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Dietary Energy Density, Satiety and Weight Management

Eleni Papagiannidou, Angelos Tsipis*, Anna Maria Athanassiadou, Emmanouil Petrou and Pauline Athanassiadou Department of Pathology, Cytology Unit, Medical School, University of Athens, Athens, Greece

Abstract

Extensive research has been done into the effects of dietary energy density on satiety. Research has shown that people tend to eat the same weight of food each day. The energy density of the diet is an effective way of increasing satiety and at the same time reducing energy intake. Thus, by reducing the dietary energy but keeping the weight of the food the same, is feasible to consume less energy and feeling more full and achieve a healthy body weight. A low energy density diet can be achieved by eating more foods with high water content; this includes dishes where water is added during cooking, foods like pasta and rice that absorb water during cooking, and foods that are naturally high in water, such as fruit and vegetables.

Keywords: Energy density; Satiety; Weight management

Introduction

According to the World Health Organization (WHO) [1] obesity is one of the greatest public health challenges of the 21st century, and its prevalence is increasing, reaching globally more than 1 billion overweight adults at least 300 million of them being obese. Obesity and overweight is associated with chronic conditions, including metabolic syndrome, type 2 diabetes, hypertension, cardiovascular disease, and stroke [2,3]. The regulation of energy balance is complex and behavioural, genetic, hormonal and neural influences are involved [4]. Studies of twins and families have indicated that heredity plays a part in the development of obesity, as well as other genetic influences - such as gene - encoding leptin mutations [5-8]. However, though more than 400 genes have been implicated in the regulation of the body weight, only 5% of obese people have genetic conditions or mutations that are linked to obesity. Therefore, gene-environment interactions must account for a significant proportion of cases of obesity. Since obesity occurs when there is an imbalance between energy intake and energy expenditure, the two main preventable causes are excess energy intake and inadequate levels of physical activity.

Source of data

We searched MEDLINE* and reference lists of literature on the role of dietary energy density and satiety on weight management in January 2009. Initial MEDLINE search using the keys words "macronutrient intake" and "weight management" provided 82 entries spanning from 1983 to 2009. This was considered inconsistent and an extended search using a combination of key words like "low-energy-density diet", "high-energy-density diet", "macronutrient intake", and "weight management" yielded 1,500 entries extending from 1970 to 2009. The database obtained was contracted by eliminating duplicates, case reports, studies on diseases and studies without weight management or energy density diet as main focus. The final database consisted of 160 studies. Some of these publications included multiple reports from the same studies. The data sources are mentioned wherever used in the text.

Energy density

Energy density is defined as the energy content per unit weight of foods (Kcal/g). Low energy density foods provide less energy per gram of food so the amount of food eaten is more without consuming too many calories. Low energy density foods include foods with high water content, such as soups, foods like pasta and rice that absorb water during cooking, and foods that are naturally high in water, such as fruit and vegetables. Foods that are high in fibre, such as wholegrain breads and cereals, and lower fat foods also tend to have a lower energy density. High energy density foods tend to include foods that are high in fat and have a low water content, for example biscuits and, crisps, nuts, oil and cheese.

Studies have shown that people tend to consume about the same amount (weight) of food each day, but not necessarily the same amount of energy (calories). So it is possible to trick ourselves into consuming less energy, without feeling hungry by eating a lower energy density diet, which still makes up the same weight of foods overall throughout the course of a day.

Physiological studies have shown that humans have a weak innate ability to recognise foods that are energy-dense and have a difficulty to compensate for this over the short-term, if large amounts of these foods are consumed [9]. Consequently, it is likely that if the over consumption of foods with high energy density become habitual, will increase the body fat [10]. Foods with high energy density tend to be associated with high palatability and, if consumed during activities such as television viewing, it is thought that satiety is not recognised, and thus leading to increased consumption of these foods [11]. Foods with high energy density generally cost less than those of low energy density, such as fresh fruit and vegetables, and lean meat, and are usually more widely available [12].

There is some evidence from epidemiological studies that a lowenergy-density diet is associated with a lower body weight [13]. Studies have shown a link between the low energy density of the diet and lower body weight, through high intakes of fruit and vegetables [14,15].

When the energy density of foods is determined by their macronutrient content, it has been shown to be related to average energy intake in short-term studies; this is not the case when energy density is only determined by the water content of foods [14]. Both dietary restraint and the changing of portion sizes to accommodate the changes in energy density occur in the long-term. Therefore, it does

*Corresponding author: Angelos Tsipis, Department of Pathology, Cytology Unit, Medical School, University of Athens, Athens, Greece, E-mail: angelosathens@netscape.net

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not allow for extrapolation of these results to the long-term, and longterm studies may find differing effects. Rolls et al. have investigated the role of energy density in weight loss in two long-term (1-year duration) studies in men and women [13]. In the first study, they found that those who consumed foods of low energy density lost more weight than those who consumed foods of high energy density, even when total energy intake was similar between groups. In the second study, participants were given dietary counselling - the first group was given some very general advice to choose lower-fat foods and to increase intake of foods that were high in water content, and the other group were given more intensive counselling and asked to restrict the amount of food eaten by limiting portion sizes, as well as decreasing the amount of fat. Both of these strategies allowed for the reduction of energy density without having to assess the amount of energy being consumed, and both groups lost weight, with the group who consumed the diet of lower energy density losing the greater amount of weight.

Satiety

Satiety is the feeling of fullness after eating which suppresses the urge to eat for a period of time after a meal. Such feelings of fullness play an important role in controlling how much we eat. If we feel really full or 'satiated' after a meal then we are likely to go much longer before we feel hungry and may eat less at the next meal. But, if we do not feel very full then we are likely to get hungry again more quickly and may be tempted to snack or eat more at the next meal. So, if we can understand how to enhance these feelings of fullness or 'satiety', we can help to control how much we eat.

Satiety is controlled by a number of factors that begin when a food or drink is consumed and continue as the food enters the gut and is digested and absorbed. Signals feed into specific areas of the brain in response to the expansion of the stomach, our sensory responses and the brain's perceptions of the food and drink consumed. Hormonal signals are also released in response to the digestion and absorption of nutrients. There are also hormones that tell the brain how much fat we have stored in the body, which affect satiety over the longer term. These signals are integrated in areas of the brain involved in the regulation of energy intake, which lead to the feeling of satiety. Although we can feel our stomachs filling up as we eat, it can take 15-20 minutes after food is first eaten, for the full range satiety signals to reach the brain. By this time, and for some time afterwards we will experience feelings of fullness.

Despite these sophisticated mechanisms that exist to control energy intake, people often still eat when they feel full or refrain from eating when hungry. There are many other factors that influence eating behaviour, in addition to the body's satiety signals, such as portion size, the variety of food and drinks available, emotional states and the social situation around an eating occasion.

Protein

Protein is the most satiating of all the macronutrients, and results from several studies show that a high-protein meal leads to decreases in subsequent food intake when compared with ingestion of a meal low in protein, and that when meals of similar energy content are consumed, the high-protein meal is the most satiating [16-19]. It is thought that high-protein diets lead to increased satiety and dietary thermogenesis, resulting in a decrease in total energy intake.

Halton and Hu [20] have recently reviewed the literature comparing the effects of lower and higher-protein diets on total weight change, total body fat change, satiety and the association with subsequent energy intake after the test meals. Fourteen studies, in both men and women, have investigated the effect of high protein intake on satiety by measuring satiety over a period of hours after meals of different protein content. The majority of these studies found that when subjects were given the pre-loads with the higher protein content, compared with either high fat, carbohydrate or alcohol levels, satiety was increased [21,22]. While some of these studies gave protein pre-loads that were unsustainable for daily consumption (around 75% of total energy from protein), significant increases in satiety were still found after more modest increases in protein content over the period of a few hours [23].

If satiety is increased after a high-protein meal, then it is important to know whether this will affect energy intake in subsequent meals. In eight out of 15 studies has been have found that high protein pre-loads were related to a decrease in energy intake at a subsequent meal [20]. These studies all used protein in the form of solid foods, whereas the studies that found no relationship between high protein pre-loads and satiety included those that gave test drinks in liquid form. The studies that found significant effects were also those that used higher pre-loads of protein (around 50% of total energy).

Evidence suggests that both appetite and subsequent energy intake are equally reduced after consumption of different carbohydrate and protein pre-loads, but that differences occur in the response of the gastrointestinal hormones, cholecystokinin and ghrelin, with glucose consumption leading to increased appetite and further glucose consumption [24]. Glucose consumption may be controlled by ghrelin, whereas cholecystokinin concentrations increased after protein ingestion, which may be responsible for the increased satiety that occurs after ingestion of high-protein foods.

The typical thermic effect of carbohydrate and fat is under half that of protein [25]. Out of 15 studies that have looked at the thermic effect of protein, all of them found it to be larger than that of either carbohydrate or fat [20]. The extra energy expended between the isocaloric diets (which only differed in terms of protein content) could, in theory, lead to a weight loss of between 1 and 2 kg per year.

If energy expenditure can be manipulated by increasing protein intakes, while holding the overall energy intake as constant as possible, then high-protein diets should lead to weight loss. When the results of 15 studies investigating the effects of such diets on weight loss were compared, the findings were inconsistent, with seven studies finding that diets that were high in protein, compared with those that were high in carbohydrate, led to greater weight loss [20]. Interestingly, the studies of shorter duration (less than 6 months) tended to find no significant differences in weight loss between the different diets [26,27]. However, we cannot draw conclusions about the effects of these diets, as the studies included in the review were of different design and duration. Furthermore, total energy intake was not identical, which means that any differences in weight loss could be due to the differences in total energy and not protein content.

Carbohydrates

In observational studies, sucrose intake is generally negatively associated with fat intake, but the effects of refined sucrose on appetite and weight control are unclear [28-32]. Some studies have found that ingesting sucrose can delay onset of hunger and subsequent eating, while others have found that carbohydrate ingestion can trigger cravings for more carbohydrates and an increase in energy intake [33,34]. These contradictory effects may be due to whether simple or complex carbohydrates are ingested, or whether the carbohydrate is in liquid or solid form [31,35]. Evidence from cross-sectional and cohort studies suggest that there is a significant positive relationship between sugar-sweetened drinks intake and overweight and obesity, both in children and in adults [36]. There is little available evidence from intervention trials, but results from the available trials indicate that interventions in children and adolescents to reduce intakes of these drinks have led to decreased weight [36]. Between the 1970s and 1990s, most dietary advice advocated diets that were low in fat and high in carbohydrates. A potential difficulty for compliance to these diets is that low-fat, high-complex-carbohydrate food sources are of relatively low energy density, which may affect satiety [22]. Refined carbohydrate ingestion has adverse effects on insulin metabolism and is associated with type 2 diabetes [37]. Melanson [38] found that the increased satiation from high-carbohydrate diets versus high-fat diets may have been due to the differences in blood glucose levels and patterns after ingestion of the two diets.

In contrast, other studies have found that sucrose delays hunger and subsequently eating [39]. Some studies have found that sugar intake is negatively correlated with fat intake, while other studies have found a positive relationship between the two nutrients [40,41]. The inconsistent effects across previous studies may be due to methodological variations between studies. If subjects are aware of, or are able to anticipate, what they will receive in the second part of a crossover design, then they may behave according to their expectations, rather than because of specific physiological changes [42]. Most of the previous studies have concentrated on the short-term effects of carbohydrate consumption and do not take into account any adaptation that may occur over the longer-term [28,43,44].

There are a few long-term studies of the effects of refined carbohydrate diet, following participants for days and weeks, rather than hours. The majority of these have been focused on overweight and obesity, and all have assessed the role of simple carbohydrates in lowfat weight-loss diets. Surwit and Poppitt [45,46] found that sucrose in the diet led to similar weight loss to diets lower in simple carbohydrate. Both studies used complex, nutrient-controlled diets, so subjects knew what they were eating but were not necessarily aware of the overall sucrose or carbohydrate content of the diet. Brinkworth [47] also found that high-carbohydrate, low-fat diets led to equivalent weight loss over more than 1 year. In contrast, Raben [48] found that a high-starch diet led to weight loss compared with high-sucrose or high-fat diets, but that people preferred the high-sucrose diet. Participants gained weight slightly on the high-sucrose diet, owing to increased energy intake from sweet drinks. Raben [49] found that sucrose supplementation increased energy intake over 10 weeks, with consequent increases in body mass index (BMI).

There have been a further three blinded trials in which either sugar or aspartame have been added to the habitual diet of normal-weight participants. Tordoff and Alleva [50] found that fructose increased energy intake over 3 weeks compared with aspartame, although the effect was complicated by gender differences. Reid and Hammersley [42], in a 7-day study, found that on day 1, participants receiving aspartame-sweetened drinks ate fewer grams of carbohydrate and had fewer eating episodes that included a high proportion of sugar.

Dietary fibre/non-starch polysaccharides

Dietary fibre intake is inversely related to body weight and body fat in many studies and high intakes of fibre have been associated with weight loss [51-53]. Fibre can moderately lower the energy density of meals. These beneficial effects of fibre are thought to be owing to a variety of factors - foods that are high in fibre may displace those foods that are high in fat and energy-dense. Also, high-fibre foods require more chewing, which leads to the production of more saliva and gastric secretions that fill the stomach and increase satiety. Satiety is also increased owing to the bulk of the fibre in the stomach. Third, fibre is thought to decrease absorption of nutrients from the small intestine [54]. Increasing fruit and vegetable consumption has also been associated with a decrease in body weight [55].

High-fibre foods, such as wholegrains, are generally rich in fatty acids, lignans, vitamins and minerals, and when these are refined to separate out, the bran, germ and endosperm losses in these macroand micronutrients occur. Wholegrains are digested and absorbed more slowly than refined grains, and thus have low glycaemic index values. A review of the literature suggested that increased consumption of wholegrains can improve insulin sensitivity and also lower serum insulin concentrations. Both soluble and insoluble fibre intake has also been shown to be inversely associated with body weight in observational studies, as well as insulin, cholesterol and blood pressure [56]. High levels of soluble fibre may exert their effects on insulin sensitivity by slowing the absorption of macronutrients, and may also result in increases in cholecystokinin, which plays a role in controlling gastric emptying.

Fat

Fat is the principal source of energy, containing 9 kcal per gram, and there is overwhelming evidence that high intakes of saturated and trans fatty acids are associated with many obesity-related chronic conditions, such as cardiovascular disease [57]. Traditionally, low-fat diets are recommended for weight loss, in order to reduce cardiovascular risk. If low-fat diets are recommended for weight loss, then this necessarily means that proportions of carbohydrate and protein are increased at the expense of fat. As stated before, foods that are high in fat are generally of high energy density.

A systematic review of 12 randomised controlled trials investigating the effects of low-fat diets on weight loss found that the low-fat diets not only produced significant weight loss, but also resulted in improvements in blood pressure, cholesterol and glucose levels after 12 months of intervention [58]. Results from these studies also indicated that low-fat diets were more effective for weight loss than either lowcarbohydrate or low-protein diets. However, there are very few studies that investigated the effects of these diets over a longer-term. Three studies had follow-up for up to 3 years, and the maximum period of follow-up in any study was 5 years [59-62].

Although high fat intake has been shown to be related to higher body weight in numerous studies, not everyone with a high fat intake will become overweight or obese [63]. Therefore, there are factors other than nutrient intake that can affect an individual's susceptibility to gain weight, including rare genetic factors [7]. Blundell reviewed results from several very large-scale surveys of diet and weight, to investigate some of these factors in men who habitually consumed a high-fat diet [64]. They compared men who had put on weight and subsequently increased their BMI with men who had maintained a BMI within the 'normal' range (i.e. 20-25 kg/m2). They identified several factors that influenced whether a habitual high-fat diet led to subsequent weight gain. Those who were of higher BMI experienced lower levels of satiety, increased desire for foods, and increased feelings of pleasure from eating, and some experienced heightened senses of smell and taste of foods. Those with a higher BMI may also have differences in the release and action of substances involved in the regulation of appetite and metabolism, such as insulin, cholecystokinin, leptin, adiponectin and ghrelin, which can lead to poorer appetite control. Such subjects also tended to eat larger meals, snack more frequently, and consume more energy-dense foods.

Physical activity

Epidemiological evidence indicates that there is an inverse

relationship between physical activity and measures of body composition, such as waist circumference, waist: hip ratio and abdominal fat measured by dual-energy X-ray absorptiometry [65-67]. Evidence indicates that low levels of physical activity are associated with a not very healthy diet [68,69]. Obesity may be a barrier of being active. While energy expenditure is clearly also very important, an overwhelming body of evidence indicates that energy intake is associated with overweight and obesity in adults.

Conclusion

There is no conclusive evidence to suggest that the macronutrient composition of a low energy diet influences dramatically the rate and the extent of weight loss in obesity and overweight in the long term. It is apparent that low-fat diets help to promote weight loss, and that replacing fat with either carbohydrates or protein increases satiety and the thermic content of the diet. Nevertheless, it is important to note that excess energy in any form will enhance body fat accumulation.

References

- 1. [No authors listed] (2000) Obesity: preventing and managing the global epidemic. Report of a WHO consultation. World Health Organ Tech Rep Ser 894: 1-253.
- Skidmore PM, Yarnell JW (2004) The obesity epidemic: prospects for prevention. QJM 97: 817-825.
- 3. Poirier P, Giles TD, Bray GA, Hong Y, Stern JS, et al. (2006) Obesity and cardiovascular disease: pathophysiology, evaluation, and effect of weight loss. Arterioscler Thromb Vasc Biol 26: 968-976.
- Lustig RH (2001) The neuroendocrinology of obesity. Endocrinol Metab Clin North Am 30: 765-785.
- Bouchard C (1996) The causes of obesity: advances in molecular biology but stagnation on the genetic front. Diabetologia 39: 1532-1533.
- Bray GA, Bouchard C (1998) Handbook of Obesity. (2nd Edn), Marcel Dekker, New York, USA.
- Farooqi IS, Jebb SA, Langmack G, Lawrence E, Cheetham CH, et al. (1999) Effects of recombinant leptin therapy in a child with congenital leptin deficiency. N Engl J Med 341: 879-884.
- Barsh GS, Farooqi IS, O'Rahilly S (2000) Genetics of body-weight regulation. Nature 404: 644-651.
- 9. Prentice AM, Jebb SA (2003) Fast foods, energy density and obesity: a possible mechanistic link. Obes Rev 4: 187-194.
- Stubbs RJ, Harbron CG, Murgatroyd PR, Prentice AM (1995) Covert manipulation of dietary fat and energy density: effect on substrate flux and food intake in men eating ad libitum. Am J Clin Nutr 62: 316-329.
- Blass EM, Anderson DR, Kirkorian HL, Pempek TA, Price I, et al. (2006) On the road to obesity: Television viewing increases intake of high-density foods. Physiol Behav 88: 597-604.
- Drewnowski A, Darmon N (2005) The economics of obesity: dietary energy density and energy cost. Am J Clin Nutr 82: 265S-273S.
- Rolls BJ, Drewnowski A, Ledikwe JH (2005) Changing the energy density of the diet as a strategy for weight management. J Am Diet Assoc 105: S98-S103.
- Westerterp-Plantenga MS (2004) Effects of energy density of daily food intake on long-term energy intake. Physiol Behav 81: 765-771.
- Ello-Martin JA, Roe LS, Ledikwe JH, Beach AM, Rolls BJ (2007) Dietary energy density in the treatment of obesity: a year-long trial comparing 2 weight-loss diets. Am J Clin Nutr 85:1465-1477.
- 16. Barkeling B, Rössner S, Björvell H (1990) Effects of a high-protein meal (meat) and a high-carbohydrate meal (vegetarian) on satiety measured by automated computerized monitoring of subsequent food intake, motivation to eat and food preferences. Int J Obes 14: 743-751.
- Latner JD, Schwartz M (1999) The effects of a high-carbohydrate, high-protein or balanced lunch upon later food intake and hunger ratings. Appetite 33: 119-128.
- Lejeune MP, Kovacs EM, Westerterp-Plantenga MS (2005) Additional protein intake limits weight regain after weight loss in humans. Br J Nutr 93: 281-289.
- Brehm BJ, D'Alessio DA (2008) Benefits of high-protein weight loss diets: enough evidence for practice? Curr Opin Endocrinol Diabetes Obes 15: 416-421.

- Halton TL, Hu FB (2004) The effects of high protein diets on thermogenesis, satiety and weight loss: a critical review. J Am Coll Nutr 23: 373-385.
- Poppitt SD, McCormack D, Buffenstein R (1998) Short-term effects of macronutrient preloads on appetite and energy intake in lean women. Physiol Behav 64: 279-285.
- Westerterp-Plantenga MS (2004) Modulatory factors in the effect of energy density on energy intake. Br J Nutr 92: S35-S39.
- Rolls BJ, Hetherington M, Burley VJ (1988) The specificity of satiety: the influence of foods of different macronutrient content on the development of satiety. Physiol Behav 43: 145-153.
- Bowen J, Noakes M, Trenerry C, Clifton PM (2006) Energy intake, ghrelin, and cholecystokinin after different carbohydrate and protein preloads in overweight men. J Clin Endocrinol Metab 91: 1477-1483.
- Westerterp-Plantenga MS, Rolland V, Wilson SA, Westerterp KR (1999) Satiety related to 24 h diet-induced thermogenesis during high protein/carbohydrate vs high fat diets measured in a respiration chamber. Eur J Clin Nutr 53: 495-502.
- 26. Farnsworth E, Luscombe ND, Noakes M, Wittert G, Argyiou E, et al. (2003) Effect of a high-protein, energy-restricted diet on body composition, glycemic control, and lipid concentrations in overweight and obese hyperinsulinemic men and women. Am J Clin Nutr 78: 31-39.
- Luscombe ND, Clifton PM, Noakes M, Farnsworth E, Wittert G (2003) Effect of a high-protein, energy-restricted diet on weight loss and energy expenditure after weight stabilization in hyperinsulinemic subjects. Int J Obes Relat Metab Disord 27: 582-590.
- Astrup A, Raben A (1995) Carbohydrate and obesity. Int J Obes Relat Metab Disord 19: S27-S37.
- 29. Poppitt SD (1995) Energy density of diets and obesity. Int J Obes Relat Metab Disord 19: S20-S26.
- Reid M, Hetherington M (1997) Relative effects of carbohydrates and protein on satiety-a review of methodology. Neurosci Biobehav Rev 21: 295-308.
- 31. Saris WH, Astrup A, Prentice AM, Zunft HJ, Formiguera X, et al. (2000) Randomized controlled trial of changes in dietary carbohydrate/fat ratio and simple vs complex carbohydrates on body weight and blood lipids: the CARMEN study. The Carbohydrate Ratio Management in European National diets. Int J Obes Relat Metab Disord 24: 1310-1318.
- Thomas DE, Elliott EJ, Baur L (2007) Low glycaemic index or low glycaemic load diets for overweight and obesity. Cochrane Database Syst Rev 18: CD005105.
- Geiselman PJ, Novin D (1982) Sugar infusion can enhance feeding. Science 218: 490-491.
- Reid M, Hammersley R (1998) The effects of blind substitution of aspartamesweetened for sugar-sweetened soft drinks on appetite and mood. British Food Journal 100: 254-259.
- DiMeglio DP, Mattes RD (2000) Liquid versus solid carbohydrate: effects on food intake and body weight. Int J Obes Relat Metab Disord 24: 794-800.
- Malik VS, Schulze MB, Hu FB (2006) Intake of sugar-sweetened beverages and weight gain: a systematic review. Am J Clin Nutr 84: 274-288.
- Frost GS, Brynes AE, Dhillo WS, Bloom SR, McBurney MI (2003) The effects of fiber enrichment of pasta and fat content on gastric emptying, GLP-1, glucose, and insulin responses to a meal. Eur J Clin Nutr 57: 293-298.
- Melanson KJ, Westerterp-Plantenga MS, Campfield LA, Saris WH (1999) Blood glucose and meal patterns in time-blinded males, after aspartame, carbohydrate, and fat consumption, in relation to sweetness perception. Br J Nutr 82: 437-446.
- Reid M, Hammersley R (1999) The effects of sucrose and maize oil on subsequent food intake and mood. Br J Nutr 82: 447-455.
- Gibney M, Sigman-Grant M, Stanton JL Jr., Keast DR (1995) Consumption of sugars. Am J Clin Nutr 62: 178S-193S.
- Macdiarmid JI, Cade JE, Blundell JE (1995) Extrinsic sugar as vehicle for dietary fat. Lancet 346: 696-697.
- Reid M, Hammersley R (1998) The effects of sugar on subsequent eating and mood in obese and non-obese women. Psychology Health & Medicine 3: 299-313.
- 43. Nordmann AJ, Nordmann A, Briel M, Keller U, Yancy WS Jr, et al. (2006) Effects of low-carbohydrate vs low-fat diets on weight loss and cardiovascular risk factors: a meta-analysis of randomized controlled trials. Arch Intern Med 166: 285-293.
- Samaha FF, Foster GD, Makris AP (2007) Low-carbohydrate diets, obesity, and metabolic risk factors for cardiovascular disease. Curr Atheroscler Rep 9: 441-447.

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- 45. Surwit RS, Feinglos MN, McCaskill CC, Clay SL, Babyak MA, et al. (1997) Metabolic and behavioral effects of a high-sucrose diet during weight loss. Am J Clin Nutr 65: 908-915.
- 46. Poppitt SD, Keogh GF, Prentice AM, Williams DE, Sonnemans HM, et al. (2002) Long-term effects of ad libitum low-fat, high-carbohydrate diets on body weight and serum lipids in overweight subjects with metabolic syndrome. Am J Clin Nutr 75: 11-20.
- 47. Brinkworth GD, Noakes M, Keogh JB, Luscombe ND, Wittert GA, et al. (2004) Long-term effects of a high-protein, low-carbohydrate diet on weight control and cardiovascular risk markers in obese hyperinsulinemic subjects. Int J Obes Relat Metab Disord 28: 661-670.
- 48. Raben A, Agerholm-Larsen L, Flint A, Holst JJ, Astrup A (2003) Meals with similar energy densities but rich in protein, fat, carbohydrate, or alcohol have different effects on energy expenditure and substrate metabolism but not on appetite and energy intake. Am J Clin Nutr 77: 91-100.
- Raben A, Vasilaras TH, Møller AC, Astrup A (2002) Sucrose compared with artificial sweeteners: different effects on ad libitum food intake and body weight after 10 wk of supplementation in overweight subjects. Am J Clin Nutr 76: 721-729.
- Tordoff MG, Alleva AM (1990) Effect of drinking soda sweetened with aspartame or high-fructose corn syrup on food intake and body weight. Am J Clin Nutr 51: 963-969.
- Howarth NC, Saltzman E, Roberts SB (2001) Dietary fiber and weight regulation. Nutr Rev 59: 129-139.
- 52. Pereira MA, Ludwig DS (2001) Dietary fiber and body-weight regulation. Observations and mechanisms. Pediatr Clin North Am 48: 969-980.
- 53. Slavin JL (2005) Dietary fiber and body weight. Nutrition 21: 411-418.
- 54. Heaton KW (1973) Food fibre as an obstacle to energy intake. Lancet 2: 1418-1421.
- 55. He K, Hu FB, Colditz GA, Manson JE, Willett WC, et al. (2004) Changes in intake of fruits and vegetables in relation to risk of obesity and weight gain among middle-aged women. Int J Obesity 28: 1569-1574.
- 56. Koh-Banerjee P, Rimm EB (2003) Whole grain consumption and weight gain: a review of the epidemiological evidence, potential mechanisms and opportunities for future research. Proc Nutr Soc 62: 25-29.

- 57. Lunn J, Theobald HE (2006) The health effects of dietary unsaturated fatty acids. Nutrition Bulletin 31: 178-224.
- 58. Avenell A, Brown TJ, McGee MA, Campbell MK, Grant AM, et al. (2004) What are the long-term benefits of weight reducing diets in adults? A systematic review of randomized controlled trials. J Hum Nutr Diet 17: 317-335.
- Pavlou KN, Krey S, Steffee WP (1989) Exercise as an adjunct to weight loss and maintenance in moderately obese subjects. Am J Clin Nutr 49: 1115-1123.
- Wadden TA, Sternberg JA, Letizia KA, Stunkard AJ, Foster GD (1989) Treatment of obesity by very low calorie diet, behavior therapy, and their combination: a five-year perspective. Int J Obes 13: 39-46.
- [No authors listed] (1990) The Hypertension Prevention Trial: three-year effects of dietary changes on blood pressure. Hypertension Prevention Trial Research Group. Arch Intern Med 150: 153-162.
- 62. de Waard F, Ramlau R, Mulders Y, de Vries T, van Waveren S (1993) A feasibility study on weight reduction in obese postmenopausal breast cancer patients. Eur J Cancer Prev 2: 233-238.
- Summerbell CD, Cameron C, Glasziou PP (2008) WITHDRAWN: Advice on low-fat diets for obesity. Cochrane Database Syst Rev 16:CD003640.
- 64. Blundell JE, Stubbs RJ, Golding C, Croden F, Alam R, et al. (2005) Resistance and susceptibility to weight gain: individual variability in response to a high-fat diet. Physiol Behav 86: 614-622.
- Pescatello L, Murphy D (1998) Lower intensity physical activity is advantageous for fat distribution and blood glucose among viscerally obese older adults. Med Sci Sports Exerc 30: 1408-1413.
- 66. Douchi T, Yamamoto S, Oki T, Maruta K, Kuwahata R, et al. (2000) The effects of physical exercise on body fat distribution and bone mineral density in postmenopausal women. Maturitas 35:25-30.
- Sörensen L, Smolander J, Louhevaara V, Korhonen O, Oja P (2000) Physical activity, fitness and body composition of Finnish police officers: a 15-year follow-up study. Occup Med (Lond) 50: 3-10.
- 68. Lynch JW, Kaplan GA, Salonen JT (1997) Why do poor people behave poorly? Variation in adult health behaviours and psychosocial characteristics by stages of the socioeconomic lifecourse. Soc Sci Med 44: 809-819.
- 69. Müller MJ, Koertzinger I, Mast M, Langnäse K, Grund A (1999) Physical activity and diet in 5 to 7 years old children. Public Health Nutr 2: 443-444.