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Different dietary strategies for weight loss in obesity: role of energy and macronutrient content

I. Abete, M. D. Parra, M. A. Zulet and J. A. Martínez*

Department of Physiology and Nutrition, University of Navarra, Irunlarrea s/n, 31008 Pamplona, Spain

Obesity is a chronic disorder caused by an imbalance of the energy metabolism with high associated burdens. Therefore, huge efforts are being currently devoted in studying new types of hypoenergetic diets and their composition, in order to characterise more specific, long-lasting and safe slimming protocols. A number of investigations are trying to determine the specific influence of the macronutrient distribution in energy-restricted diets on the management of excessive body weight. In this context, very-low-energy diets supplying between 1670 and 3350 kJ (400 and 800 kcal)/d have been beneficial in short-term treatments causing a weight loss of 300–500 g/d. Such strategies place more emphasis on energy restriction than on the macronutrient composition of the diet prescription. Weight loss produced by either low-carbohydrate or low-fat moderately energy-restricted diets ranges from 0·5 to 1·0 kg/week, while diets with high or moderately high protein content have also been applied in weight-reducing programmes by inducing losses of 0·2–0·4 kg/week. Other factors that determine weight loss by dieting are sex, age, initial body weight, race, genetics, regional fat deposition, etc, which must be taken into account to explain the variability in the outcomes of different low-energy diets. Therefore, more research is needed about the impact of diets with different fuel substrates and foods on the characteristics of the weight-loss process.

Obesity: Macronutrient distribution: Energy-restricted diets: Low-carbohydrate diets: Low-fat diets: Weight loss

Introduction

Obesity is a major global health problem that has been associated with highly occurring disorders such as hypertension, type 2 diabetes, hyperinsulinaemia, dyslipidaemia, atherosclerosis and certain types of cancer (Cheah & Kam, 2005). Indeed, the epidemic of overweight and obesity, which is rising worldwide, inflicts not only a reduced life quality and large healthcare-associated costs, but also an increased risk of death (Wyatt, 2003; Popkin & Gordon-Larsen, 2004).

Nowadays, the increasing Westernisation, urbanisation and mechanisation occurring in most countries around the world are accompanied by changes in the diet towards high-energy-yielding food consumption and a sedentary lifestyle (Popkin, 2001; Gordon-Larsen *et al*. 2004). This shift is also related to the current rapid changes in the rates of childhood and adult obesity (Swinburn *et al.* 2004). Trend analysis in relation to obesity suggests that in most countries the majority of the population is less active than they should be for maintaining good health, while they are simultaneously eating more than they need (Jebb, 2005). Weight gain is considered as a consequence of excessive energy intake as compared with energy expenditure, while successful weight loss depends upon achieving negative energy balance (Walker & O'Dea, 2001). In this context, environmental influences, such as an inactive lifestyle and the consumption of energy-dense diets, appear of overriding importance on excessive weight gain in addition to genetic predisposition (Kemper *et al.* 2004; Marti *et al.* 2004).

Drugs currently available are able to help the obese patient lose up to 10 kg body weight within the first year of treatment, but their potential effectiveness in the long term, not least with regard to adverse effects, is unclear (Petersen & Harper, 2004). Thus, pharmacological therapy is considered as a supplement to lifestyle intervention, which is a commonly used approach to treat the obese patient, through the adherence to specific dietary and/or physical exercise programmes. In fact, weight loss and, more importantly, long-term maintenance of the weight loss, is likely to involve behavioural changes in habits and dietary skills. Indeed, patients with better compliance to a slimming programme tend to achieve a better weight loss than those with poorer adherence (Petersen & Harper, 2004).

Weight management in the obese may take into account the energy intake and the dietary macronutrient distribution.

Abbreviation: VLED, very-low-energy diet.

* **Corresponding author:** Professor J. Alfredo Martínez, fax +34 948425649, email jalfmtz@unav.es

Therefore, a number of nutritional approaches and diets with different proportions of lipids, proteins and carbohydrates are being investigated (Table 1), which may be energy restricted or prescribed *ad libitum* (Bravata *et al.* 2003; Plodkowski & St Jeor, 2003; Volek *et al.* 2005). However, not only the different macronutrient composition is of interest, but also the micronutrient content and specific dietary components could also be important (Rodriguez *et al.* 2005). Thus, previous studies have shown that dietary fibre improves the benefits of weight-reducing diets (Slavin, 2005), while PUFA and MUFA are factors contributing to weight loss and preventing weight gain (Grundy *et al.* 2002; Nettleton & Katz, 2005). Furthermore, it has been proposed that the glycaemic index of foods can influence body-weight control (Acheson, 2004). Short-term studies suggest that low-glycaemic index carbohydrates and fibre intake could delay hunger and decrease subsequent energy intake compared with high-glycaemic index foods (Roberts, 2003). On the other hand, dietary Ca could play a role in controlling body weight, since epidemiological human studies support an association between long-term Ca intake, particularly from skimmed dairy products, and body-weight reduction (Schrager, 2005).

The present review reports a nutritional perspective about the implementation of different dietary strategies devised for overweight and obesity treatments based not only on energy restriction, but also on changes in the macronutrient distribution of the prescribed diet.

Balanced low-energy diet

The prescription of nutritionally equilibrated low-energy diets is a common strategy for body-weight reduction (Finer, 2001). These diets are designed according to traditional nutrient recommendations to supply a balanced ratio of protein (10–20 % energy), carbohydrate (50–65 % energy), and fat (25–35 % energy) in reduced quantities to provide an energy intake of 3350–6280 kJ (800–1500 kcal)/d (Finer, 2001).

Hypoenergetic diets can achieve short-term weight loss, but often the slimming process is not sustainable in the long term (Pirozzo *et al.* 2002). The comparison of different nutritional strategies designed to produce weight loss suggests that specifically fat-restricted diets were no better than traditional energy-restricted diets in achieving long-term weight loss in overweight or obese individuals (Fig. 1).

A typical intervention study (Labayen *et al.* 2004) conducted in obese women (BMI $>30\,kg/m^2$), who followed a 10-week balanced dietary hypoenergetic intervention regimen, was able to induce a body-weight loss of 4·2 (SD 1·1) kg, while the percentage body fat decreased by about 5 %. Another conventional trial evaluated during 2 months the efficacy and safety of a moderately hypoenergetic diet based on the Mediterranean diet model by assessing the changes in body composition and in the metabolic profile in obese women (De Lorenzo *et al.* 2001). Following such a diet, body weight decreased −4·9 (SD 0·9) kg and basal insulin decreased significantly too, indicating that balanced low-energy diets prevent loss of fat-free mass and improve metabolic parameters in obese individuals.

Conventional balanced low-energy diets seem to be most efficient when prescribed in addition to group therapy than other more restrictive diets (Arai *et al.* 1992), but the long-term success of dietary treatment for obesity based upon these approaches is unclear (Monnier *et al.* 2000).

A study about the effect of energy restriction and diet composition on weight loss and changes in plasma lipids and glucose levels concluded that all energy-restricted diets improve glycaemic control independently of diet composition, while only the lipoprotein profile was affected by the macronutrient composition (Heilbronn *et al.* 1999).

However, the traditional nutritionally adequate low-energy diets frequently failed to promote stable weight losses, and the explanations for such limited success were mostly the ‘poor adherence’ to specific low-energy diets. Despite that, it has been reported that following a balanced but energy-restricted diet is accompanied by increases in fat utilisation (Labayen *et al.* 2004), weight loss induced by a balanced energy-restricted diet reduces BMR, which makes the maintenance of the slimming process difficult (Stubbs *et al.* 1996).

Very-low-energy diets

Very-low-energy diets (VLED) provide less than 3350 kJ (800 kcal)/d, being designed to cover the daily allowances of all essential nutritional requirements (Foster *et al.* 1992). The purpose of VLED is to achieve a large weight loss, while providing adequate nutrition and preserving vital lean body mass (Mustajoki & Pekkarinen, 2001), averaging weight losses of 20 kg in 12 weeks in some cases (Wadden *et al.* 1983). The VLED are used in weight reduction programmes in many obesity clinical settings, but their usefulness in the treatment of obesity is not fully established. The applications of this kind of diets have no apparent serious harmful effects and can safely be used in patients suffering chronic diseases under supervision

Table 1. Summary of dietary features and associated weight losses achieved by different nutritional intervention strategies to treat obesity

Diet	Features	Application	Weight loss (kg/week)
Hypoenergetic diets	<5020 kJ (<1200 kcal)/d	6–12 months	0·5–1·5
Very-low-energy diets	<1670 kJ (<400 kcal)/d	2–4 weeks	1·2–2·0
High-fat diets (↓ carbohydrate)	*Ad libitum*	3–6 months	0·3–0·4
Low-fat diets (↑ carbohydrate)	Energy restriction	6–10 weeks	0·5–1·0
Low-fat diets (↑ carbohydrate)	*Ad libitum*	3–6 months	0·2–0·3
High-protein diets	Energy restriction	4–12 weeks	0·5–1·0

↓, Decreased; ↑, increased.

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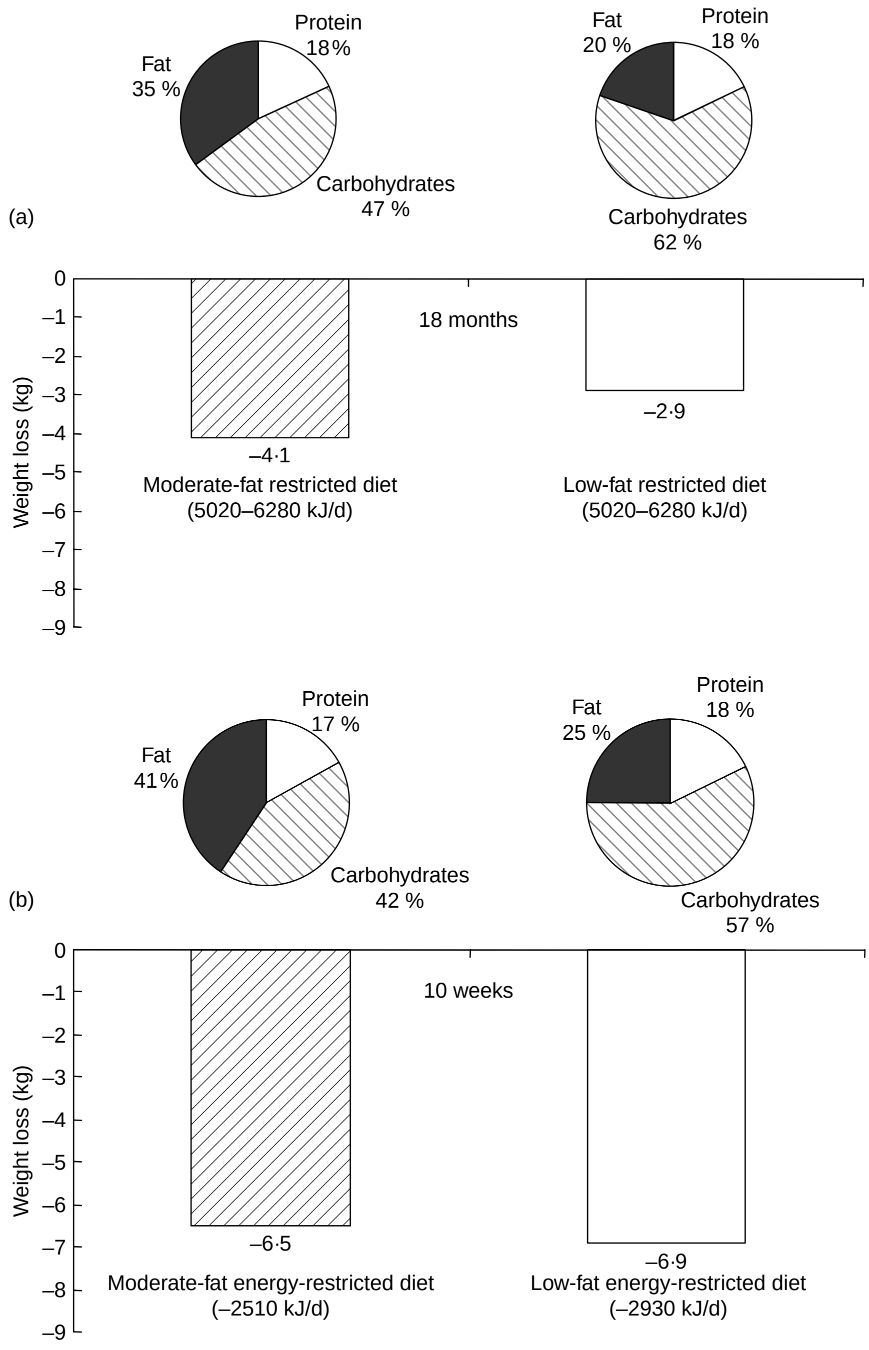

Fig. 1. Weight losses induced by several hypoenergetic diets, following two energy-restricted approaches with different fat or carbohydrate content and similar energy coming from proteins. (a) From McManus *et al.* (2001); (b) from Petersen *et al.* (2006).

(Hart & Warriner, 2005). Hence, VLED are used when rapid weight loss is needed because of an obesity-related disease or for bariatric surgery preparation (Mustajoki & Pekkarinen, 2001).

A VLED can be based on normal food when a protein source, vitamins and trace elements are added (Wadden & Stunkard, 1986). The amount of daily carbohydrate intake in VLED preparations varies from 10 to 80 g, but the optimal amount of carbohydrate has not been established at present. An argument for low carbohydrate content is the fact that there is better protein sparing and fat mobilisation; however, this issue is still controversial despite early studies in this area (Wadden *et al.* 1983). Daily fibre intake varies from almost nothing to 20 g and the amount of fat supplied differs from 1 to 20 g (Kamrath *et al.* 1992).

The major problem to be resolved is the long-term maintenance of the large weight losses achieved with these diets (Wadden *et al.* 1983). In fact, VLED lead to greater initial weight loss, but the long-term outcome seems to be no better than more moderate energy-restricted diets

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(Hensrud, 2004). Metabolic rate and fat-free mass decrease secondary to rapid weight loss in patients after a VLED compared with moderate energy-restricted diets (Wadden *et al.* 1990). On the other hand, the combination of a VLED with a moderate energy-restricted diet, behaviour modification or medications does not improve long-term results produced by diet alone (Mustajoki & Pekkarinen, 2001). However, it has been reported that ongoing, intermittent use of a VLED might improve long-term results (Lantz *et al.* 2003).

The application of behavioural therapies with and without VLED programmes revealed that the mean weight loss ranged from 9·2 to 19·3 kg and the non-VLED programmes ranged from 6·2 to 14·3 kg (Mustajoki & Pekkarinen, 2001). Studies with 1- or 2-year follow-up have shown a mean weight loss of 7·2–12·9 kg with VLED and 5·7–9·5 kg without VLED (O'Neil & Jarrell, 1992). Thus, no trial has conclusively shown that the long-term VLED are better than non-VLED programmes (Mustajoki & Pekkarinen, 2001) because weight loss is rapidly regained (Wing, 1995; Hensrud, 2004).

Ryttig *et al.* (1997) compared the weight loss on a balanced low-energy diet to that of a VLED after 2 months of treatment and further compared the weight maintenance after 26 months in obese patients. During the first 2-month period, the mean body-weight loss in the VLED group was 18·9 (SD 7·1) kg compared with 7·2 (SD 4·8) kg in the hypoenergetic diet-treated group. Weight losses and drop-out rates were similar in all groups. Previously, Kekwick & Pawan (1956) looked for the factor with the greater effect on weight loss by VLED: restriction of energy or alteration in the proportions of macronutrient through different series of diets. In the first series, the proportions of protein, carbohydrate and fat were kept constant and the intake of energy was varied. In all of them protein supplied about 20 %, fat 33 % and carbohydrate 47 % of the energy. In diets of the second series, the patients followed dietary patterns in which the energy intake was kept constant at 4180 kJ (1000 kcal)/d and 90 % of it was provided, in turn, by carbohydrate, fat or protein. They found that weight loss was proportional to the deficiency in energy intake when the proportions of macronutrients were kept constant at each level of energy restriction, while when energy intake was constant at 4180 kJ (1000 kcal)/d, the rate of weight loss varied greatly on diets of different composition (Kekwick & Pawan, 1956).

The comparison of a 3350 kJ (800 kcal) mixed diet and a 3350 kJ (800 kcal) ketogenic low-carbohydrate high-fat diet on the composition of weight loss for 2 weeks revealed that subjects on the 3350 kJ (800 kcal) ketogenic diet lost 466·6 (SE 51·3) g/d, while on the isoenergetic mixed diet, which provided carbohydrate and fat in conventional proportions, they lost 277·9 (SE 32·1) g/d (Yang & Van Itallie, 1976). Interestingly, these researchers found that the mean quantity of fat lost during the ketogenic diet was 163·4 g/d, compared with 166·7 g/d lost during the isoenergetic mixed diet, and the differences should be related to distinct water losses. On the other hand, Wadden *et al.* (1985) compared two VLED: protein-sparing modified fast *v.* protein-formula liquid diet. Both diets provided about 1670 kJ (400 kcal) daily. Analysis of the appetite data showed that protein-sparing-modified-fast subjects reported significantly less hunger and concerns with eating than liquid-diet subjects during 2 out of the 4 weeks on a VLED. Although the energy intake was similar, the form seemed to be crucial for the therapy success (Wadden *et al.* 1985).

At the moment, there is a general agreement that VLED should not be used alone, but always in connection with cognitive and behaviour counselling for permanent lifestyle changes (Mathus-Vliegen, 2005). During short periods of time, these diets are an alternative to other conservative weight-reduction programmes in patients who meet the indications, although research about the best formula for this type of diet is needed to improve the adherence.

High-fat and low-carbohydrate diets

High-fat diets are also being currently studied as an alternative in the nutritional treatment of obesity (Dansinger *et al.* 2005). These diets are commonly referred to as low-carbohydrate diets, since they usually contain a relatively low proportion of carbohydrate (Jebb, 2005). The content of fat is usually about 45 to 65 %, while the carbohydrate content can be $<$ 30 % as energy per d (Fig. 2).

There is a widespread and growing interest in high-fat diets (for example, the 'Atkins diet') in relation to other more conventional approaches (McAuley *et al.* 2005). Individuals are attracted to follow low-carbohydrate diets because they are prone to think that energy intake is not important in a slimming programme and that they can eat as much fat as they like and still lose weight (Roberts, 2001; Ornish, 2004). The mechanisms responsible for decreased energy intake as induced by a low-carbohydrate diet with unrestricted protein and fat intake are not completely elucidated, but the higher consumption of protein may play a role in limiting food intake, through changes in plasma or central satiety factors or through other specific mediators that affect appetite and dietary adherence (Foster *et al.* 2003; Mithieux *et al.* 2005). This fact raises the possibility that a very-low-carbohydrate diet, normally associated with a high protein intake, could be more satiating. Many short-term studies suggest that individuals on low-carbohydrate diets voluntarily reduce their food intake (Volek *et al.* 2000). Energy intake restriction can also be related to the monotony or simplicity of the diet, because food carbohydrate choices are greatly limited by the requirements of minimising carbohydrates intake (Brehm *et al.* 2003; Samaha *et al.* 2003).

Freedman *et al.* (2001) stated that individuals consuming high-fat, low-carbohydrate diets may lose weight because the intake of protein and fat is self-limiting and overall energy intake is decreased. Many individuals following this diet successfully lose weight in the short term; however, few can sustain the significant dietary and lifestyle changes required to maintain losses over the long term (Wilkinson & McCargar, 2004). Furthermore, restricting carbohydrates involves fat mobilisation producing ketone bodies. In this condition, the key benefit is that blood glucose and insulin levels are reduced, and appetite is suppressed. Several authors contend that a high-fat, low-carbohydrate diet results in weight loss, body fat loss, preservation of lean body mass, and correction of serious medical complications of diabetes (Bernstein, 1997), heart disease, and high blood pressure (Atkins, 1992). Indeed, the low-carbohydrate diet brings a dramatic weight reduction within the first few days, but much of this weight is a loss of glycogen and protein accompanied by a depletion of large quantities of water and minerals. Still, for many individuals the low-carbohydrate diet is apparently believed to be associated with a greater weight loss with less effort than conventional or high-carbohydrate diets in the longer term (Bravata *et al.* 2003); despite that, controlled trials have only recently been carried out concerning this issue following energy restriction or *ad libitum* approaches (Fig. 2).

In this context, Foster *et al.* (2003) conducted a trial to evaluate the efficacy of a high-fat low-carbohydrate diet on weight loss. Obese men and women were randomly assigned to either an *ad libitum* low-carbohydrate, high-protein, high-fat diet (without restricting consumption of fat and protein) or a low-energy, high-carbohydrate, low-fat diet designed to contain 5020–6280 kJ (1200–1500 kcal)/d for women and 6280–7530 kJ (1500–1800 kcal)/d for men (60 % carbohydrate, 25 % fat, 15 % protein). In the high-fat group, carbohydrate intake was limited to 20 g/d for the first 2 weeks and then it was gradually increased until a stable and desired weight was achieved. Subjects on the low-carbohydrate diet lost more weight than subjects on the conventional diet at 3 months (−6·8 (SE 5·0) *v.* −2·7 (SE 3·7) % body weight) and 6 months (−7·0 (SE 6·5) *v.* −3·2 (SE 5·6) % body weight), although the differences at 12

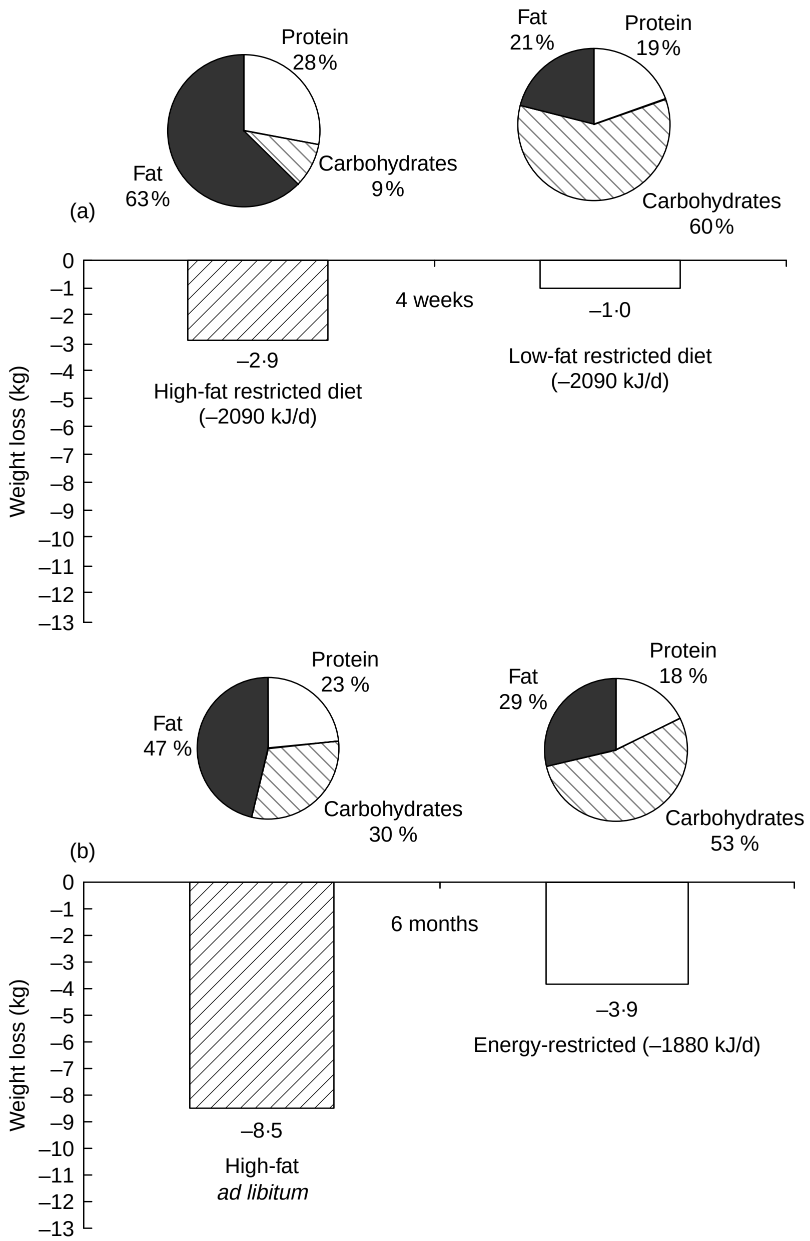

Fig. 2. Weight losses induced by diets with very different fat content (high *v.* low) when prescribed *ad libitum* or under an energy-restriction pattern. (a) From Volek *et al.* (2004); (b) from Brehm *et al.* (2003).

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months were not significant. The analysis of the differences in weight loss in this trial demonstrates an overall greater energy deficit in the low-carbohydrate group, which contrasted with the instructions to reduce energy intake in the conventional-diet group (Foster *et al.* 2003).

Additionally, Brehm *et al.* (2003) found a spontaneous restriction of food intake in a high-fat low-carbohydrate group to an equal level to that of the control subjects, who were following a prescribed restriction of energy. In this intervention trial, obese volunteers were randomised to follow during 6 months either an *ad libitum* very-low-carbohydrate diet or an energy-restricted diet with 29 % energy as fat. The very-low-carbohydrate group lost more weight (−8·5 (SE 1·0) *v.* −3·9 (SE 1·0) kg) and more body fat (−4·8 (SE 0·67) *v.* −2·0 (SE 0·75) kg) than the low-fat-diet group after 6 months (Fig. 2).

Later, Stern *et al.* (2004) reported preliminary results at 6 months and final results at 1 year on obese individuals following a high-fat low-carbohydrate regimen. Participants received counselling to either restrict carbohydrate intake to less than 30 g/d or to restrict energy intake by 2090 kJ (500 kcal)/d with less than 30 % energy from fat. Individuals on the low-carbohydrate diet maintained most of their 6-month weight loss, whereas those on the conventional diet continued losing weight throughout the year. The final weight loss at 1 year was not different between both strategies.

Furthermore, Yancy *et al.* (2004) fed overweight, hyperlipidaemic volunteers either a low-carbohydrate diet (less than 20 g carbohydrate daily) or a low-fat diet (with less than 30 % fat, <300 mg cholesterol daily and a deficit of 2090–4180 kJ (500–1000 kcal)/d) to induce weight loss. After 24 weeks of treatment, weight loss was greater in the low-carbohydrate- than in the low-fat-diet group (mean change, −12·9 *v.* −6·7 %). Patients in both groups lost substantially more fat mass (change, −9·4 kg with the low-carbohydrate diet *v.* −4·8 g with the low-fat diet) than fat-free mass (change, −3·3 *v.* −2·4 kg, respectively).

McAuley *et al.* (2005) compared in a randomised trial a high-fat, a high-protein and a conventional diet in overweight insulin-resistant women. Body weight, waist circumference, triacylglycerols and insulin levels decreased with all three diets, but, apart from insulin, the reductions were significantly greater in the high-fat and high-protein groups than in the conventional-diet group.

On the other hand, the type of fat in the diet may play an important role (Mozaffarian, 2005). Thus, higher proportions of PUFA have been associated with improvements in cardiovascular risk factors (Nettleton & Katz, 2005).

No definitive evidence exists to suggest that high-fat low-carbohydrate diets have a metabolic disadvantage over more conventional diets for weight reduction (Astrup *et al.* 2004). Studies consistently show that under conditions of negative energy balance, weight loss is more a function of energy intake, rather than diet composition. In some cases, individuals on high-fat low-carbohydrate diets appear to lose weight because they consume less energy.

High-carbohydrate and low-fat diets

Low-fat diets are specifically designed to promote weight loss through a reduction of fat consumption in order to decrease energy intake, which is usually accompanied by a high or moderately high carbohydrate supply (Strasser & Pichler, 2004). These high-carbohydrate low-fat diets are based primarily on the intake of vegetables, fruits, whole grains and beans, non-fat dairy products and small amounts of white flour, sugar and animal protein, which may benefit from a rotating model for changing the variety of specific food groups (Raynor *et al.* 2004). The low-fat approach has been applied either in energy-restricted protocols, but also in *ad libitum* strategies (Astrup *et al.* 2002).

Diets with a high carbohydrate (low fat) content may provide protection against weight gain, but if the diet is rich in sugar, this association may not apply (Swinburn *et al.* 2004). Simple sugars have hedonistic value and sweetening increases the palatability of many foods, which may lead to overconsumption (Drewnowski, 1999). Research in this area is complicated by the diversity of dietary carbohydrates, which may be identified on the basis of their fibre content, proportion of whole grain, non-milk extrinsic sugar or added sugar content (Jebb, 2005).

There are important associations between the type of carbohydrate consumed and the risk of metabolic diseases (Jebb, 2005). *Ad libitum* programmes based upon low-fat product intake have shown that the nature of the carbohydrate content, (single *v.* complex) could be involved in the weight evolution (Astrup *et al.* 2002). Low-fat high-carbohydrate diets usually mean consuming more high-complex carbohydrates and high-fibre foods due to the reduced energy value of these compounds as compared with lipids (Raben *et al.* 2002). This low energy density strategy enables individuals to eat as much as they want, and to lose weight safely without apparent hunger (Freedman *et al.* 2001), while low-fat energy-restricted diets combine a reduced fat intake within a hypoenergetic diet.

The prescription of hypoenergetic low-fat diets to reduce body weight with at least 55 % of the energy coming from carbohydrates has shown that a reduced content from fat (<25 %) is associated with similar (Pelkman *et al.* 2004; Petersen *et al.* 2006) or lower weight losses (McManus *et al.* 2001; Volek *et al.* 2004), although a specific role from carbohydrate (quality and quantity) or protein intake should not be discarded in such experimental outcomes (Figs. 1, 2 and 3). Also, the fatty acid composition, i.e. long-chain triacylglycerols *v.* medium-chain triacylglycerols (Kasai *et al.* 2003; St-Onge & Jones, 2003), or the MUFA *v.* PUFA content (Colette *et al.* 2003; Pelkman *et al.* 2004), of the slimming diets could be involved in the weight-loss evolution (Fig. 3).

Hays *et al.* (2004) designed a study to examine the effect of a 12-week *ad libitum* high-carbohydrate diet with different fibre content. A control diet (1·7 g fibre/1000 kJ; 7 g fibre/1000 kcal) and a high-carbohydrate diet (6·2 g fibre/1000 kJ; 26 g fibre/1000 kcal) were investigated (Fig. 4). The low-fat groups with fibre lost more body weight (−3·2 (SEM 1·2) kg) and a higher percentage of body fat (−2·2 % (SEM 1·2) %) than controls (0·1 (SEM 0·6) kg and 0·2 % (SEM 0·6) %) respectively, even with no measurable decrease in total energy intake.

Also, Poppitt *et al.* (2002) studied the long-term effects of an *ad libitum* high-carbohydrate low-fat diet. Thus, subjects with metabolic risk factors received a control diet,

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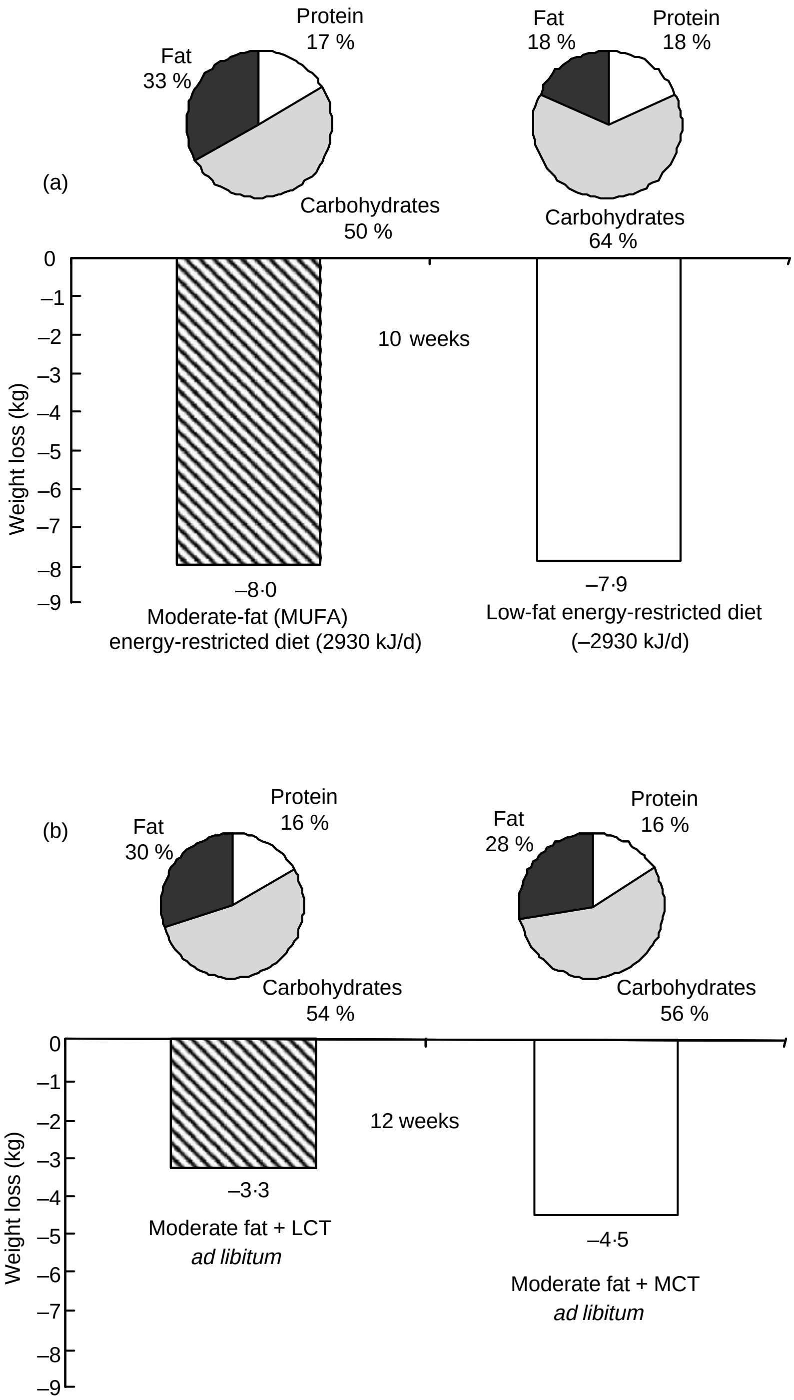

Fig. 3. Weight losses induced by low- to moderate-fat-containing diets with different MUFA or long-chain triacylglycerol (LCT) or medium-chain triacylglycerol (MCT) content, and prescribed following energy-restricted or *ad libitum* approaches. (a) From Pelkman *et al.* (2004); (b) from Kasai *et al.* (2003).

a high-complex-carbohydrate low-fat diet or a high-simple-carbohydrate low-fat diet for 6 months. Between 0 and 6 months, body weight changed by 1·03, −4·25 and −0·28 kg in the control, complex-carbohydrate low-fat, and simple-carbohydrate low-fat groups, respectively. Only in the complex-carbohydrate low-fat group did the BMI decrease significantly (Poppitt *et al.* 2002). These findings are complemented by data from a study of Saris *et al.* (2000), in which moderately obese adults were allocated for 6 months either to a seasonal or a control group (no intervention) or to two experimental *ad libitum* groups with different carbohydrate nature (simple *v.* complex). Body-weight loss in the high-simple-carbohydrate low-fat and high-complex-carbohydrate low-fat groups was 0·9 and 1·8 kg,

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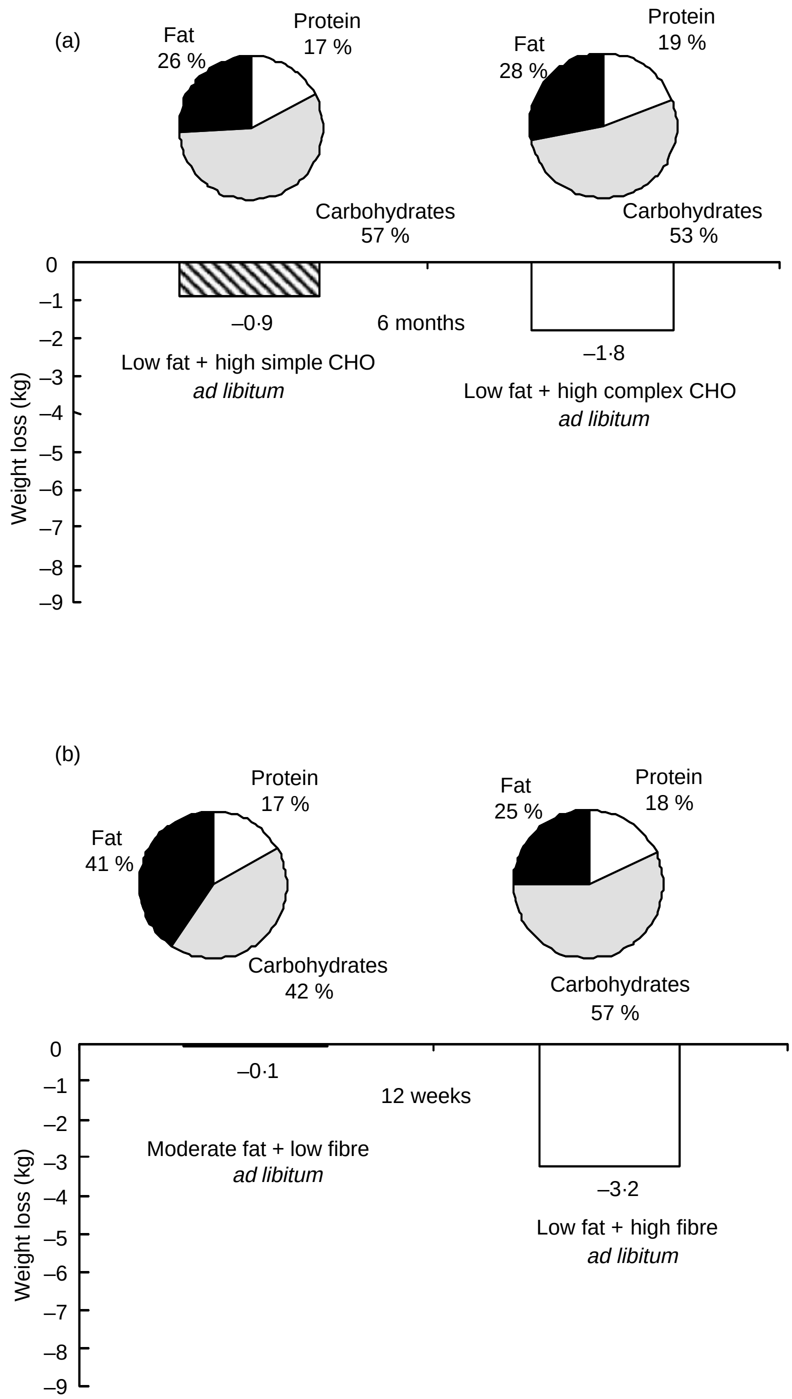

Fig. 4. Weight losses induced by *ad libitum* diets with different type of carbohydrate or fibre content and low-to-moderate fat amounts. (a) From Saris *et al.* (2000); (b) from Hays *et al.* (2004).

while the control and seasonal groups eventually gained weight (0·8 and 0·1 kg) along the trial (Fig. 4).

Another study from Mueller-Cunningham *et al.* (2003) demonstrated that adherence to a high-carbohydrate very-low-fat diet (less than 15 % energy intake) that was consumed during an 8-month period *ad libitum* caused weight loss in the 5–10 % range, while the decrease in percentage body fat was of 2·7 (SD 0·2) %. Because of a possible reduction in vitamin E and *n*-3 fatty acid intake, emphasis on foods with high content in these nutrients may need to be encouraged for those consuming a high-carbohydrate very-low-fat diet. So, the effects of the inclusion of long-chain triacylglycerols and medium-chain triacylglycerols in diets with a relatively high content of carbohydrate (> 50 %) and low lipid content have been explored in two independent intervention trials (Kasai *et al.* 2003; St-Onge & Jones, 2003), which have revealed that medium-chain triacylglycerols intake may produce a greater fat oxidation leading to a higher weight loss despite *ad libitum* feeding (Fig. 3). Comparing the effect of low- and high-fat diets on nutrient intakes, it was concluded that low-fat diets may not provide sufficient energy, essential fatty acids and micronutrients (especially vitamin E and Zn) for healthy untrained individuals. Interestingly, increasing fat intake to 50 % of energy improved nutritional status, and did not negatively affect some cardiovascular risk factors (Meksawan *et al.* 2004).

Ad libitum, fat-reduced diets seem to be effective in preventing weight regain after weight loss (Toubro & Astrup, 1997) and can induce a weight loss of about 5–10 kg (Astrup *et al.* 1997). Anderson *et al.* (2000) suggested that diets low in saturated fat and high in carbohydrate and dietary fibre significantly improve health by increasing insulin sensitivity and lowering the risk of CVD.

The current evidence suggests that low-fat standard-carbohydrate diets are safe, efficacious for weight loss, and improve cardiovascular risk profiles, but it is important that these type of diets should be based on complex carbohydrates and fibre (Fig. 4), not sugar, and that moderate fat intakes should include mainly monounsaturated and polyunsaturated fats (avoiding *trans* or saturated fats). Moreover, the role of low-fat hypoenergetic diets may be different than when applied in *ad libitum* conditions for preventing weight gain (Astrup *et al.* 2002).

High-protein low-carbohydrate diets

High-protein low-carbohydrate diets are gaining popularity, although there is still insufficient evidence to make recommendations for or against the use of these diets. These dietary approaches have been proposed as an alternative to conventional diets, in order to reduce or treat the risk of obesity, CVD and type 2 diabetes mellitus (Noakes *et al.* 2005). These nutritional plans commonly advocate dramatic reductions in carbohydrate intake coupled with high fat consumption producing a ketotic acidosis, which could be involved in the appetite-suppressing effect (Bravata *et al.* 2003).

High-protein low-carbohydrate diets are effective for weight loss (Fig. 5) as demonstrated by Skov *et al.* (1999), who found a higher reduction in body weight (8·9 *v.* 5·1 kg) when offered on an *ad libitum* pattern during 6 months between a high-protein diet (25 % energy) as compared with a normal-protein diet (12 % energy). Also, another study designed by Samaha *et al.* (2003) was carried out with subjects assigned to a high-fat low-carbohydrate diet providing a moderately high protein content (22 % energy) as compared with a traditional supply of protein (16 %). The subjects assigned to the normal-protein diet were advised to reduce energy intake sufficient to create a deficit of 2090 kJ (500 kcal) per d, with 35 % or less of total energy derived from fat. Compared with the subjects on the control-protein diet, subjects on the moderately high-protein diet reported a non-significantly greater reduction in energy intake. This intervention trial revealed that subjects on the diet containing more protein lost more weight during the 6-month study than those on the control-protein diet did (−5·8 (SD 8·6) *v.* −1·9 (SD 4·2) kg), which may be also explained by differences in the fat and carbohydrate content between both diets (Fig. 5).

An increase in dietary protein from 15 % to 30 % energy with a constant carbohydrate intake results in significant weight loss (Parker *et al.* 2002; Weigle *et al.* 2005). However, a systematic review reported that the weight loss is associated with the duration of the diet and the restriction of energy intake with no association to carbohydrate restriction itself (Freedman *et al.* 2001; Luscombe *et al.* 2003). In this context, Due *et al.* (2004) compared 6 months of *ad libitum* high protein intake (25 % energy) with a diet of medium protein content (12 % energy), reporting that a fat-reduced high-protein diet had more favourable effects on body-weight loss, providing a better long-term maintenance of reduced intra-abdominal fat stores (Due *et al.* 2004). Furthermore, Johnston *et al.* (2004) compared two 6-week low-fat energy-restricted diets: high-protein (30 % energy) or high-carbohydrate (60 % energy). They found that both diets were equally effective at reducing body weight and fat mass. However, subjects consuming the high-protein diet reported more satisfaction and less hunger.

Another study conducted by Layman *et al.* (2003) examined the efficacy of two hypoenergetic diets with modified carbohydrate:protein ratios on the weight-loss process. After consuming the diets for 10 weeks, they demonstrated that increasing the proportion of protein to carbohydrate in the diet of adult women has positive effects on body composition and satiety during weight loss.

Despite it being known that high-protein low-carbohydrate diets produce an increased weight loss over 3–6 months, the long-term results are unclear (Astrup *et al.* 2004). The carbohydrate restriction produces a depletion of glycogen stores leading to excretion of bound water, and a ketogenic effect. The satiety effect of proteins and the boredom related to the diet are involved in the rapid weight loss due to spontaneously reducing food intake (Astrup *et al.* 2004). Moreover, it was suggested that the weight loss could be partially produced by the thermogenic effect of proteins (Mikkelsen *et al.* 2000). However, this fact apparently only involves a small fraction of the observed weight loss (Astrup *et al.* 2004). Moreover, high-protein diets with more than 30 % energy as protein have been described as potentially harmful for the renal function, limiting the design of these strategies to induce weight loss (Martin *et al.* 2005); however, this issue remains to be elucidated, since no severe adverse effects have been reported so far.

Therefore, high-protein low-carbohydrate diets, which in some cases approach the high-fat low-carbohydrate models, look to be effective in the short term, but the long-term effects, not only on weight loss, but also on health and disease prevention are unknown; because of that, there is insufficient evidence to make recommendations for or against these types of diets.

Conclusions

In summary, different dietary approaches based upon changes in the macronutrient distribution rather than food restriction to treat obesity are becoming increasingly popular because they might favourably affect weight loss

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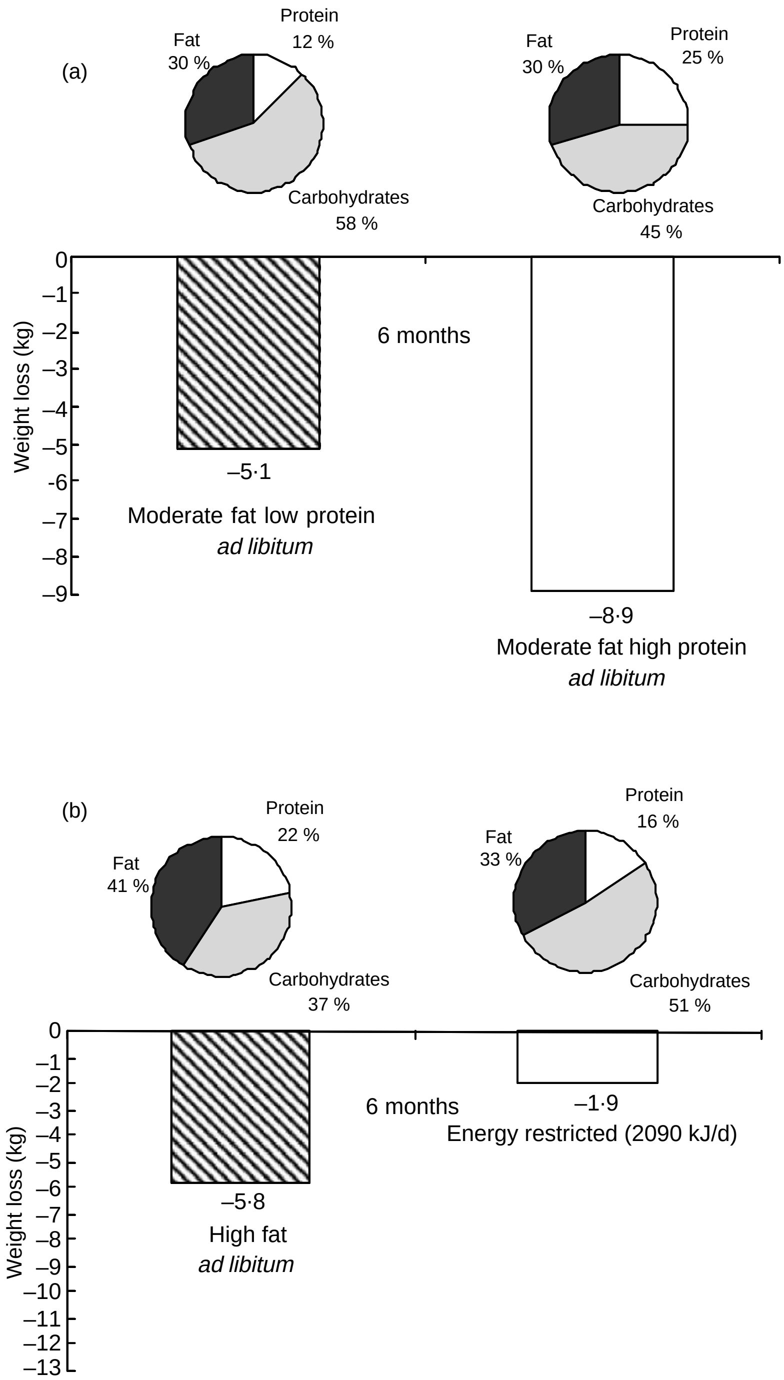

Fig. 5. Weight losses induced by high-protein diets (>20 % energy) as compared with other dietary interventions based on energy-restricted or *ad libitum* strategies. (a) From Skov *et al.* (1999); (b) from Samaha *et al.* (2003).

and the lipid profile. Therefore, regimens based on energy restriction and different macronutrient composition have been investigated with different success rates to be implemented in obese subjects in order to reduce and maintain weight losses. These diets, when energy is restricted, produce a moderate weight loss of about 0·5–1·0 kg/week, but when consumed *ad libitum*, and guided to low fat consumption or a high fat–low carbohydrate intake, produce an average weight loss of 0·2–0·4 kg/week. However, there are several factors that determine weight loss induced by diets with different composition, such as the genetic predisposition, concomitant diseases and environmental influences. The current available evidence is insufficient to make recommendations for or against the use of low-carbohydrate high-fat or high-carbohydrate low-fat diets and further research is necessary, as well as an individualised design of the nutritional therapy to get adherence.

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References

Acheson KJ (2004) Carbohydrate and weight control: where do we stand? *Current Opinion in Clinical Nutrition and Metabolic Care* **7**, 485–492.

Anderson JW, Konz EC & Jenkins DJ (2000) Health advantages and disadvantages of weight-reducing diets: a computer analysis and critical review. *Journal of the American College of Nutrition* **19**, 578–590.

Arai K, Miura J, Ohno M, Yokoyama J & Ikeda Y (1992) Comparison of clinical usefulness of very-low-calorie diet and supplemental low-calorie diet. *American Journal of Clinical Nutrition* **56**, 275S–276S.

Astrup A, Astrup A, Buemann B, Flint A & Raben A (2002) Low-fat diets and energy balance: how does the evidence stand in 2002? *Proceedings of the Nutrition Society* **61**, 299–309.

Astrup A, Meinert Larsen T & Harper A (2004) Atkins and other low-carbohydrate diets: hoax or an effective tool for weight loss? *Lancet* **364**, 897–899.

Astrup A, Toubro S, Raben A & Skov AR (1997) The role of low-fat diets and fat substitutes in body weight management: what have we learned from clinical studies? *Journal of the American Dietetic Association* **97**, S82–S87.

Atkins RC (1992) *Dr. Atkins' New Diet Revolution*. New York: Avon Books, Inc.

Bernstein RK (1997) *Dr. Bernstein's Diabetes Solution*. Boston, MA: Little, Brown & Co.

Bravata DM, Sanders L, Huang J, Krumholz HM, Olkin I, Gardner CD & Bravata DM (2003) Efficacy and safety of low-carbohydrate diets: a systematic review. *Journal of the American Medical Association* **289**, 1837–1850.

Brehm BJ, Seeley RJ, Daniels SR & D'Alessio DA (2003) A randomized trial comparing a very low carbohydrate diet and a calorie-restricted low fat diet on body weight and cardiovascular risk factors in healthy women. *Journal of Clinical Endocrinology and Metabolism* **88**, 1617–1623.

Cheah MH & Kam PC (2005) Obesity: basic science and medical aspects relevant to anaesthetists. *Anaesthesia* **60**, 1009–1021.

Colette C, Percheron C, Pares-Herbute N, Michel F, Pham TC, Brillant L, Descomps B & Monnier L (2003) Exchanging carbohydrates for monounsaturated fats in energy-restricted diets: effects on metabolic profile and other cardiovascular risk factors. *International Journal of Obesity and Related Metabolic Disorders* **27**, 648–656.

Dansinger ML, Gleason JA, Griffith JL, Selker HP & Schaefer EJ (2005) Comparison of the Atkins, Ornish, Weight Watchers, and Zone diets for weight loss and heart disease risk reduction: a randomized trial. *Journal of the American Medical Association* **293**, 43–53.

De Lorenzo A, Petroni ML, De Luca PP, Andreoli A, Morini P, Iacopino L, Innocente I & Perriello G (2001) Use of quality control indices in moderately hypocaloric Mediterranean diet for treatment of obesity. *Diabetes Nutrition and Metabolism* **14**, 181–188.

Drewnowski A (1999) Intense sweeteners and energy density of foods: implications for weight control. *European Journal of Clinical Nutrition* **53**, 757–763.

Due A, Toubro S, Skov AR & Astrup A (2004) Effect of normal-fat diets, either medium or high in protein, on body weight in overweight subjects: a randomised 1-year trial. *International Journal of Obesity and Related Metabolic Disorders* **28**, 1283–1290.

Finer N (2001) Low-calorie diets and sustained weight loss. *Obesity Research* **9**, 290S–294S.

Foster GD, Wadden TA, Peterson FJ, Letizia KA, Bartlett SJ & Conill AM (1992) A controlled comparison of three very-low-calorie diets: effects on weight, body composition, and symptoms. *American Journal of Clinical Nutrition* **55**, 811–817.

Foster GD, Wyatt HR, Hill JO, McGuckin BG, Brill C, Mohammed BS, Szapary PO, Rader DJ, Edman JS & Klein S (2003) A randomized trial of a low-carbohydrate diet for obesity. *New England Journal of Medicine* **348**, 2082–2090.

Freedman MR, King J & Kennedy E (2001) Popular diets: a scientific review. *Obesity Research* **9**, 1S–40S.

Gordon-Larsen P, Adair LS, Nelson MC & Popkin BM (2004) Five-year obesity incidence in the transition period between adolescence and adulthood: the National Longitudinal Study of Adolescent Health. *American Journal of Clinical Nutrition* **80**, 569–575.

Grundy SM, Abate N & Chandalia M (2002) Diet composition and the metabolic syndrome: what is the optimal fat intake? *American Journal of Medicine* **113**, 25S–29S.

Hart KE & Warriner EM (2005) Weight loss and biomedical health improvement on a very low calorie diet: the moderating role of history of weight cycling. *Behavioral Medicine* **30**, 161–170.

Hays NP, Starling RD, Liu X, Sullivan DH, Trappe TA, Fluckey JD & Evans WJ (2004) Effects of an *ad libitum* low-fat, high-carbohydrate diet on body weight, body composition, and fat distribution in older men and women: a randomized controlled trial. *Archives of Internal Medicine* **164**, 210–217.

Heilbronn LK, Noakes M & Clifton PM (1999) Effect of energy restriction, weight loss, and diet composition on plasma lipids and glucose in patients with type 2 diabetes. *Diabetes Care* **22**, 889–895.

Hensrud DD (2004) Diet and obesity. *Current Opinion in Gastroenterology* **20**, 119–124.

Jebb SA (2005) Dietary strategies for the prevention of obesity. *Proceedings of the Nutrition Society* **64**, 217–227.

Johnston CS, Tjonn SL & Swan PD (2004) High-protein, low-fat diets are effective for weight loss and favorably alter biomarkers in healthy adults. *Journal of Nutrition* **134**, 586–591.

Kamrath RO, Plummer LJ, Sadur CN, Adler MA, Strader WJ, Young RL & Weinstein RL (1992) Chotelelithiasis in patients treated with a very-low-calorie diet. *American Journal of Clinical Nutrition* **56**, 255S–257S.

Kasai M, Nosaka N, Maki H, Negishi S, Aoyama T, Nakamura M, Suzuki Y, Tsuji H, Uto H, Okazaki M & Kondo K (2003) Effect of dietary medium- and long-chain triacylglycerols (MLCT) on accumulation of body fat in healthy humans. *Asia Pacific Journal of Clinical Nutrition* **12**, 151–160.

Kekwick A & Pawan GL (1956) Calorie intake in relation to body-weight changes in the obese. *Lancet* **271**, 155–161.

Kemper HC, Stasse-Wolthuis M & Bosman W (2004) The prevention and treatment of overweight and obesity. Summary of the advisory report by the Health Council of The Netherlands. *Netherlands Journal of Medicine* **62**, 10–17.

Labayen I, Diez N, Parra MD, Gonzalez A & Martinez JA (2004) Time-course changes in macronutrient metabolism induced by a nutritionally balanced low-calorie diet in obese women. *International Journal of Food Sciences and Nutrition* **55**, 27–35.

Lantz H, Peltonen M, Agren L & Torgerson JS (2003) Intermittent versus on-demand use of a very low calorie diet: a randomized 2-year clinical trial. *Journal of Internal Medicine* **253**, 463–471.

Layman DK, Boileau RA, Erickson DJ, Painter JE, Shiue H, Sather C & Christou DD (2003) A reduced ratio of dietary carbohydrate to protein improves body composition and blood lipid profiles during weight loss in adult women. *Journal of Nutrition* **133**, 411–417.

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. *International Journal of Obesity and Related Metabolic Disorders* **27**, 582–590.

McAuley KA, Hopkins CM, Smith KJ, McLay RT, Williams SM, Taylor RW & Mann JI (2005) Comparison of high-fat and high-protein diets with a high-carbohydrate diet in insulin-resistant obese women. *Diabetologia* **48**, 8–16.

McManus K, Antinoro L & Sacks F (2001) A randomized controlled trial of a moderate-fat, low-energy diet compared with a low fat, low-energy diet for weight loss in overweight adults. *International Journal of Obesity and Related Metabolic Disorders* **25**, 1503–1511.

Marti A, Moreno-Aliaga MJ, Hebebrand J & Martinez JA (2004) Genes, lifestyles and obesity. *International Journal of Obesity and Related Metabolic Disorders* **28**, Suppl. 3, S29–S36.

Martin WF, Armstrong LE & Rodriguez NR (2005) Dietary protein intake and renal function. *Nutrition and Metabolism* **2**, 25.

Mathus-Vliegen EM; Balance Study Group (2005) Long-term maintenance of weight loss with sibutramine in a GP setting following a specialist guided very-low-calorie diet: a double-blind, placebo-controlled, parallel group study. *European Journal of Clinical Nutrition* **59**, S31–S38.

Meksawan K, Pendergast DR, Leddy JJ, Mason M, Horvath PJ & Awad AB (2004) Effect of low and high fat diets on nutrient intakes and selected cardiovascular risk factors in sedentary men and women. *Journal of the American College of Nutrition* **23**, 131–140.

Mikkelsen PB, Toubro S & Astrup A (2000) Effect of fat-reduced diets on 24-h energy expenditure: comparisons between animal protein, vegetable protein, and carbohydrate. *American Journal of Clinical Nutrition* **72**, 1135–1141.

Mithieux G, Misery P, Magnan C, Pillot B, Gautier-Stein A, Bernard C, Rajas F & Zitoun C (2005) Portal sensing of intestinal gluconeogenesis is a mechanistic link in the diminution of food intake induced by diet protein. *Cell Metabolism* **2**, 321–329.

Monnier L, Colette C, Percheron C & Boniface H (2000) Very-low-calorie-diets: is there a place for them in the management of the obese diabetics. *Diabetes Metabolism* **26**, 46–51.

Mozaffarian D (2005) Effects of dietary fats versus carbohydrates on coronary heart disease: a review of the evidence. *Current Atherosclerosis Reports* **7**, 435–445.

Mueller-Cunningham WM, Quintana R & Kasim-Karakas SE (2003) An *ad libitum*, very low-fat diet results in weight loss and changes in nutrient intake in postmenopausal women. *Journal of the American Dietetic Association* **103**, 1600–1606.

Mustajoki P & Pekkarinen T (2001) Very low energy diets in the treatment of obesity. *Obesity Research* **2**, 61–72.

Nettleton JA & Katz R (2005) n-3 Long-chain polyunsaturated fatty acids in type 2 diabetes: a review. *Journal of the American Dietetic Association* **105**, 428–440.

Noakes M, Keogh JB, Foster PR & Clifton PM (2005) Effect of an energy-restricted, high-protein, low-fat diet relative to a conventional high-carbohydrate, low-fat diet on weight loss, body composition, nutritional status, and markers of cardiovascular health in obese women. *American Journal of Clinical Nutrition* **81**, 1298–1306.

O'Neil PM & Jarrell MP (1992) Psychological aspects of obesity and very-low-calorie diets. *American Journal of Clinical Nutrition* **56**, 185S–189S.

Ornish D (2004) Was Dr Atkins right? *Journal of the American Dietetic Association* **104**, 537–542.

Parker B, Noakes M, Luscombe N & Clifton P (2002) Effect of a high-protein, high-monounsaturated fat weight loss diet on glycemic control and lipid levels in type 2 diabetes. *Diabetes Care* **25**, 425–430.

Pelkman CL, Fishell VK, Maddox DH, Pearson TA, Mauger DT & Kris-Etherton PM (2004) Effects of moderate-fat (from monounsaturated fat) and low-fat weight-loss diets on the serum lipid profile in overweight and obese men and women. *American Journal of Clinical Nutrition* **79**, 204–212.

Petersen M & Harper A (2004) Weight loss strategies a change of focus is required. *Obesity Review* **5**, 239–240.

Petersen M, Taylor MA, Saris WH, Verdich C, Toubro S, Macdonald I, Rössner S, Stich V, Guy-Grand B, Langin D, *et al.*; The NUGENOB Consortium (2006) Randomised, multi-centre trial of two hypoenergetic diets with different fat content in obese subjects. *International Journal of Obesity (London)* **30**, 552–560.

Pirozzo S, Summerbell C, Cameron C & Glasziou P (2002) Advice on low-fat diets for obesity. *Cochrane Database Systematic Review*, CD003640.

Plodkowski RA & St Jeor ST (2003) Medical nutrition therapy for the treatment of obesity. *Endocrinology and Metabolism Clinics of North America* **32**, 935–965.

Popkin BM (2001) The nutrition transition and obesity in the developing world. *Journal of Nutrition* **131**, 871S–873S.

Popkin BM & Gordon-Larsen P (2004) The nutrition transition: worldwide obesity dynamics and their determinants. *International Journal of Obesity and Related Metabolic Disorders* **28**, S2–S9.

Poppitt SD, Keogh GF, Prentice AM, Williams DE, Sonnemans HM, Valk EE, Robinson E & Wareham NJ (2002) Long-term effects of *ad libitum* low-fat, high-carbohydrate diets on body weight and serum lipids in overweight subjects with metabolic syndrome. *American Journal of Clinical Nutrition* **75**, 11–20.

Raben A, Astrup A, Vasilaras TH, Prentice AM, Zunft HJ, Formiguera X, Verboeket-van de Venne WP, Poppitt SD, Seppelt B, Johnston S, *et al.* (2002) The CARMEN trial: increased intake of carbohydrates – simple or complex – and unchanged blood lipids in overweight subjects (article in Danish). *Ugeskrift for Laeger* **164**, 627–631.

Raynor HA, Jeffery RW, Tate DF & Wing RR (2004) Relationship between changes in food group variety, dietary intake, and weight during obesity treatment. *International Journal of Obesity* **23**, 813–820.

Roberts DCK (2001) Quick weight loss: sorting fad from fact. *Medicine Journal of Australia* **175**, 637–640.

Roberts SB (2003) Glycemic index and satiety. *Nutrition in Clinical Care* **6**, 20–26.

Rodriguez C, Martínez de Morentin B, Parra M[a]D, Perez S & Martinez JA (2005) Nutrientes y otros componentes de los alimentos implicados en la regulación del peso corporal (Nutrients and other food components implicated in the regulation of body weight). *Revista Española de Obesidad* **8**, 5–11.

Ryttig KR, Flaten H & Rossner S (1997) Long-term effects of a very low calorie diet (Nutrilett) in obesity treatment. A prospective, randomized, comparison between VLCD and a hypocaloric diet + behavior modification and their combination. *International Journal of Obesity and Related Metabolic Disorders* **21**, 574–579.

Samaha FF, Iqbal N, Seshadri P, Chicano KL, Daily DA, McGrory J, Williams T, Williams M, Gracely EJ & Stern L (2003) A low-carbohydrate as compared with a low-fat diet in severe obesity. *New England Journal of Medicine* **348**, 2074–2081.

Saris WH, Astrup A, Prentice AM, Zunft HJ, Formiguera X, Verboeket-van de Venne WP, Raben A, Poppitt SD, Seppelt B, Johnston S, *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. *International Journal of Obesity and Related Metabolic Disorders* **24**, 1310–1318.

Schrager S (2005) Dietary calcium intake and obesity. *Journal of American Board of Family Practice* **18**, 205–210.
Skov AR, Toubro S, Ronn B, Holm L & Astrup A (1999) Randomized trial on protein *vs* carbohydrate in *ad libitum* fat reduced diet for the treatment of obesity. *International Journal of Obesity and Related Metabolic Disorders* **23**, 528–536.
Slavin JL (2005) Dietary fiber and body weight. *Nutrition* **21**, 411–418.
Stern L, Iqbal N, Seshadri P, Chicano KL, Daily DA, McGrory J, Williams M, Gracely EJ & Samaha FF (2004) The effects of low-carbohydrate versus conventional weight loss diets in severely obese adults: one-year follow-up of a randomised trial. *Annals of Internal Medicine* **140**, 778–785.
St-Onge MP & Jones PJ (2003) Greater rise in fat oxidation with medium-chain triglyceride consumption relative to long-chain triglyceride is associated with lower initial body weight and greater loss of subcutaneous adipose tissue. *International Journal of Obesity and Related Metabolic Disorders* **27**, 1565–1571.
Strasser B & Pichler B (2004) Diet and physical activity in the treatment of obesity. *Wiener Medizinische Wochenschrift* **154**, 313–319.
Stubbs RJ, van Wyk MC, Johnstone AM & Harbron CG (1996) Breakfasts high in protein, fat or carbohydrate: effect on within-day appetite and energy balance. *European Journal of Clinical Nutrition* **50**, 409–417.
Swinburn BA, Caterson I, Seidell JC & James WP (2004) Diet, nutrition and the prevention of excess weight gain and obesity. *Public Health Nutrition* **7**, 123–146.
Toubro S & Astrup A (1997) Randomised comparison of diets for maintaining obese subjects' weight after major weight loss: ad lib, low fat, high carbohydrate diet *vs* fixed energy intake. *British Medical Journal* **314**, 29–34.
Volek JS, Gomez AL & Kraemer WJ (2000) Fasting lipoprotein and postprandial triacylglycerol responses to a low-carbohydrate diet supplemented with n-3 fatty acids. *Journal of the American College of Nutrition* **19**, 383–391.
Volek JS, Sharman MJ, Gomez AL, DiPasquale C, Roti M, Pumerantz A & Kraemer WJ (2004) Comparison of a very low-carbohydrate and low-fat diet on fasting lipids, LDL subclasses, insulin resistance, and postprandial lipemic responses in overweight women. *Journal of the American College of Nutrition* **23**, 177–184.
Volek JS, Vanheest JL & Forsythe CE (2005) Diet and exercise for weight loss: a review of current issues. *Sports Medicine* **35**, 1–9.
Wadden TA, Foster GD, Letizia KA & Mullen JL (1990) Long-term effects of dieting on resting metabolic rate in obese outpatients. *Journal of the American Medical Association* **264**, 707–711.
Wadden TA & Stunkard AJ (1986) Controlled trial of very low calorie diet, behavior therapy, and their combination in the treatment of obesity. *Journal of Consulting and Clinical Psychology* **54**, 482–488.
Wadden TA, Stunkard AJ & Brownell KD (1983) Very low calorie diets: their efficacy, safety, and future. *Annals of Internal Medicine* **99**, 675–684.
Wadden TA, Stunkard AJ, Brownell KD & Day SC (1985) A comparison of two very-low-calorie diets: protein-sparing-modified fast versus protein-formula-liquid diet. *American Journal of Clinical Nutrition* **41**, 533–539.
Walker KZ & O'Dea K (2001) Is a low fat diet the optimal way to cut energy intake over the long-term in overweight people? *Nutrition Metabolism and Cardiovascular Diseases* **11**, 244–248.
Weigle DS, Breen PA, Matthys CC, Callahan HS, Meeuws KE, Burden VR & Purnell JQ (2005) A high-protein diet induces sustained reductions in appetite, ad libitum caloric intake, and body weight despite compensatory changes in diurnal plasma leptin and ghrelin concentrations. *American Journal of Clinical Nutrition* **82**, 41–48.
Wilkinson DL & McCargar L (2004) Is there an optimal macronutrient mix for weight loss and weight maintenance? *Best Practice and Research. Clinical Gastroenterology* **18**, 1031–1047.
Wing RR (1995) Use of very-low-calorie diets in the treatment of obese persons with non-insulin-dependent diabetes mellitus. *Journal of the American Dietetic Association* **95**, 569–572.
Wyatt HR (2003) The prevalence of obesity. *Primary Care* **30**, 267–279.
Yancy WS, Olsen MK, Guyton JR, Bakst RP & Westman EC (2004) A low carbohydrate, ketogenic diet versus a low fat diet to treat obesity and hyperlipidemia. *Annals of Internal Medicine* **140**, 769–777.
Yang MU & van Itallie T (1976) Composition of weight lost during short-term weight reduction. Metabolic responses of obese subjects to starvation and low-calorie ketogenic and nonketogenic diets. *Journal of Clinical Investigation* **58**, 722–730.