Obesity (body mass index (BMI) higher or equal to 30 kg/m²), and to a lesser extent overweight (BMI higher or equal to 25 kg/m²), is characterized as an excessive accumulation of energy in the form of body fat. It has reached an epidemic proportion globally and the most recent estimate indicates that more than 1 billion adults worldwide are overweight, of whom at least 300 million are obese. This poses serious health problems and a huge economic burden on society because overweight and obesity lead to adverse metabolic effects on blood pressure, blood lipids, and insulin resistance, consequently increase the risk of chronic diseases such as type 2 diabetes, cardiovascular disease (CVD), hypertension, stroke, certain forms of cancer and premature death.

One of the few non-controversial facts about obesity is that weight is only gained when energy intake exceeds energy expenditure for a prolonged time period. A high total energy intake is the main driver of higher body weights in modern populations. During the past several decades, a large number of studies have investigated the effects of different dietary composition factors and eating behaviours on energy intake, weight gain and obesity. This review addresses some of these factors and summarizes the mechanisms underlying their potential associations with weight change or obesity. Several associated popular weight loss diets are also briefly discussed for their safety and efficacy in the maintenance of weight loss.

**Keywords:** Obesity – weight management – diet – determinants.

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**Introduction**

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**Physiological regulation of food intake**

Food intake is under-sophisticated regulation which involves many psychological, hormonal and nutrient-related factors. In general, it can be divided into two phases: satiation and satiety. Satiation develops during a meal, ends eating, and determines the meal sizes. Satiety develops after foods have been ingested, delays the onset of the next meal and controls the inter-meal intervals. The regulation of energy intake by satiation and satiety is conducted by the hypothalamic signalling pathway. This pathway integrates three main sets of signals.

The first set comprises gut hormones such as cholecystokinin (CCK), glucagon-like peptide-1 (GLP-1) and ghrelin. Ghrelin is the only gut hormone stimulating meal initiation (reducing satiety). CCK and GLP-1 are released from the gut following food consumption to terminate meals (satiation) and their...
effects depend on gastric distention. In addition, metabolites in blood after absorption could influence people's feeling of fullness (satiety). For example, the transient and dynamic declines in blood glucose concentrations could promote eating (glucostatic hypothesis).

Signals secreted by adipose tissue and pancreas, including leptin and insulin, represent the second set of signals. They monitor the nutritional status of the body, mediate the effects of gut hormones on the hypothalamus, and influence the sensitivity of the hypothalamus to satiety hormones such as CCK. For example, leptin deficiency induced by fasting limits the satiating effect of CCK, which, in turn, leads to an increased food intake during a meal, thereby restoring energy balance.

Signals released by the central nerve system, especially the hypothalamus, are the third set of signals and include alpha-melanocyte-stimulating hormone (α-MSH) and its precursor pro-opiomelanocortin (POMC) (inhibits food intake) and neuropeptide Y (NPY) (increases food intake). A simplistic overview of the physiological regulation of energy intake is depicted in figure 1.

**Weight loss, weight maintenance and the prevention of weight gain**

Obesity is a preventable condition and the prevention is easier, less expensive and more effective as compared to the treatment. However, given the current obesogenic environment, which is characterized by an essentially cheap and unlimited supply of convenient, highly palatable, energy-dense foods, coupled with a lifestyle prohibiting a sufficient level of physical activity, the incidence and prevalence of obesity is escalating. Weight reduction, even in a modest amount, among those who are obese could significantly improve obesity-related conditions, such as CVD and diabetes. However, initial weight loss is very difficult to sustain due to the compensatory physiological processes which seem to stimulate a weight regain. The amount of quick weight loss is less important if the weight is eventually regained. In other words, the real challenge of weight loss regimes is to maintain weight loss and prevent weight regain. The main determinant of the amount and rate of weight loss is the extent of energy deficit, while the effects of dietary composition are likely to be very small. For weight loss maintenance,
however, dietary composition might play a role through influencing the insulin secretion and leptin production, thus energy intake and energy balance\(^9\). More importantly, dietary composition could significantly influence cardiovascular risk through its impact on factors other than body composition, such as blood pressure, blood lipid profile, and insulin sensitivity\(^10\).

In the following section of the current tutorial, we summarize the mechanisms of several major dietary determinants of weight change, with a focus on the prevention of weight gain or regain. Popular weight loss diets are briefly discussed for their safety and efficacy in the maintenance of weight loss.

**Dietary determinants of weight change**

**I. DIETARY FACTORS IN RELATION TO OVERALL ENERGY INTAKE**

**Energy density (ED)**

Energy density (ED) is defined as the amount of available energy per unit weight of foods or meals (kJ/g or kcal/g). Experimental data convincingly show that people tend to eat a constant volume/weight of food to feel satiated\(^4\), and, accordingly, energy-dense foods could cause passive over-eating in terms of energy. Furthermore, energy-dense foods, usually high in fat and sugar but low in fibre and water, tend to be less satiating and highly palatable, thus could stimulate over-eating\(^11\). It is believed that the generally accepted harmful impact of high fat diets on obesity is primarily mediated by dietary ED. Several intervention studies consistently demonstrate that ED reduction is associated with weight loss\(^12,13\). Results from most, but not all, of the long-term observational studies also support a positive association between ED and weight gain\(^14-17\).

**Fruits and vegetables**

Fruits and vegetables are fibre rich, low in ED and high in vitamins and antioxidants therefore are of potential benefit for weight control. Although not completely consistent, findings in general support the beneficial role of fruit- and vegetable-rich diets in preventing weight gain\(^18-20\). Therefore, fruits and vegetables are usually included in dietary guidelines to combat obesity.

**Portion size**

Larger portion size is often accompanied by a higher total energy content, and thus could contribute to weight gain\(^21\). Large portion sizes served at restaurants and produced by manufactures may be an important cause for the rising prevalence of obesity\(^22\). However, the influence of portion size on food intake may vary by age\(^23\) and weight status, and may also depend on the ED of the foods, because it is possible that consumption of a larger portion of lower energy dense foods, such as fruits and vegetables, is protective against weight gain\(^21\).

**Eating outside home**

Eating outside home may be a risk factor of obesity because foods prepared at restaurants, especially fast food restaurants, are often of lower nutritional quality and have higher fat and energy contents than foods eaten at home\(^24\). Individuals who eat more fast foods tend to have a higher intake of energy, fat, and soft drinks, and a lower intake of dietary fibre, fruits and vegetables\(^25\). In addition, portion sizes served at restaurants are often larger and the palatability and variety of restaurant-prepared foods are often increased\(^22\). These factors may contribute to an increased energy intake subsequently leading to obesity\(^22\).

**II. FAT INTAKE**

Dietary fat has long been blamed as the main cause for the current obesity epidemic because its higher ED and palatability and lower satiety power could promote energy intake\(^26\). Moreover, its metabolic efficiency is higher (i.e. lower thermogenesis) as compared to carbohydrates and protein. Therefore, the high-fat diet would lead to a more efficient energy storage in the adipose tissue\(^27\). In a meta-analysis of 16 trials comparing ad libitum low-fat diets with control diets, the low-fat intervention group lost on average 3.2 kg more weight than the control group during the 2-12 months intervention periods\(^28\). In a recent analysis of data from the US Nurses’ Health Study, total fat intake was weakly but positively associated with weight gain over 8 years\(^29\). In the Women’s Health Initiative Dietary Modification Trial, weight loss in the first year was more pronounced among women who had the greatest decrease in percentage of energy from fat\(^30\). However, most of the lost weight was regained and the difference in weight loss between the two groups was negligible at the end of the follow-up period\(^30\). Similarly, there is no association between fat intake and long-term weight and waist change observed in a large prospective cohort study in Europe\(^31\).

Not all fats are alike. The harmful effects of saturated fatty acids (SFAs) and the potential health benefits of n-3 polyunsaturated fatty acids (PUFAs) and monounsaturated fatty acids (MUFAs) have been well established in the past two decades\(^32\). These fatty acids may also have different impacts on body fat accumulation, due to their diverse metabolic fate in humans\(^29,33\).
Therefore, encouraging a low SFA, high MUFA and n-3 PUFA diet may favourably influence the metabolic and CVD risk, which is important for those who are overweight or obese.

III. Carbohydrate-related dietary factors

As carbohydrates are stored less efficiently than fat, high carbohydrate foods are thought to reduce weight gain in the long term as compared to high fat diets. However, in spite of the reported cutting down of fat consumption in the western world since decades, the prevalence of obesity has continued to rise. This secular trend data tends to implicate carbohydrate intake as a contributor to the current obesity epidemic. However, there is no clear evidence that altering the energy percentage of total carbohydrate is an important determinant of energy intake, thus weight change.

Carbohydrates are composed of various nutrients which have diverse effects on energy intake and general health. Of particular interest are dietary fibre, free sugars, particularly fructose, sugar-sweetened beverages (SSB), and glycaemic index and load.

Dietary fibre

Dietary fibre is defined as the edible parts of plant foods that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. It can facilitate body weight control through different physiological mechanisms. Firstly, fibre-rich foods tend to be more satiating due to their relatively low energy density and palatability as compared to low fibre foods. Secondly, dietary fibre, especially soluble fibre, could increase the viscosity of diets and slow down the gastric emptying and digestion, thus stimulating the release of gut hormones and promote satiety. In addition, dietary fibre could provide a mechanical barrier to the enzymatic digestion of other macronutrients such as fat and starch in the small intestine. Moreover, the slower digestion and absorption rate of carbohydrates in high fibre foods would lead to a reduced postprandial blood glucose response, which increases satiety and, over a long term, could improve insulin sensitivity and influence fuel partitioning to favour fat oxidation. Findings from many, if not all, studies indicate a beneficial role of dietary fibre in weight control.

Free sugar and fructose

Free sugars are a collection of added sugars and concentrated sugars in honey, syrups and fruit juices. Foods high in free sugars have been proposed to contribute weight gain because they are normally low in fibre and micronutrients, high in ED and palatability which could easily cause overconsumption. Over the past decades, the food industries in the USA and some other countries have increasingly used high fructose corn syrup in manufactured foods such as soft drinks, baked goods, and desserts. This trend is in parallel with the trend in obesity in the US. Fructose follows a different metabolic pathway as compared to glucose: insulin is not increased, leptin is not increased but reduced, and ghrelin is suppressed to a much lesser degree. This will lead to a reduced satiety and a positive energy balance. In addition, fructose ingestion favours de novo lipogenesis, which could increase adiposity and cardiovascular risk. Consumption of fructose-sweetened beverages has been found to increase visceral adiposity and lipids and to decrease insulin sensitivity among overweight or obese people.

Sugar-sweetened beverages (SSB)

Sugar-sweetened beverages (SSB) generally contain a large amount of liquid energy, which is poorly compensated and may result in excess energy intake. In addition, added sugars in the SSB are absorbed rapidly, which may promote visceral fat accumulation due to the insulin resistance and increased de novo hepatic fatty acid synthesis caused by the added sugars. Increased consumption of SSB, mainly soft drinks and fruit juices, is considered as a main driving force for weight gain and obesity, especially among children and adolescents. Although large high-quality clinical trials are lacking, the evidence in general supports that consumption of SSB is a probable risk factor for obesity.

Glycaemic index and glycaemic load

The glycaemic index (GI) is a quantitative measure of carbohydrate quality based on the blood glucose response after consumption. Glycaemic load (GL) measures the entire blood glucose-raising potential of dietary carbohydrates and is calculated as the product of GI and total carbohydrates. It has been suggested that low GI or GL diets can help to prevent body weight gain and stimulate weight loss. This is because the mild blood glucose and insulin response following a low GI or GL diet consumption could stimulate a higher satiation and satiety, thus leading to a decrease in energy intake, regulate energy partitioning resulting in a reduced fat storage, and limit the decrease of the resting metabolic rate under energy restriction. However, findings in literature are inconsistent. For example, some trials found that low GI and low GL diets are more effective in promoting body fat loss...
(~1 kg more) than comparison diets\textsuperscript{54,55}, but not the others\textsuperscript{56,57}. Some cohort studies found that GI was positively associated with a change in weight or waist circumference, but not GL\textsuperscript{34,58}. Some found low GI diets associated with a lower weight and waist circumference gain in women, but not in men\textsuperscript{59}.

IV. PROTEIN INTAKE

Protein has a higher satiety value than iso-energetic quantities of other macronutrients, and therefore higher protein intake could decrease total energy intake\textsuperscript{60}. Also, protein has a greater thermogenic effect and may therefore result in an increased energy expenditure\textsuperscript{61}. In the USA, the consumption of protein, both at absolute level and as percentage of total energy intake, has remained relatively stable during the past decades, while the obesity prevalence has increased dramatically\textsuperscript{62,63}. Although these secular trend data do not support the hypothesis that protein plays an important role in the development of obesity, several recent studies have observed an inverse association between protein intake and obesity\textsuperscript{64,65}. Furthermore, some researchers proposed the so-called ‘protein leverage hypothesis’, which means that the body must be supplied with a certain level of dietary protein\textsuperscript{66}. When a protein-rich diet is consumed, this demand can be easily reached with a lower level of fat and carbohydrate thus total energy intake, otherwise a higher amount of total energy must be consumed to obtain enough protein.

Popular weight loss diets

I. ATKINS DIET

The Atkins diet, the most popular weight-loss diet to date, was first introduced in the 1970s by Dr. Atkins. It involves restricting carbohydrates severely (≤ 20 g per day for the induction phase and ≤ 50 g per day after for the ongoing weight loss phase) to produce ketosis. The underlying reasons for the weight loss effects of the Atkins diet include the satiating effect of protein, possible appetite suppression effect of ketosis, reduced energy intake caused by restrictive food choices, and the greater loss of water and glycogen\textsuperscript{60}. In addition, the reduced carbohydrate intake could lead to a lowered insulin response thereby promoting lipolysis and causing body fat loss\textsuperscript{67}.

In a one-year intervention study conducted by Dansinger et al., the Atkins diet was not associated with a larger weight loss as compared to the other popular weight loss diets\textsuperscript{68}. A larger dropout rate was observed and the sustained adherence to an assigned diet, rather than the type of diet, was the main determinant of weight loss and cardiac risk factor reduction in this study\textsuperscript{68}. In another study, the Atkins diet produced a substantially larger weight loss and improvement in cardiovascular risk factors as compared to other weight loss programs at the initial stage, but most of the lost weight was regained during the weight maintenance phase\textsuperscript{69}. In the study by Gardner et al. weight loss was significantly larger in the Atkins diet group at 12 months\textsuperscript{70}, but the greater speed of relapse may implicate that the difference between the groups would disappear if the study continues. Therefore, there is still insufficient evidence to make recommendations for or against this diet\textsuperscript{71}.

Dietary quality comparison of a range of popular weight loss diets has shown that the Atkins diet had the lowest score (worst quality)\textsuperscript{72,73}. The high fat - especially saturated fat - and cholesterol contents of the Atkins diet is the major concern due to the potential hazardous effect on cardiovascular risks\textsuperscript{67,71}. Long-term prospective studies investigating the impact of the Atkins diet on the morbidity and mortality of CVD are lacking. Furthermore, this type of diet is inherently low in whole grains, cereals and fruits and therefore may be nutritionally inadequate: low in vitamins E, A, thiamin, B\textsubscript{6}, folate, calcium, magnesium, iron, potassium, and dietary fibre\textsuperscript{6}.

II. WEIGHT WATCHERS

Weight Watchers\textsuperscript{®} is a commercial weight loss program based on long-standing medical advice. The diet emphasizes a high fibre, low ED and small portion size\textsuperscript{68}.

In a 2-year randomized trial with more than 400 obese subjects, the weight losses at 1 year and 2 years were greater among subjects in the Weight Watchers\textsuperscript{®} group (4.3 kg at 1 year and 2.9 kg at 2 years) as compared to those in the control group (1.3 kg and 0.2 kg, respectively)\textsuperscript{74}. However, in another trial comparing the effects of Weight Watchers\textsuperscript{®} with other popular weight loss diets, including the above mentioned Atkins diet, none of these diet plans led to a significantly larger weight loss at 1 year\textsuperscript{68}.

The dietary quality evaluation has revealed that the Weight Watchers\textsuperscript{®} and the Ornish diet (discussed later) have a relatively higher quality compared to other popular weight loss diets implicating their potential benefits for CVD prevention\textsuperscript{75}. No foreseeable safety problem has been reported for the Weight Watchers\textsuperscript{®}.

III. ORNISH DIET

The Ornish dietary plan was first described by Dr. Ornish in his book Eat More, Weigh Less and is basically a vegetarian diet which is characterized as a strict
restriction on high fat foods (<10% of total energy intake), including oils, nuts, seeds, meat, poultry, and fish. It is very high in carbohydrates, such as fruits, vegetables, legumes and whole grains. These foods are generally healthy with a potential to reduce the risk of many chronic diseases including CVD, diabetes and cancer.

Low fat diets could result in more weight reduction as compared to control diets in clinical trials of short term. In long-term studies (>1 year), however, the impact of the fat percentage was low. In the two recent clinical trials comparing the effects of the Ornish diet with the Atkins diet and other popular weight loss diets on weight, the Ornish diet did not provide extra benefits in 12 months. Nevertheless, there was no trend of relapse in weight loss from the 6th month to the 12th month of the intervention. This is in line with earlier evidence showing that a low fat, high carbohydrate diet has a better long-term effect for maintaining weight loss.

Because meat and fat intake is extremely low, following the Ornish dietary plan may cause vitamin E, B₁₂ and zinc deficiency.

IV. ZONE DIET

The Zone diet was introduced by Dr. Sears in 1995 advocating a “40:30:30” ratio of calories from carbohydrates, proteins, and fats, respectively. This represents a 0.75 ratio of protein to carbohydrates, which is approximately three times the ratio of 0.25 according to the conventional dietary recommendation. The “Zone” is a term for a metabolic state in which the human body operates at optimal efficiency: the insulin to glucagon ratio is reduced, allowing the excess body fat to be burned and leading to the production of good anti-inflammatory eicosanoids.

Short-term studies have found that high protein diets are more effective for preventing weight regain and preserving fat free mass. Several long-term intervention studies have found that a high protein diet is associated with improved weight maintenance and a reduced CVD risk. For example, Clifton and colleagues have observed that a higher protein (protein to carbohydrates ratio = 46:34) intake led to a larger weight loss after 1 year as compared to those reporting a higher carbohydrates diet (ratio = 17:64). In the OmniHeart study, substitution of carbohydrates with protein has been associated with lowered blood pressure, improved lipid levels, and reduced estimated cardiovascular risk. But, recent clinical trials comparing the effect of the Zone diet with the Ornish diet and the Atkins diet failed to observe any significant benefits of the Zone diet in promoting body weight or fat loss or preserving lean body mass. Therefore, the currently available scientific literature does not support a beneficial role of the Zone diet for weight control and general health.

Although long-term data on the risk of a high protein diet is still lacking, protein, especially from animal sources, is generally associated with total fat, saturated fat, and cholesterol. Therefore long-term high protein consumption may cause an increased risk of CVD. It is also of concern that a high protein diet may have potential deleterious effects on the kidneys. Moreover, a relatively low level of carbohydrate intake may lead to a low intake of vitamins and fibre.

Challenges to dietary research

In spite of the wide awareness of the obesity problem, there are actually only a few high-quality long-term dietary intervention studies on weight change. One of the potential reasons is the low compliance rate. It is very difficult to promote a substantial and sustainable lifestyle behaviour change, due to all kinds of internal and external barriers. For example, in the above mentioned study by Dansinger et al., 42% of participants did not complete the study at 12 months and the main reasons for the dropout were either ‘dis-like the diet’ or ‘unable to adhere’. In another study comparing the weight loss effects of 4 diets with different macronutrient composition by Sacks et al., the protein intake difference between the high-protein-diet group and the average-protein-diet group was intended to be 10% of energy, but the actual difference was only 1-2% difference.

Another main challenge in dietary intervention trials, as well as in observational studies with dietary exposures, may be the inaccuracy of dietary measurements, especially among obese individuals. This may limit the strength of the conclusions derived. To overcome this problem, some dietary intervention trials provided all the foods and beverages, free of charge, to the study participants, through either a study supermarket or controlled-feeding program. This promotes a better monitoring of the food consumption, avoids reporting errors, and may also increase compliance. However, it may cause a tendency of over-eating and is not of benefit for the establishment of a sustainable behaviour change. New technologies, such as metabonomics, may provide more accurate measurements of dietary exposures in the future.

Conclusion and recommendation

The fundamental point for weight control is the energy balance. Multiple dietary approaches are available to prevent excessive energy intake, such as increase the intake of fruits and vegetables, choose small portion size, and stay away from sugar-sweetened beverages.
For body fat loss, the degree of energy deficit is the predominant determinant and adherence determines whether the lost weight will be regained. Maintaining a healthy body weight is a lifelong task therefore people should choose a diet best suited to his or her food preferences, budget, lifestyle, daily challenges and medical conditions to maximize long-term adherence. More importantly, being physically active and having a balanced nutritionally adequate diet are critical for health, where the ultimate purpose of losing extra weight lies. A diet high in healthy substances, such as low GI complex carbohydrates, fibre, MUFA's, n-3 PUFAs and plant protein, but low in calories and harmful or less healthy compounds such as SFA, trans-fatty acids, cholesterol, free sugars and red meat may be optimal.

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