the effect of two levels of energy density (1.25 and 1.75 kcal/g) at three levels of fat (25, 35 and 45%) (30). The results showed that energy density influenced energy intake across all fat levels. The

participants ate similar amounts of food on the different test days which meant that in the low-energy-density conditions they had an average 20% reduction in daily energy intake (approximately 500 kcal) (30).

In the foregoing studies the variations in energy density were covert, which raises the question of whether, when people know they are eating a food that is reduced in energy density, they will compensate for differences in energy intake. This hypothesis was tested by Kral et al. (31) with foods at breakfast, lunch, and dinner that were similar to those in the study by Bell and Rolls (30), at three levels of energy density (1.25, 1.5 and 1.75 kcal/g) and one level of fat (25%). Participants were randomized to two groups; one group was informed of the energy density of the foods, and the other was not. Providing information about energy density did not affect intake; participants in both groups had similar patterns of food intake across the three levels of energy density. Energy density significantly affected daily energy intake such that participants in both groups combined consumed 22% less in the low-energy-density conditions that incorporated extra vegetables and fruits (31).

In a study designed to determine whether people will compensate for the reduced energy intake from the modified foods when they can choose whatever else they want to eat, the habitual daily energy intakes of lean and obese women were determined (32). Over 4-day periods the participants were served entrées they were required to consume that represented 50% of their usual energy intake at breakfast, lunch, and dinner. In one of these periods, extra fruits and vegetables were incorporated into the compulsory foods to reduce the energy density. Additional foods could be consumed ad lib during and between meals. Over the four days, cumulative energy intake was reduced by a total of 742 kcal in the low- compared with the high-energy density condition for both lean and obese women. Ratings of hunger were similar on the two diets. Thus, when only a portion of the diet was modified, reductions in energy density, by the incorporation of fruit and vegetables, still had a significant effect on energy intake.

The first study to emphasize how fruit and vegetables could affect energy density and food intake was conducted in 1983 (33). As in most of the studies reviewed in the next

section, the energy density of the experimental diets was reduced by both increasing the proportion of fruit and vegetables and lowering the fat content. In this initial study, participants stayed in a clinical research unit and were provided with two different diets for five days, with a washout period between the diets (33). The low-energy-density diet (0.7 kcal/g) contained minimal fat and a large amount of fresh fruit, vegetables, whole grains, and dried beans. The high-energy-density diet (1.5 kcal/g) contained more fat and fewer fruits and vegetables. The diets also varied in fibre content (7 g/1000 kcal vs. 1 g/1000 kcal). Despite these differences in composition, participants rated the diets as equally acceptable. Because they consumed a consistent amount of food per day, they ate twice as many calories on the high-energy-density diet as they did on the low-energy-density diet (3000 vs. 1570 kcal/ day). When on the low-energy-density diet, both obese and lean subjects ate their meals more slowly and were less likely to eat until unpleasantly full than when they were on the diet higher in energy density. The authors suggested that the prolonged eating time associated with low-energy-density foods, such as fruit and vegetables, is at least part of the explanation for their influence on satiety. Because the decreased fat intake and the increased fruit and vegetable intake were not tested independently, it is not clear how much of the reduction in energy intake was attributable to each. Other studies, however, have demonstrated that adding fruit and vegetables to the diet while maintaining the fat content is associated with a decrease in energy intake (8, 30, 31). This reduction in intake is likely to be related to the reduced energy density of the diets.

In summary, studies in which the energy density of the diet was reduced by adding fruit and vegetables showed that participants consumed a consistent amount of food per day. Because the energy density was lower there was a spontaneous reduction in daily energy intake. This reduction in intake was not associated with increased hunger even when the manipulation lasted up to five days. In all of these studies of satiation, a variety of fruit and vegetables were added; no studies have examined differences between specific types of fruits and vegetables. Water, fibre and macronutrient content, and method of

preparation might all affect satiation, but as yet there are no systematic studies on the effects of these variables.

5. Effects of fruit and vegetables on body weight

The studies reviewed above have been short-term controlled trials in which participants were fed test foods or diets that varied in their amount of fruit and vegetables. A critical question is whether the effects of fruit and vegetables on satiety and satiation persist over a longer period of time, leading to decreased body weight. This section reviews longer-term interventions in which the researchers provided all the foods consumed by the subjects, and randomized controlled trials in which subjects were advised to increase fruit and vegetable consumption. These trials were aimed at reducing risk factors associated with chronic disease and did not include weight loss as a goal. Finally, the few trials that have specifically tested advice to increase consumption of fruits and vegetables as a strategy for weight loss are evaluated.

5.1 Provision of a diet high in fruit and vegetables

In one longer-term trial, Shintani et al. examined the effects of providing a traditional native Hawaiian diet, rich in fruit and vegetables, on food intake and body weight in overweight Hawaiians (Table 3) (34). The traditional diet, which could be consumed ad lib, was considerably lower in energy density (0.8 kcal/g) and in fat (7% of energy) than the subjects' habitual diet (1.5 kcal/g and 32% of energy from fat). Over the 3-week test period, subjects reduced their daily energy intake (from 2594 to 1569 kcal) and lost a significant amount of weight (mean, 7.8 kg). Despite the reduction in energy intake, the subjects reported the diet to be moderately to highly satiating. One explanation for this finding is that subjects were allowed to eat unlimited amounts of the native fruits and vegetables and thus were able to consume enough food to avoid feeling deprived. Of particular interest was the fact that the average weight of food consumed was similar on the traditional and habitual diets (1872 vs. 1711 g/day), confirming the findings of short-term

studies of satiation where energy density was varied (8, 30, 33). Thus, it is likely that the decrease in daily energy intake was related to the low energy density of the traditional diet. Shintani et al. have since conducted a similar trial in which they increased the energy contribution from fat to 12% (35). The obese men and women in this study also reduced their ad lib energy intake and lost weight (mean, 4.9 kg) over the 3-week period.

In summary, these two studies demonstrate that when people are provided a low-energy-density diet to consume ad lib, they spontaneously reduce their energy intake and lose weight. Because the energy density of the diets was reduced both by increasing fruit and vegetable content and by decreasing fat content, it is not possible to determine the separate effects of these changes on weight loss. However, the increased intake of fruits and vegetables may have aided in hunger control, because participants could be satisfied with an amount of food similar to that which they normally ate, while consuming 40% less energy. Intervention trials to examine whether unsupervised persons, who are not being provided with food, respond to advice to increase fruit and vegetable intake and whether such advice can affect body weight are reviewed below.

5.2 Interventions to increase fruit and vegetable intake

The intervention trials reviewed in this section (Table 4) include those advising an increased intake of fruit and vegetables as part of a comprehensive dietary plan to decrease risk for chronic diseases, such as coronary heart disease and cancer. Many of these studies also included advice to reduce dietary fat, but none of the trials reviewed in this section included weight loss as an objective. The following trials were included because they report the outcomes of fruit and vegetable consumption as well as body weight or BMI. Many similar studies have focused solely on advice to increase fruit and vegetable consumption, but few reported body weight or BMI at the end of the intervention.

5.2.1 Studies advising only an increase in fruit and vegetable intake

Several small studies indicate that advice to increase fruit and vegetable intake, without a reduction in fat intake or an emphasis on weight loss, was associated with no change in body weight. In the largest of these studies conducted by Smith-Warner and colleagues, the only dietary advice given to subjects was to increase their intake of fruit and vegetables; the subjects exceeded their goal and consumed more than 10 servings of fruit and vegetables per day (36). Because the proportion of fat in the diet decreased from 33.6% to 30.6% but overall energy intake did not change, there may have been some displacement of higher-fat foods. The findings showed that body weight did not change after one year on the diet. Similar results were observed in other shorter-term studies that advised an increase in fruit and vegetables without fat reduction (37, 38). Subjects increased their consumption of fruit and vegetables and spontaneously decreased the proportion of fat in their diet, yet their weight did not change. In one of these studies, however, subjects did increase their energy intake, which may have been due to the significant increase in juice consumption (37). In the Smith-Warner study, a significant increase in juice intake was also seen and this increase partially offset the decrease in energy associated with the reduced fat intake (36).

In summary, these few studies that advised subjects to increase consumption of fruit, vegetables, and juices, but did not give advice on weight loss found that they maintained body weight. This suggests that it is important to give advice on the form of the food, as well as on increasing intake of fruit and vegetables, in order for people to maintain their weight. It is known from short-term studies that fruit juice does not have the same effect on satiety as whole fruit; consumption of juice could add excess energy to daily intake while contributing relatively little to satiety (22, 23). Fruit and vegetables higher in energy density, such as dried fruit and dried potatoes, could also have much less influence on satiety than lower-energy-density fruit and vegetables, while adding appreciably to daily energy intake.

5.2.2 Studies advising an increase in fruit and vegetable intake and a decrease in fat intake

The following intervention trials included advice not only to increase fruit and vegetable consumption, but also, in at least one study arm, to reduce fat intake (Table 5). A study by Djuric et al. suggests that dietary interventions unaccompanied by specific advice on weight loss may have variable, even unanticipated, effects on body weight (39). This one-year trial tested dietary strategies to improve breast health. All women were counselled to maintain energy intake and body weight. A group of women advised both to increase fruit and vegetable intake and decrease fat intake maintained their weight; a second group that was instructed only to decrease fat intake lost an average of 2.3 kg. An unexpected finding was that subjects in a third group, who were advised only to increase fruit and vegetable consumption, gained an average of 2.7 kg. It appears that the fruit and vegetables added extra calories rather than displacing some high-fat foods as was found in the studies reviewed previously (36-38). Interpretation of these results is limited, because little information is given about the types of fruit and vegetables consumed. However, participants could count fruit juice, fried potatoes, dried fruit and tomato sauces toward their intake goals. These choices would be unlikely to have the same positive effects on satiety, total dietary fibre, and energy density as would lower-energy-density choices, such as whole fruits and vegetables without added fat or sugar.

Another such large-scale intervention was the Women's Healthy Eating and Living Study (40). Subjects were counselled to consume a daily diet that included specific amounts of fruit, vegetable, and juice, as well as fibre, and had 15 to 20 % of energy from fat. After one year, the subjects in the intervention group had made significant changes in the composition of their diet; but their overall energy intake did not change. As a result, the intervention and control groups did not differ significantly in BMI. Since weight loss did not differ between the two groups, data from both were combined to analyze the relationship between dietary changes and weight loss. In all subjects combined, 11% lost weight, 74% maintained weight, and 15% gained weight. Multivariate analysis of the diets of the subjects who lost weight showed that increases in energy-adjusted intake of vegetables and dietary fibre, but not fruit, were associated with a decrease in BMI. A

decrease in percentage energy from fat was not, however, associated with a decrease in BMI. This study is one of the few that reported the effects of fruit and vegetables on weight loss independent of other dietary factors.

Combining fat reduction with increased fruit and vegetable consumption was also the dietary strategy used in the Polyp Prevention Trial (41). This 4-year multicentre trial advocated a diet low in fat and high in fruit and vegetables to decrease the recurrence of adenomas of the colon. Subjects significantly decreased their intake of fat and increased their intake of fruit and vegetables within the first year, and they lost a significant, but modest amount of weight (mean, 2.0 kg). At the end of the trial, although subjects had sustained the dietary changes, some of the weight had been regained. It is notable that even without a weight loss component, the subset of subjects who had increased their intake of fruit and vegetables and decreased their intake of fat remained below their baseline weight after four years.

In several trials by Singh and colleagues, the primary focus was for cardiac patients to incorporate a large amount of fruit and vegetables into a standard fat-reduced diet (42-44). In the first study, the intervention group was advised to add at least 400 g of these foods per day to their prescribed American Heart Association (AHA) fat-reduced diet. The participants exceeded the advised amount, consuming an average of 575 g of fruits and vegetables per day, and they lost a significant amount of weight (mean, 6.3 kg) after one year. The control group, who followed the AHA fat-reduced diet without added fruits and vegetables, gradually increased their intake of fat and calories over the course of the year and lost significantly less weight (mean, 2.4 kg). The results suggest that adding the extra fruits and vegetables to the diet may have increased satiety and contributed to the sustainability of the diet in the long-term. A limitation of the trial is that the control group received less individual counselling than the intervention group, which may have affected the amount of weight loss.

In a shorter-term study (43), subjects followed a similar diet, but in addition, were instructed to consume the fruits and vegetables before major meals when they were hungry. After 12 weeks, mean body weights did not differ significantly from baseline, and there

were no significant differences between the groups in terms of weight change. While significant weight loss was not seen, short-term studies suggest that consuming low-energy-density foods before meals can increase satiety, and the merits of this approach for weight management should be tested further (4, 25, 26).

In the largest and most recent trial by Singh et al., 499 men and women added over 350 g of fruits and vegetables per day to their reduced fat diet (Indo-Mediterranean diet), and lost 4 kg at the end of two years (44). The 501 men and women in the control group, who consumed the reduced-fat diet without added fruits and vegetables, lost only 1 kg after two years. In this study, many participants were already consuming a diet rich in fruits and vegetables, yet increasing intake of these foods even further resulted in a reduction in energy intake and subsequently, a reduction in body weight.

In summary, trials which combined advice to increase fruit and vegetable intake and decrease dietary fat but did not prescribe weight loss, found that most participants maintained their body weight or spontaneously lost weight. The reason for the variability in outcomes between studies is not clear from the information provided—perhaps unreported psychological variables such as dietary restraint and concern with body weight had an influence. Alternatively, there may have been differences between the studies in terms of the dietary advice given or in the composition of the diet that was achieved, but there are insufficient data to relate these differences to changes in body weight. For example, descriptions of the foods that were counted as fruit and vegetable servings (e.g., dried fruit, juices, fried potatoes) are missing from many of the studies reviewed or vary greatly between studies. This variability makes it difficult to compare studies or to determine how choices of fruit and vegetables could affect the energy density of the diet. Also, most of the interventions combined increases in fruit and vegetables with fat reduction, which reduces the energy density of the diet, yet none of the studies provided information on the actual energy density of the diets that were consumed. Similar trials are needed that encourage increased intake of fruit and vegetables and provide more detailed information on food choices and how those choices affect energy density.

In the Multiple Risk Factor Intervention Trial (MRFIT), men at risk for heart disease were advised to lose weight to help improve blood lipids and blood pressure. This randomized controlled trial was similar to studies in the previous section in emphasizing fat reduction (to less than 35% of energy from fat) and increased intake of fruit and vegetables (to 5 or more servings) per day. In addition, an increased consumption of grains was recommended (48). A major difference was that instruction on weight loss and weight maintenance was a component of the intervention. During six years of follow-up, 40% of the subjects in the intervention group lost 2.3 kg or more, 42% remained weight stable (within 2.3 kg of baseline weight), and 18% gained weight. An increase in fruit and vegetable intake was related to sustained weight loss and subjects who lost more weight also had a greater intake of fruit and vegetables (Table 5).

A recent study, the PREMIER clinical trial, also advised subjects to lose weight to improve blood pressure (50). Participants in the control group received one individual counselling session and educational materials. Participants in two other groups received behavioural interventions with different dietary goals aimed at achieving a weight loss of 6.8 kg by the end of six months. Subjects in the first intervention group were advised to decrease dietary fat to less than 30% of energy, but were given no goals for intake of fruit, vegetables, or dairy products. Subjects in the second intervention group were advised to follow the diet used in the DASH (Dietary Approaches to Stop Hypertension) trial, which emphasizes an increased intake of fruit and vegetables (to 9-12 servings per day) and of low-fat dairy products (to 2-3 servings per day), as well as a reduction in dietary fat (to \leq 25% of energy) (51). After six months, subjects in the second intervention group lost a mean of 5.8 kg, while subjects in the first intervention group lost 4.9 kg, but this difference did not reach statistical significance ($p = 0.07$).

Investigators at the University of Alabama at Birmingham, USA, demonstrated long-term weight maintenance in a clinical setting when they paired advice to increase fruit and vegetable consumption with advice to restrict total energy intake (52). These researchers tested the efficacy of a low-fat, low-energy-density diet in unsupervised, obese patients for six months. The diet was restricted to 1000 kcal per day, and dieticians

encouraged unlimited consumption of fruit, vegetables and whole grains. This approach was chosen to increase satiety while maintaining a low calorie intake, and to improve sustainability of the diet and long-term compliance. The amount of weight lost at the end of the trial was commensurate with the energy-restricted diet. After the intervention, 44% of the subjects continued to lose weight, and 92% remained below their baseline weight during the average 17-month (range 3–42 months) follow-up period. Although there was no control group for comparison, this pattern of post-treatment weight maintenance is better than that seen in other studies of weight loss (53-55).

An appealing aspect of advice to increase fruit and vegetable intake for weight management is that the emphasis is on a positive message related to increased consumption of particular foods rather than on restriction. The value of such an approach was seen in an intervention that promoted an increase in fruit and vegetable consumption in non-obese children and their obese parents. Epstein et al. randomized families to one of two groups in which the parents participated in an energy-restricted behavioural weight management programme (56). In one group, the parents were encouraged to increase fruit and vegetable intake, and in the other they were advised to decrease intake of high-fat/high-sugar foods. Materials for the children advocated the same dietary changes as for their parents but without energy restriction. Over the year of the study, parents in the increased fruit and vegetable group lost significantly more weight (mean, 7.5 kg) than parents in the decreased high-fat/high-sugar group (mean, 2.5 kg). Each intervention significantly affected the targeted intakes; in addition, both parents and children in the group with the fruit and vegetable emphasis spontaneously decreased their intake of high-fat/high-sugar foods. This finding is similar to that of several other studies in adults where increased fruit and vegetable intake was associated with a spontaneous reduction in fat intake (36-38).

In summary, these intervention trials show that advice to increase consumption of fruit and vegetables is a beneficial component of a weight management programme. All the studies showed that increased consumption of fruit and vegetables and reduced fat intake was associated with weight loss and maintenance of weight loss.

6. Epidemiological Studies

The relation of fruit and vegetable intake to weight change was not the primary focus of most of the epidemiological studies reviewed in this section; most included only a report on the bivariate relation of fruit and vegetable intake and BMI. Data from children and adults are presented separately.

6.1 Children

Only two studies of children were identified in the literature search, both of which examined the relation between fruit and vegetable intake and body weight as the primary objective in large populations (greater than 3000) (Table 6). The Growing Up Today Study (GUTS) was a prospective cohort study in which dietary assessment was done with a food frequency questionnaire (FFQ) for youths and adolescents, and anthropometric measures were collected by self-report by Field et al (58). No association was found during the 3-year follow-up between changes in age- and sex-specific z-scores of BMI and total fruit and vegetable intake, fruit intake (without juice), and fruit juice intake, in either boys or girls (58). Among boys, but not girls, vegetable intake (with and without the inclusion of French fries or chips) was inversely related to changes in BMI z-score. However, this association was no longer statistically significant after adjustment for total energy intake. These analyses were controlled for age, age-squared, Tanner stage of development, activity, inactivity, age- and sex-specific z-score of baseline BMI and height change during study follow-up.

The other study was a cross-sectional analysis by Lin and Morrison who used data from the Continuing Survey of Food Intakes by Individuals (CSFII) of two non-consecutive 24-h dietary recalls and self-report of height and weight (59). They reported that overweight boys ate fewer total vegetables (including white potatoes, $p < 0.01$), less fruit (including fruit juice, $p < 0.01$) and fewer white potatoes ($p < 0.01$) than did their normal-weight and counterparts at risk of overweight (at risk of overweight denotes those having a

BMI between the 85th and 95th percentiles of the US Centers for Disease Control and Prevention paediatric growth charts). The overweight and at-risk of overweight girls ate less fruit (including fruit juice, $p < 0.05$) although no significant difference in vegetable (without potatoes) or white potato consumption was found. These analyses were controlled for age, sex, and race/ethnicity.

Excessive fruit-juice and fruit-drink intake has been raised as a particular concern among children. Six studies have examined the association between fruit-juice and fruit-drink intake and weight in children, but the results are inconsistent (79-84). Therefore the relationship of juice intake and weight status in children remains unclear and warrants further research.

6.2 Adults

One prospective cohort and 15 cross-sectional studies in adults were identified in the literature search (Table 2) (59-74). Only one study examined the relationship between fruit and vegetable intake and body weight as a primary objective (59). Two studies examined the relationship of fruit and vegetable intake to several outcomes, including body weight (60, 61). The main goal of the other studies was to examine the relationship between fruit and vegetable intake and disease, such as cardiovascular disease, diabetes, or cancer, or a particular health behaviour (62-74). Because these analyses were designed to address different outcomes, the authors reported only the bivariate association of fruit and vegetable intake with an anthropometric outcome.

All the studies had fairly large sample sizes (range, 405–79 236). Nine studies included both men and women (59-63, 65, 68, 69, 73). Three included only middle-aged men (66, 67, 72) and three included only middle-aged women (64, 70, 71). One study adjusted for both demographic and lifestyle confounders (65); six adjusted for at least demographic factors (59-62, 68, 74) and nine reported only bivariate associations and therefore did not adjust for any potential confounders (63, 64, 66, 67, 69-73). With the exception of one study which followed a cohort of subjects (61), all analyses were cross-sectional. However, many of the cross-sectional analyses were conducted using data

collected at only one time point from a cohort participating in a larger study (63, 64, 66, 67, 70, 72-74). With the exception of fried white potatoes and fruit juice, none of the studies considered the preparation methods or physical form of the fruit and vegetables consumed (e.g., whole, purée, or dried).

The first of the three studies that examined the relation of vegetable and fruit intake in separate categories, used data from the Continuing Survey of Food Intake of Individuals (CSFII). Lin and Morrison reported that obese men consumed significantly fewer vegetables (excluding white potatoes) and more white potatoes than did men in lower BMI categories (59). Among women, there was no significant difference in vegetable or white potato consumption across BMI categories. Both obese men and obese women consumed significantly less fruit than did men and women in lower BMI categories. These analyses were controlled for age, sex and race/ethnicity.

An examination of Behavioral Risk Factor Surveillance System data which investigated the relationship of weight status to total fruit and vegetable intake, excluded fried potatoes, did not exclude fruit juice in the calculation of total intake, and adjusted for potential confounding variables (60). It was found that underweight women more frequently consumed more than five servings of fruit and vegetable combined (excluding fried potatoes) per day (adjusted odds ratio (OR), 1.4; 95% confidence interval (CI), 1.1–1.8) than did normal-weight women (no significant difference was seen between normal-weight and overweight women). Among men, no significant differences in fruit and vegetable consumption were seen by weight category. There were no significant differences reported for separate categories of vegetable or fruit consumption across categories of BMI for both men and women. The analyses were adjusted for age, race, and education and were stratified by sex.

6.2.1 Analyses that assessed vegetable intake

In the Cancer Prevention Study II, a cohort study, Kahn et al. reported an inverse association between vegetable consumption (which included fried potatoes) and a 10-year change in both BMI and waist circumference among both men and women (61). In

multivariate analysis (adjusted for age, education, baseline BMI, slope of BMI change, change in marital status, region of country, and estimated total energy intake) there was a decrease of 0.12 kg/m² over 10 years and the likelihood of gain in waist circumference decreased (adjusted OR, 0.81 for men and 0.71 for women) with vegetable intake of “> approximately 19 servings per week” compared with “< 19 servings per week” (approximately 2.7 servings per day).

6.2.2 Analyses where the main outcome was another chronic disease

Cross-sectional data from the National Health and Nutrition Examination Survey Epidemiologic Follow-up Study, analyzed by Bazzano et al., showed a significant decrease in BMI as total fruit and vegetable intake (including fried potatoes and fruit juice) increased, after controlling for education, sex, race, diabetic status and total energy intake (65). An analysis of data from the National Health and Nutrition Examination Survey II by Patterson et al. showed no association of BMI with servings of fruit and vegetable combined, after controlling for age, race, and sex. It is notable that the range of BMIs in this analysis was 24.9 to 25.6 which is quite small and may have prevented detection of an association (68).

Other studies reported only the bivariate association. The analysis by Rissanen et al. excluded fried potatoes and examined 4-day diet data from middle-aged men in Finland participating in the Kuopio Ischaemic Heart Disease Risk Factor Study (66). Men who reported higher intakes of fruit and vegetables combined (excluding fried potatoes) had lower body weights (unadjusted effect, $p = 0.037$). One analysis of the protective effect of fruit and vegetables on the development of stroke in men reported an increase in BMI with an increase in fruit and vegetable intake (67).

An analysis of fruit, vegetable, and dietary fibre intake and the risk of colorectal cancer reported no appreciable difference in BMI by quartile of fruit and vegetable intake (71), and in an analysis of factors influencing low fruit and vegetable consumption, obesity was not significantly associated with fruit and vegetable consumption (70).

In the Washington State Cancer Risk Behavior Survey, Trudeau et al. reported that vegetable intake (including fried potatoes) was not associated with BMI in men or women. Among women only fruit intake (not including juice) was lower in women in the highest BMI category compared to all other categories ($p < 0.001$), after adjustment for sex, education, and marital status (62). Flood and colleagues reported a trend of decreasing BMI with increasing quintile of fruit and vegetable intake (64). However, BMI did not vary appreciably across fruit and vegetable intake quintiles in an analysis by Liu et al. (70).

6.2.3 Analyses that assessed vegetable and fruit intake separately

Using data from four independent, cross-sectional population surveys (known as the FINRISK studies), Lahti-Koski et al. found that obesity did not vary with level of vegetable consumption (“less than daily” compared with “daily” and including fried potatoes) after controlling for age and education (men: OR, 0.88; 95% CI, 0.77–1.01) (women: OR, 0.89; 95% CI 0.79–1.01) (74).

The results of the other analyses which excluded potatoes from the vegetable category, which did not adjust for any confounders, and which reported only the bivariate associations, were inconsistent. Williams et al. reported that a lower BMI was associated with more consistent “frequent” vegetable intake (63). Liu et al. reported that BMI did not vary by category of vegetable intake (72) and Kobayashi et al. (73) also reported no significant differences in BMI across quintiles of vegetable intake. An analysis of data from the Women’s Health Study, which was limited to professional women aged 45–75 years, showed no significant differences in BMI by quintile of fruit intake (excluding juice) (70). A significant bivariate association ($p < 0.001$) between higher BMI and lower fruit intake was reported by Flood et al. (64).

6.3 Issues related to Fruit and Vegetable Intake in Epidemiologic Studies

The associations found in the studies reviewed above must be viewed within the context of the type of data available and the manner in which the data were collected and analysed.

The epidemiological studies reviewed were limited in their ability to address the relation between fruit and vegetable consumption and body weight. Fifteen of the seventeen studies reviewed were cross-sectional analyses (59, 60, 62-74). Causality cannot be inferred from cross-sectional analyses because the data are collected at a single point in time and the direction of the association can not be determined (one cannot conclude that the outcome i.e., weight status, came before or after the exposure i.e., level of fruit and vegetable intake). Prospective cohort studies are preferable to cross-sectional studies because information on fruit and vegetable intake is collected before the outcome of weight status is determined.

Several other variables can affect the conclusions drawn from epidemiological studies. These include dietary assessment issues, such as method of food preparation and the physical form in which the food is consumed; adjustment for demographic factors; adjustment for total energy intake; and dietary patterns.

In contrast to clinical studies, epidemiological studies most commonly assess dietary intake, with varying levels of detail, by use of FFQs or multiple 24-h recall methods. The FFQ is often used to determine long-term intake, but does not usually collect information on the method of preparation or the physical form of food. In contrast, multiple 24-h recalls allow for detailed information on day-to-day variability, food preparation, and physical form of food consumed. The method of preparation influences the energy density and calorie content of a food. Fruit and vegetables in their natural state are low in energy density. However, they become more energy dense when fried (e.g., French fries and potato chips), served with high-calorie sauces (e.g., salad dressing, sour cream, butter, and cheese sauce), prepared as mixed dishes (e.g., high-calorie casseroles, pies, and baked goods), or dried (e.g., raisins). Some epidemiological studies have found a positive correlation between increased vegetable consumption and increased fat intake (15, 22) whereas others have not (76, 77). With the exception of fried potatoes and fruit juice, none of the studies reviewed accounted for the manner of preparation or fats added. Because these factors (e.g., frying and the addition of sauces) tend to increase energy intake, failing to take them into

account tends to diminish an association between the consumption of fruit and vegetable as intentional substitutes for higher calorie foods and intentional weight-control strategies.

The physical form in which the food is consumed directly influences satiety. Whole fruit has higher satiety ratings than do fruit purées, and purées have higher satiety ratings than do fruit juices (76-78). Fruit juice is relatively low in fibre and thus has a low satiety rating regardless of its caloric content.

Given the difficulties of assessing detailed information on long-term dietary intake, some misclassification of intake is inherent in epidemiological studies. In addition, many such studies rely on self-reported body weight rather than measured values and it has been shown that misclassification of body weight may occur because many persons under-report their weight (85, 86).

Both fruit and vegetable intake and weight status are associated with lifestyle and demographic factors. In the studies reviewed, higher fruit and vegetable intake has been associated with being older (60, 62, 64, 68, 70), being white (60, 68), being more educated (60, 62, 64, 65), engaging in physical activity (60, 62, 64, 70, 72), not smoking (60, 62, 64, 65, 70, 77, 87, 88), and having lower intakes of fat and red meat and higher intakes of wine, multivitamins, dairy products and fibre (60, 62, 64, 65, 70, 89). However, most of the analyses reviewed did not adjust for potential demographic or lifestyle confounders, largely because they were addressing research questions other than the relation of weight to fruit and vegetable intake. Only about half of the studies adjusted for any demographic confounders, and only one adjusted for the lifestyle factors of physical activity and smoking. The potential effect of such lack of adjustment is unclear. Adjustment for some confounders, such as education and physical activity, which are associated with both lower weight and higher fruit and vegetable intake, may attenuate the association between fruit and vegetable consumption and body weight. Other potential confounders such as smoking are associated with both lower weight and lower intake. An adjustment for total energy intake may also attenuate the relationships. Therefore, adjustment for these confounders could lead to a stronger association.

7. Conclusions

Although the data are limited, and many of the studies were not designed to test specifically the effects of increased consumption of fruit and vegetables alone, the findings of this review suggest that fruit and vegetables may play an important role in weight management. Both of the intervention studies in which weight loss as an outcome showed that a diet high in fruit and vegetables and low in fat resulted in significant weight loss among men and women. However, these interventions were only three weeks long, with no additional follow-up. Among the studies which gave dietary advice to increase intake of fruit and vegetables (including juice) and had no explicit weight loss component in the intervention, four reported no weight loss and one study reported weight gain. Yet, when this same advice was given along with the advice to decrease fat intake there were six studies that reported weight loss and only one with no significant weight loss. The length of these studies ranged from eight weeks to one year.

There were four studies that specifically advised participants to increase their fruit and vegetable intake as a weight loss strategy and all of those reported significant weight loss. These studies ranged in length from six months to one year. In the epidemiological literature, eight studies on women and five studies on men reported an association between higher fruit and vegetable intake and a lower BMI, while six studies in women and five in men reported no difference in BMI by level of fruit and vegetable intake. There was only one study that reported an association between higher fruit and vegetable intake and a higher BMI among men. The two epidemiological studies among children found that higher vegetable intake among boys was associated with lower BMI z-scores and one study found that overweight girls and boys ate less fruit.

Many of the studies reviewed lacked detailed information on the fruit and vegetables consumed by the study participants. Among the intervention studies, four studies did include specific information, while 14, the majority, provided no data or limited specific data on fruit and vegetable intake. Of the epidemiological studies, seven included specific information, nine did not. This lack limits possibilities of interpretation and

extrapolation of the data to other populations, communities and policy. Future studies need to collect and report detailed information in order to provide a greater understanding of this issue.

Studies of satiety have shown that some fruit and vegetables enhance satiety and reduce hunger. As yet, systematic studies designed to compare the effects on satiety of a range of fruit and vegetables in different amounts and forms have not been conducted. Such studies could help to clarify the relative roles of the energy density and the water, fibre, and carbohydrate content of fruit and vegetables.

Studies of satiation show that the addition of vegetables to mixed dishes to lower their energy density is associated with a spontaneous reduction in ad lib energy intake. This effect is seen even when participants consume diets low in energy density over the course of several days. Despite this reduction in energy intake, participants do not report an increase in hunger. These studies show that a reduction in the energy density of the diet by the addition of fruits and vegetables, independent of changes in fat content, is associated with decreased energy intake.

Long-term intervention studies designed to test the effects of various dietary interventions extend the laboratory-based studies and suggest a role for fruits and vegetables in weight management. Interventions which advise an increase in fruit and vegetable consumption along with a reduction in dietary fat show that even when there is no emphasis on body weight, some people spontaneously lose weight and most maintain their weight. It is possible that having no limitation on intake of fruit and vegetables enhances satiety and may help to avoid feelings of deprivation and hunger. More consistent weight loss and weight maintenance is seen when advice to increase consumption of fruit and vegetables is combined with advice to reduce intake of fat and energy. Even with successful weight loss, studies repeatedly show that weight is regained if the dietary messages delivered during the intervention are not reinforced. It will be important for future studies to determine how frequently the intervention messages should be reinforced to help with long-term dietary compliance and the maintenance of weight loss.

This review has presented data from intervention and epidemiological studies related to fruit and vegetable consumption. Both types of study are needed to reach a conclusion regarding the relation between fruit and vegetable consumption and weight management. Interventions can aid understanding of both behavioural responses and physiologic mechanisms within a controlled setting. Epidemiologic studies can be used to identify influences on dietary intake among the general population without exerting control over their decisions.

Author's note: This chapter on fruit and vegetable intake and body weight is an amalgam of two papers published during 2004, namely:

Rolls BJ et al. What can intervention studies tell us about the relationship between fruit and vegetable consumption and weight management? *Nutrition Reviews*, 2004, 62(1):1–17.

Carlton Tohill B et al. What can epidemiologic studies tell us about the relationship between fruit and vegetable consumption and body weight? *Nutrition Reviews*, 2004, 62(10):365–374.

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Table 1. Studies of effects of fruit and vegetables on satiety

Author (reference)	Research design	Subjects	Measurements	Results	Notes
Gustafsson et al. (16)	Added vegetables (96–164 g, 4.4 g fibre; carrots, peas, Brussels sprouts, spinach) to isocaloric lunches	10 men	Rated satiety for 210 min after consumption; measured glucose, insulin, C-peptide	Addition of vegetables did not affect satiety compared with control lunch	Suggest lack of effect on satiety due to small amount of vegetables added
Gustafsson et al. (17)	Randomized study of effect of adding cut or minced spinach (150 and 250 g) to a meal	10 men	Rated satiety for 210 min after meal; measured plasma variables	Satiety scores correlated positively to fibre and water content in spinach, but not to processing method	Attribute satiety effect to both fibre and water bound within spinach
Gustafsson et al. (18)	Randomized study of different portions (100, 200, 300 g) of boiled carrot added to isocaloric meal	10 men	Rated satiety for 210 min after meal; measured plasma variables	Satiety increased as portion of carrots increased; minimum of 200 g carrot for effect	Attribute satiety effect to both fibre and water bound within carrots
Gustafsson et al. (19)	Two randomized studies of effects of processing and cooking of carrots added to a meal	10 men in each study	Rated satiety for 210 min after meal; measured plasma variables	Satiety greater after raw carrots only in one study	Attribute satiety effect to water content of carrots
Leathwood & Pollet (20)	Within-subject comparison of bean flakes (slow-release carbohydrate) or potato purée added to normal isocaloric meals	6 men & women	Rated hunger/satiety for 240 min after consumption; measured plasma glucose	Bean purée delayed return of hunger compared with the potato purée	Energy density and macronutrient content varied between meals
Raben et al. (21)	Crossover design comparing high-fibre (4.7 g/MJ pea fibre) with low-fibre (1.7 g/MJ) meal	10 men	Rated hunger/satiety for 6.5 h after meal; measured plasma variables, fat oxidation, and thermogenesis	Fullness increased and desire to eat decreased after high-fibre meal	High-fibre meal decreased diet-induced thermogenesis and fat oxidation and was less palatable

Author (reference)	Research design	Subjects	Measurements	Results	Notes
Holt et al. (15)	Measured satiety after isocaloric servings (240 kcal) of 38 foods divided into 6 categories	11 to 13 men & women per category	Satiety rated over 2 h and area under response curve calculated	Best predictor of satiety was serving weight (energy density); protein, water, and fibre content also correlated positively with satiety	Potatoes (other vegetables not tested) had the highest satiety; the fruit group had the highest overall satiety
Haber et al. (22)	Within-subject test of the effects of whole apple, purée, and fibre-free juice (60 g usable sugar)	10 men & women	Rated hunger/satiety for 180 min after consumption; measured plasma glucose and insulin	Juice significantly less satiating than purée and purée less satiating than whole apples	Test foods all consumed in same amount of time; fibre, water content, energy density, and food form varied
Bolton et al. (23)	Within-subject test of whole orange vs. juice and whole grapes vs. juice (54 g usable sugar)	10 healthy volunteers (men & women)	Rated hunger/satiety for 180 min after consumption; measured plasma glucose and insulin	Satiety greater after whole fruit than after juice, and return of hunger was delayed	Two forms of same food consumed in same amount of time; fibre, water content, energy density, and food form varied.
Tiwarly et al. (24)	Tested twice with orange juice or juice with 5, 10, 15, or 20 g pectin	49 men	Rated satiety for 4 h and then given fixed amount of ice-cream	All doses of pectin increased satiety for 4 h and after ice-cream	Amount of pectin that affected satiety similar to that in fruits

Table 2. Studies of effects of fruit and vegetables on satiation

Author (reference)	Research design	Subjects	Measurements	Results	Notes
Bell et al. (8)	Within-subject design comparing ad lib consumption over 2 days of diets of 3 different EDs	18 women	Rated hunger/satiety before and after meals; measured food and energy intake	Ate a constant weight of food so that daily energy intake significantly reduced in low-ED condition with no difference in hunger or satiety	ED reduced by adding vegetables to mixed dishes
Bell & Rolls (30)	Within-subject design; 6 conditions with 3 levels of fat and 2 levels of ED for the entrées of all meals over a day	19 lean & 17 obese women	Rated hunger/satiety before and after meals; measured food and energy intake	Ate a constant volume of food so that daily energy intake significantly reduced in low-ED conditions across all fat levels with small differences in hunger or satiety	ED reduced by adding vegetables to mixed dishes
Kral et al. (31)	Within-subject design; 3 levels of ED for all meals over a day; half informed about ED of meals and half not	40 women	Rated hunger/satiety before and after meals; measured food and energy intake	Information about ED did not affect pattern of intake; ED affected energy intake – intake significantly reduced in low-ED condition	ED reduced by adding vegetables to mixed dishes
Rolls et al. (32)	Within-subject design in which either fat content or ED of compulsory foods equivalent to 50% of usual intake varied for 4 days; ad lib access to variety of foods	17 lean & 17 obese women	Rated palatability of foods to ensure similarity across conditions; measured intake of ad lib foods	Intake of ad lib foods lower when compulsory foods were low ED, but fat content had no effect when ED held constant	ED reduced by adding vegetables to meals, thus portions of low-ED compulsory foods bigger
Duncan et al. (33)	Crossover design comparing 5-day ad lib intake of low-ED vs. high-ED diet	10 obese and 10 non-obese men & women	Rated hunger/satiety before and after meals; measured energy intake	Daily energy intake reduced (1570 vs. 3000 kcal) on the low-ED diet; satiety ratings and palatability similar for both diets	Low-ED diet reduced in fat and high in fruits, vegetables, whole grains, and dried beans

ED = energy density

Table 3. Studies of provision of fruit and vegetables on body weight

Author (reference)	Intervention	Length of study	Subjects	Energy from dietary fat		Fruit & vegetable intake		Weight loss (lb)
				pre- intervention	during intervention	<i>pre-intervention</i>	post- intervention	
Shintani et al. (Waianae Diet Program) (34)	Foods (native Hawaiian fruits and vegetables) provided on-site and packed-out ^a	21 days	10 men & 10 women BMI = 39.6	32.0%	7%	NR	ad lib	17.2
Shintani et al. (35)	Foods (native Hawaiian fruits and vegetables) provided on-site and packed-out	21 days	10 men & 13 women BMI = 35.6	NR	12%	NR	ad lib	10.8

BMI, mean body mass index (kg/m²); NR, not reported.

^aPacked-out, study foods were packaged for subjects to take and consume outside of the laboratory.

Table 4. Studies of dietary advice to increase intake of fruits and vegetables

Author (reference)	Intervention	Length	Subjects	Energy from dietary fat		Fruit & vegetable intake ^a		Weight loss
				pre	post	<i>Pre-intervention</i>	<i>Post-intervention</i>	
Smith-Warner et al. (36)	I: ↑F&V ^b (including juice & fried potatoes); nutritionist counselled; individual counselling C: usual care	1 year	I: 100 men & women BMI: 27.6	33.6%	30.6%	Veg: 4.3 Fruit: 2.4 Juice: 0.5	5.5 [‡] 4.9[‡] 1.6[‡]	None
			C: 101 men & women BMI: 27.8	35.5%	34.5%	Veg: 3.7 Fruit: 2.4 Juice: 0.6	3.5 [‡] 2.1[‡] 0.6[‡]	
Zino et al. (37)	I: ↑F&V (including juice & fried potatoes); nutritionist counselled C: usual care	8 weeks	I: 44 men & women BMI: 25.3	35%	32%	Veg: 228 ± 127 Fruit: 93 ± 118 Juice: 56 ± 96	332 ± 149 ^{†‡} g/day 256 ± 132 ^{†‡} g/day 413 ± 283 ^{†‡} g/day	None
			C: 43 men & women BMI: 25.6	36%	36%	Veg: 196 ± 87 Fruit: 37 ± 51 Juice: 25 ± 68	218 ± 104 [‡] g/day 55 ± 84 [‡] g/day 46 ± 104 [‡] g/day	
Maskarinec et al. (38)	I: ↑F&V (including juice & fried potatoes); dietitian counselled; individual counselling C:	6 months	I: 13 women BMI: NR	31%	27%	Veg: 1.7 Fruit: 1.5	3.9 [‡] 3.5 [‡]	None
			C: 16 women BMI: NR	30%	30%	Veg: 2.0 Fruit: 1.3	2.1 [‡] 2.0 [‡]	

I, intervention group; C, control group; BMI, mean body mass index (kg/m²); NR, not reported; † significantly different from baseline; ‡ significantly different between groups.

^a servings per day unless otherwise stated;

^b ↑F&V = subjects were advised to increase fruit and vegetable intake;

[‡] reported as a post-hoc analysis.

Table 5. Studies of dietary advice to increase intake of fruit and vegetables and decrease fat intake

Author, study (reference)	Intervention	Length	Subjects	Energy from dietary fat		Fruit & vegetable intake ^a		Weight change (lb)
				pre	post	pre-intervention	post-intervention	
Djuric et al. (39)	I ₁ : ↑F&V ^b	1 year	I ₁ : 25 W	31.2%	28.9%	Veg: 2.4	5.9 [†]	+6
	I ₂ : ↑F&V, ↓fat ^c		BMI: NR			Fruit: 1.8	5.2 [†]	
	I ₃ : ↓ fat (including juice & fried potatoes); dietitian counselled:		I ₂ : 23 W	32.3%	16.7%	Veg: 2.2	5.9 [†]	
Rock et al. Women's Healthy Eating and Living Study (40)	I: ↑F&V, ↓fat (including juice); dietitian counselled: telephone counselling; C: no counselling	1 year	I: 507 W	27.8%	21.4%	Veg: 3.1	4.9 [†]	0
			BMI: 27.0			Fruit: 2.7	3.6 [†]	
			C: 503 W	28.1%	27.7%	Veg: 2.9	3.2 [†]	
Lanza et al. Polyp Prevention Trial (41)	I: ↑F&V, ↓fat; dietitian counselled: individual & group counselling;	1 year	I: 968 M & W	32.2%	21.2%	Veg & fruit: 5.0	7.8 [‡]	-4.3
			BMI: 27.6			5.4 [‡]	0	
		C: 993 M & W	32.4%	32.1%	Veg & fruit: 5.0	8.6 [‡]	-1.4	
Singh et al. (42)	I: ↑F&V, ↓fat; dietitian counselled; C: AHA diet	1 year	I: 923 M & W		20.6%			-13.9
			C: 916 M & W		30.1%			
			I: 204 M & W	26.0%	23.8%	Veg & Fruit: 172 ± 23.5	575 [‡] ± 91.4 g/d	
	BMI: 24.3	24.1%	28.0%	165 ± 18.8	185 [‡] ± 25.4 g/d	-5.3		
	C: 202 M & W		BMI: 23.3					

Author, study (reference)	Intervention	Length	Subjects	Energy from dietary fat		Fruit & vegetable intake ^a		Weight change (lb)	
				pre	post	pre-intervention	post-intervention		
Singh et al. Indian Diet Heart Study (43)	I: ↑F&V, ↓fat dietitian counselled; C: AHA step 1 diet	3 months	I: 262 M, 48 W BMI: 24.3	26.8%	24.5%	Veg & fruit: 256.4 ± 23.5		0	
			C: 269 M, 42 W BMI: 24.8	28.5%	27.5%	261.4 ± 47.8	278.5 ± 65.5 g/d	0	
Singh et al. Indo-Mediterranean Diet Heart Study (44)	I: ↑F&V, ↓fat dietitian counselled; C: NCEP diet	2 years	I: 499 M & W BMI: 24.3	27.8%	26.3%	Veg & fruit: 215 ± 29		-8.8	
			C: 501 M & W BMI: 24.1	28.0%	29.1%	207 ± 23	231 ± 19 g/d	-2.2	
Baer (45)	I: ↓fat, ↑F&V dietitian counselled: AHA step 1 diet C: Usual care	1 year	I: 33 M BMI: NR	38%	31%	Veg: 2.0 Fruit: 4.0	4.0 6.0	-11	
			C: 37 M BMI: NR	37%	36%	NR	NR	+1	
Henderson et al. Women's Health Trial (46)	I: ↓fat, ↑F&V dietitian counselled; C: Usual care	1 year	I: 173 W BMI: NR	39.1%	21.6%	Veg: 140 Fruit: 132	113 [†] kcal/d 169 ^{†c} kcal/d	-6.4	
			C: 114 W BMI: NR	38.9%	37.3%	Veg: 133 Fruit: 142	128 kcal/d 143 kcal/d	-1.4	
		2 years	I: 163 W C: 101 W		22.6%		Veg: 140 Fruit: 132	124 [†] kcal/d 185 ^{†c} kcal/d	-4.2
						36.8%		Veg: 133 Fruit: 142	128 kcal/d 159 kcal/d

Author, study (reference)	Intervention	Length	Subjects	Energy from dietary fat		Fruit & vegetable intake ^a		Weight change (lb)
				pre	post	pre-intervention	post-intervention	
Gambera et al. (47)	I: ↓ fat, ↑F&V, ↑ exercise ^d dietitian counselled: AHA step 2 diet C: ↑ exercise only	3 months	I: 8 M	38.0%	21.0%	Veg: 2.3	2.6	-4.8
			BMI:			Fruit: 0.9	3.4 [†]	
			27.1	41.0%	26.0%	Veg: 1.9	2.6	-3.0
			7 W			Fruit: 0.6	3.9 [†]	
			BMI: 24.0	NR	NR	NR	NR	+0.7
			C: 12 M	NR	NR	NR	NR	0
			BMI:					
			25.2					
			5 W					
			BMI: 25.1					
Stamler & Dolecek (48)	I: ↓ fat, ↑F&V dietitian	6 years	1159 M ^d	38.4%	35.4%	Veg: 2.9 Fruit: 3.9	3.8% energy 5.7% energy	+5 or more
Tillotson et al. MRFIT (49)	counselled: individual and group counselling		2645 M ^d	38.4%	34.4%	Veg: 2.9 Fruit: 3.9	4.0% energy 6.4% energy	±5
	C: (usual care)		1160 M ^d	38.4%	33.9%	Veg: 2.9 Fruit: 3.9	4.0% energy 7.0% energy	-5 to -9
			697 M ^d	38.4%	33.3%	Veg: 2.9 Fruit: 3.9	4.4% energy 7.9% energy	-10 to -14
			628 M ^d	38.4%	33.1%	Veg: 2.9 Fruit: 3.9	5.1% energy 8.8% energy	-15 or more

Author, study (reference)	Intervention	Length	Subjects	Energy from dietary fat		Fruit & vegetable intake ^a		Weight change (lb)
				pre	post	pre-intervention	post-intervention	
Appel et al. PREMIER Clinical Trial (50)	I ₁ : ↑F&V, ↓fat I ₂ : ↓fat dietitian counselled: individual & group counselling; C: Single-visit counselling	6 months	I ₁ : 233 M & W	33.3%	23.8%	Veg & fruit: 4.8	7.8 [†]	-12.8
			I ₂ : 238 M & W	33.4%	29.4%	Veg & fruit: 4.6	5.1	-10.8
			C: 242 M & W	32.9%	31.9%	Veg & fruit: 4.4	4.9	-2.4
Weinsier et al. (52)	I: ↑F&V, ↓fat dietitian counselled: 1000 kcal/d	6 months	18 M	NR	19%	NR	ad lib	-28.4
			42 W	NR	19%	NR	ad lib	-13.6
Epstein et al. (57)	I: ↑F&V C: ↓fat & sugar family counselling: 1200 and 1500 kcal/d	1 year	I: 15 obese parents (M & W)	NR	NR	Veg & fruit: 3.8	7.2 [*]	-16.4 [†]
			C: 15 obese parents (M & W)	NR	NR	Veg & fruit: 4.2	4.0	-5.4 [†]

I, intervention group; C, control group; NR, not reported; M, men; W, women; AHA, American Heart Association; Where is this one used? NCEP, ; Multiple Risk factor Intervention Trial MRFIT, ; * significantly different from baseline; † significantly different between groups.

^a servings per day unless otherwise stated;

^b subjects advised to increase fruit and vegetable intake;

^c subjects advised to decrease fat intake;

^d subjects advised to increase exercise;

^e reported as a post-hoc analysis;

^f actual weight losses of parents; personal communication from author.

Table 6. Studies reporting the relationship between fruit and vegetable consumption and body weight in children

Author (reference)	Research design and sample	Measurements	Analysis and results	Notes
Field et al. (58)	Prospective cohort study of children (9–14 yr) participating in the Growing Up Today Study (1996–1998)	Diet: FFQ adapted for adolescents; Anthropometrics: Self-reported	Conditional linear models. Among boys, vegetable intake was inversely related to changes in BMI z-score, attenuated after control for caloric intake. No relationship was reported among girls	Controlled for Tanner stage of development, age, height change, activity, and inactivity. Less than 25% of participants consumed at least 5 servings of fruits and vegetables per day
Lin and Morrison (59)	Cross-sectional analysis among 3064 children and adolescents (5–18 yr) participating in CSFII (1994–1996, 1998)	Diet: Two 24-h recalls; Anthropometrics: Self-reported by parent	Regression analysis. Overweight boys ate less total vegetables, fruit and white potatoes. Overweight girls and girls at risk of overweight ate less fruit	Controlled for age, sex, and race/ethnicity.

BMI z-score, body mass index (Note: the z-score for an item indicates how far and in what direction that item deviates from its distribution's mean, expressed in units of its distribution's standard deviation); CSFII, Continuing Survey of Food Intake by Individuals

Table 7. Analyses that examined the association between fruit and vegetable consumption and body weight

Author (reference)	Research design and sample	Measurements	Analysis and results	Notes
Lin and Morrison (59)	Cross-sectional analysis among 9117 adults participating in the CSFII (1994–1996, 1998)	Diet: Two 24-h recalls; Anthropometrics: Self-reported	Regression analysis. Obese men ate fewer F&V and more white potatoes. Obese women ate less fruit	Controlled for age, sex, and race/ethnicity
Serdula et al. (60)	Cross-sectional analysis among 21 892 adults participating in the BRFSS (1990)	Diet: FFQ, 6 F&V items; Anthropometrics: Self-reported	Multiple logistic regression models. Women with a BMI ≤ 19 more frequently consumed F&V ≥ 5 times per day	Adjusted for age, race, and education
Kahn et al. (61)	Prospective cohort of 79 236 white adults participating in the Cancer Prevention Study II (1982–1992)	Diet: FFQ, 7 F and 8 V items; Anthropometrics: Self-reported	Linear and logistic models Change in BMI and waist gain associated with a greater vegetable intake for men and women.	Adjusted for age, education, BMI, BMI change, marital status, country region, and estimated total energy intake. No fruit consumption data
Trudeau et al. (62)	Cross-sectional study among 1450 adults participating in the Washington State Cancer Risk Behavior Survey, (1995–1996)	Diet: FFQ, 6 F&V items; Anthropometrics: Self-reported	Multivariate linear regression models Obese women had lower fruit intake	Adjusted for sex, education, marital status, and BMI
Williams et al. (63)	Cross-sectional analysis among 1122 adults participating in the Isle of Ely Study (1994–1997)	Diet: FFQ; Anthropometrics: Measured	Descriptive analysis Lower BMI was associated with more consistently frequent vegetable intake	

Author (reference)	Research design and sample	Measurements	Analysis and results	Notes
Flood et al. (64)	Cross-sectional analysis among 45 490 women from the Breast Cancer Detection Demonstration Project (1987–1989)	Diet: FFQ, 5 F and 14 V items; Anthropometrics: Self-reported	Separate trend tests for F&V quintiles Trend of decreasing BMI with increasing F&V quintiles	Controlled for total energy intake in models to generate relative risks for colorectal cancer cases
Bazzano et al. (65)	Cross-sectional analysis among 9608 adults (from the NHANES Epidemiologic Follow-up Study, 1971–1975; 1982–1984, 1986, 1987, and 1992)	Diet: FFQ, 3 F&V items and a 24-h recall; Anthropometrics: Measured	ANOVA for continuous variables. Decrease in BMI as frequency of F&V intake increased	Multivariate models adjusted for physical activity, education, alcohol, smoking, vitamin use, total energy intake, sex, race, and diabetic status
Rissanen et al. (66)	Cross-sectional analysis of men participating in the Kuopio Ischaemic Heart Disease Risk Factor Study (1984–1989)	Diet: 4-day food record; Anthropometrics: Measured	ANOVA comparing groups of mean F&V intake BMI was lower with higher F&V intake	All-cause mortality was lower among men with the highest consumption of fruits, berries and vegetables
Gillman et al. (67)	Cross-sectional analysis among 832 men participating in The Framingham Study (1966–1969)	Diet: One 24-h recall; Anthropometrics: Measured	<i>p</i> values for trend test. BMI increased as F&V intake increased	
Patterson et al. (68)	Cross-sectional analysis among 1335 black and 10 313 white adults in NHANES II (1976–1980)	Diet: One 24-h recall; Anthropometrics: Measured	Regression coefficients to obtain estimates of means. No associated increase in obesity with increasing F&V intake	Adjusted for age, race, and sex. Caloric and fat intake increased as F&V intake increased
LaForge et al. (69)	Cross-sectional analysis of 405 adults in the greater Providence area, RI, USA (1992)	Diet: 24-h recall; FFQ, 1 F and 3 V items; Anthropometrics: Self-reported	Descriptive analyses No significant difference in percentage of adults consuming ≥ 5 servings of F&V per day by obesity status	15% of the sample reported usual daily consumption of 5 or more servings of F&V

Author (reference)	Research design and sample	Measurements	Analysis and results	Notes
Liu et al. (70)	Cross-sectional analysis among 39 127 women in the Women's Health Study (1993)	Diet: FFQ, 16 F and 28 V items; Anthropometrics: Method not clearly stated	Separate trend tests BMI did not vary appreciably across F&V quintiles	FFQ assessed at baseline only; median intake of total F&V ranged from 2.6 to > 10/day across quintiles
Terry et al. (71)	Cross-sectional analysis among 61 463 women in the Swedish Mammography Screening Cohort (1987–1998)	Diet: 7-day diet record, FFQ, 5 F and 7 V questions; Anthropometrics: Self-reported	Correlation of baseline characteristics and F&V intake. No significant difference in BMI among F&V quartiles	Controlled for total energy intake by including it in the multivariate risk-factor models as a continuous variable
Liu et al. (72)	Cross-sectional analysis among 15 220 men in the Physician's Health Study (1982)	Diet: FFQ that included 8 V items; Anthropometrics: Measured	Baseline descriptive analysis BMI did not vary by category of vegetable intake	No fruit consumption data
Kobayashi et al. (73)	Cross-sectional analysis within a cohort of 43 140 adults in the Japan Public Health Center study (1990)	Diet: FFQ, 4 V and 3 F items; Anthropometrics: Measured	Descriptive analyses No significant difference in BMI across quintiles of vegetable intake	No fruit consumption data
Lahti-Koski et al. (74)	Four independent cross-sectional surveys among 24 604 Finnish adults (1982–1997)	Diet: FFQ, 10 F&V items; Anthropometrics: Measured	Logistic regression Vegetable intake was weakly associated with obesity	Controlled for age and education. No fruit consumption data

CSFII, Continuing Survey of Food Intake by Individuals; BRFSS, Behavioral Risk Factor Surveillance System; FFQ, food frequency questionnaire; F, fruit; V, vegetables; BMI, body mass index (kg/m²); NHANES, National Health and Nutrition Examination Survey