Proceedings of the Nutrition Society (2014), **73**, 509–518 doi:10.1017/S0029665114000718
 First published online 5 September 2014

Joint meeting between the Belgian Nutrition Society, The Nutrition Society and Société Française de Nutrition was held at the Faculté de Médecine, Lille on 28–29 May 2013

Conference on 'Sustainable diet and food security'

Long-term weight status in regainers after weight loss by lifestyle intervention: status and challenges

Marta Stelmach-Mardas[1]*, Marcin Mardas[2,3], Jarosław Walkowiak[4] and Heiner Boeing[1]

[1]*Department of Epidemiology, German Institute of Human Nutrition, Potsdam-Rehbruecke, Germany*
[2]*Department of Human Nutrition and Hygiene, Poznan University of Life Sciences, Poland*
[3]*Department of Oncology, Poznan University of Medical Sciences, Poland*
[4]*Department of Gastroenterology and Metabolism, 1st Chair of Pediatrics, Poznan University of Medical Sciences, Poland*

After having participated in a weight loss trial, most participants do not stabilise the obtained weight loss but return to their initial weight. The aim of this review is to describe the main determinants of continued low weight status after weight loss, and the effectiveness of physical activity (PA), energy restriction and macronutrient composition of the diet for low long-term weight regain. Studies with intervention periods of at least 3 months duration of weight reduction measures and a follow-up at least 2 years after the intervention period were considered as eligible for the review. Owing to limited data, the studies describing the role of PA in weight management were eligible with a follow-up of 1 year only. It appears that a diet with self-regulation of dietary intake seems to be given a prominent role in the strategy of successful long-term weight loss among the obese. This measure could be combined with behaviour therapy and PA and tailored to the individual situation. However, considering available evidence it is difficult to conclude regarding unambiguous measures and to recommend a specific dietary intervention. Nevertheless, interventions should be effective in promoting intrinsic motivation and self-efficacy. The harmonisation and standardisation of data collection in the follow-up period of long-term weight loss studies is a major challenge.

Weight regain: Weight status: Obesity

According to the World Health Organization, 12 % of adults aged over 20 years are obese globally (2008) as well as in the World Health Organization European Region with 58·3 % of males and 51·2 % of females being overweight[(1)]. Therefore successful approaches for the treatment of obesity are being looked for since even a moderate reduction of weight of about 10 % can significantly decrease the severity of obesity-associated risk factors[(2)]. It has already been shown that obese subjects can manage to achieve the expected weight loss, with special emphasis being put on proper diet and physical activity (PA). Unfortunately, most subjects participating in such short-term weight loss studies (~70 %) will regain at least half the weight lost within the next 2 years and will return to their baseline weight within the next 3–5 years[(3–5)].

The challenge for clinicians and nutritionists is to develop weight management strategies for obese people which not only promote initial weight loss, but also contribute to a subsequent weight maintenance phase[(6–9)]. From a nutritional perspective, weight management strategies should take into account personalised dietary programmes.

In this review, we analysed the intervention studies with long-term weight reduction incorporating dietary and PA means in overweight and obese subjects. The studies with at least 3 months intervention and a follow-up period of at least 2 years were considered as

Abbreviation: PA, physical activity.

*Corresponding author: M. Stelmach-Mardas, fax 004933200 882444, email stelmach@dife.de

Table 1. The potential determinants of weight status after using slimming diet in obese subjects[11]

Potential determinants of weight status	Maintainers *v.* Regainers	
	Successful	Unsuccessful
Using tailored clothing as the primary indicator for weight status	X	
Greater support during weight loss maintenance	X	
Self-monitoring of intake over time	X	
More difficulties continuing food and/or activity routines over time 'by regainers'		X
Avoided the scale out of shame or denial, weighing themselves less often because they knew it was undesirable news 'by regainers'		X
Applying more unproductive problem-solving styles around the challenges of maintenance, citing avoidance or denial related to weight regain 'by regainers'		X
Less adapting to changes and adjusting their lifestyle in order to continue diet and exercise habits 'by regainers'		X
Using less positive self-talk during weight loss maintenance 'by regainers'		X
Offering less detail about the reaction to setbacks and more likely to put off immediate changes 'by regainers'		X
Having a seemingly lower self-efficacy concerning weight regain, and cited less specific tactics to use immediately 'by regainers'		X

eligible for the analysis. Due to limited data, the studies describing the role of PA in weight management were eligible with a follow-up of 1 year only.

The aim of this review is to describe the main determinants of continued low weight status after weight loss, and the effectiveness of energy restriction and macronutrient composition of the diet and of PA on low long-term weight regain.

Potential determinants of continued low weight status after weight loss

It is known that important changes in eating behaviours can differ between short- and long-term weight changes[10]. Reyes *et al.*[11] documented the existing similarities and differences between weight loss in regainers (those who had regained ≥33 % of their weight loss as compared with the end of intervention) and subsequent maintainers (those who had sustained their initial weight loss for at least 1 year and regained ≤15 % as compared with the end of intervention; Table 1). They identified only three determinants of low weight status after using a slimming diet: self-monitoring of dietary intake over time, large support during the weight regain phase, and using small size clothing. Furthermore, they reported the main determinants connected with unsuccessful maintenance of low weight status: worse adaptation to changes in the lifestyle to continue diet and PA, using less positive self-talk and loss of effectiveness in problem-solving techniques during the weight regain phase. Researchers[3] have speculated on some additional explanations why obese subjects gain weight after successful weight loss. The main factors according to Byrne *et al.*[3] were: failure to achieve weight goals and dissatisfaction with the weight achieved, a tendency to evaluate self-worthiness in terms of weight and shape, lack of vigilance in weight control and a dichotomous (black-and-white) thinking style. Regainers also did not permit themselves to any of the food they really enjoyed and therefore felt deprived[12]. Moreover, stress during the weight regain phase seems to be an important factor for weight change, also demonstrating it to be a critical factor for inducing overeating[13]. The study of Sarlio-Lähteenkorva *et al.*[14] carried out in men with 6 and 15 years follow-up documented the failure to maintain weight loss as a result of a stressful life and high alcohol intake.

One of the most important aspects influencing the motivation towards a long-term weight regain is also the low initial weight loss[15]. The retrospective analyses of pooled data from two multicentric, randomised, placebo-controlled clinical trials were in line with this statement. Weight loss of >5 % body weight after 12 weeks diet and Orlistat were a good indicator of 2-year weight loss, whereas ≥2·5 kg initial weight loss during the 4-week run-in phase and ≥10 % weight loss after 6 months did not add significantly to the prediction of the 2-year outcome[16]. In weight regainers, it has also been shown that self-monitoring of food intake and weight control decline over time[3]. According to Teixeira *et al.*[17] lowering emotional eating and adopting a flexible dietary restraint pattern are critical factors for sustained low weight status. Therefore, for long-term success, interventions must also be effective in promoting exercise, intrinsic motivation and self-efficacy. Self-efficacy can be improved during the study conduct; however, in regainers it was connected with low intrinsic motivation leading to easily giving up[18]. In the study by Dennis and Golberg[19] the type of disbelievers berating themselves for their perceived aberrant behaviour intensified their already hesitant self-efficacy beliefs. The disbelieving women did not believe they had the inner strength or self-control to do what needed to be done to manage their weight successfully. Additionally, they reflected doubt, self-recrimination, and marked dependency needs in weight control.

Some studies could show that weight regain is more pronounced when food choice is unrestricted and high in fat content[20,21]. However, a high fat content of the diet might prevent food craving which has been also identified as factor favouring weight regain[22].

https://doi.org/10.1017/S0029665114000718 Published online by Cambridge University Press

As shown by Anton *et al.*[23] a high-fat diet (40 % energy from fat) reduced cravings for carbohydrates at month 12 ($P<0{\cdot}05$) and fruit and vegetables at month 24. Additionally, participants reported significant reductions in food cravings for specific types of foods (i.e. high-fat foods, fast food, fats; $P<0{\cdot}05$). Conversely, Martin *et al.*[24] showed that compared with the low carbohydrate diet, the low-fat diet induced significantly larger decreases in cravings for high-fat foods. No evidence was found to support the belief that restricting intake of certain foods could lead to increased craving for these foods[25]. The future challenge would be to develop a strategy that diminishes craving for high energy sweets and fast food. The study of Batra *et al.* [26] suggested that a better strategy than the reduction in craving could be a reduction in hunger. Thomas *et al.*[27] hypothesised that subjective hunger and desire for food can change significantly, after 1d over- or underfeeding. Currently, it seems impossible to assess the effectiveness of hunger-suppressing *v.* craving-suppressing strategies for obesity therapy.

Sleep in weight regulation

A number of studies have suggested that there is a link between sleep loss and weight gain in adults[28]. Physiological studies have shown that sleep deprivation may influence weight through effects on appetite, PA and/or thermoregulation[29]. Experimental reductions in sleep duration support the claim that sleeping time could alter metabolic rates or affect the levels of appetite regulatory hormones such as leptin and ghrelin[30]. An association between insufficient sleep and increased energy intake has been demonstrated in some studies[29–31].

Sleep restriction was associated with an increase in energy consumption with no change in energy expenditure through PA or leptin and ghrelin concentrations[32]. As shown by Nedeltchova *et al.*[33], bedtime restriction promotes overeating and low activity which was accompanied by increased intake of energy from snacks with higher carbohydrate content without a statistically significant change in the consumption of energy from meals. Markwald *et al.*[34] found that insufficient sleep increased not only total daily energy expenditure by ~5 %, but also energy intake, especially at night after having finalised the dinner. The increase in energy intake was exceeding the energy needed to maintain the energy balance. The insufficient sleep was leading to 0·82 (SD 0·47) kg weight gain. Recent studies found evidence[35] that sleep deprivation significantly decreases activity in appetitive evaluation regions, within the human frontal cortex and insular cortex during food desirability choices, combined with a converse amplification of activity within the amygdala. Another question that is encountered in the clinical setting is whether this bi-directional change in the profile of brain activity is further associated with a significant increase in the desire for weight-gain promoting high-energy foods[35]. These findings suggest a role for improving sleep duration as a component of weight management strategy[35].

Effectiveness of energy restriction and macronutrient composition of the diet on regain

The detailed results of intervention studies investigating weight regain identified from the systematic literature search and selected for this review are shown in Table 2. The number of participants in each study was at least 110 and the baseline average BMI in the studied subjects was higher than 35 kg/m^2. Champagne *et al.*[39], Kuller *et al.*[40] and Svetkey *et al.*[43] included also overweight participants. In the weight loss period, all authors[36–43] applied the reduction of energy intake to at least 5020·8–7531·2 kJ/d[37–40,42,43] even to very low energy diet[41] and with ready-to-use formula (Optifast)[36]. The content of fat in the diet was taken into account especially by Wadden *et al.*[37], Milson *et al.*[38], Kuller *et al.*[40] and Svetkey *et al.*[43]. In these studies, consumption under 30 % of energy from fat intake was generally taken as goal for the participants. In all studies included in this review article, increase in PA (goal about 180 min/week) was one of the intervention measures, with the exception of the studies performed by Kuller *et al.*[40] and Lantz *et al.*[41]. Each study conducted the education and dietary counselling for participants as individual as well as group sessions and provided this counselling in different forms, mostly face-to-face but also via email or telephone. Phases of meal replacements were applied in the studies performed by Bischoff *et al.*[36] and Wadden *et al.*[37]. The measurements of weight gain during follow-up were different across the studies and included direct weight measurements, self-reports of attained weight and assessment of biomarker concentrations. Furthermore, in some studies data on determinants of weight management were also collected. Milsom *et al.*[38], for example, added a weight management questionnaire to the assessment of weight development after 3·5 years follow-up. The questionnaire results showed that unsuccessful participants were less engaged in record keeping, in regular self-weighing, in planned meals ahead of time and in goal setting subscales, e.g. energy, fruit and vegetables, fat. After 3 years, Wadden *et al.*[37] presented in addition to the results on weight changes also data on self-reported energy intake and energy expenditure (Paffenberger Activity Questionnaire). In this study, the oldest participants (65–76 years) reported lower daily energy intake than younger individuals and men significantly higher weekly energy expenditure from PA and higher energy intake than women. At year 4, intensive lifestyle intervention (ILI) participants achieved a mean loss of 4·7 (SE 0·2) % of initial weight, compared with 1·1 (SE 0·2) % for individuals in diabetes support and education ($P<0{\cdot}0001$). Also Svetkey *et al.*[43] provided similar data in addition to weight change. Lantz *et al.*[41] and Bischoff *et al.*[36], showed only the changes in body weight and BMI after 2-years observation. Champagne *et al.*[39] presented additionally the changes related to diet by the application of a FFQ. Significant increases from baseline to 6 months were seen in per cent energy from carbohydrate (8·4 (SE 0·3) %) and protein (0·9 (SE 0·1) %), daily dairy servings (0·4 (SE 0·03)) and daily

https://doi.org/10.1017/S0029665114000718 Published online by Cambridge University Press

Table 2. Long-term weight status after energy restriction and changes in macronutrient composition of the diet

Authors	Population	Duration of intervention	Lifestyle modification	Results	Follow-up	Weight status and used measurements
Bischoff *et al.*[36]	*N* = 8296 BMI = 40·8 kg/m^2 Allocated to long-term follow-up (*n* 421)	1-year	*The five programme phases included:* a) 1-week introduction b) 12-week-period of low-energy diet 3347·2 kJ/d (Optifast 800 formula) c) 6-week-refeeding phase: solid food was reintroduced and formula diet stepwise replaced by normal diet without change of total energy intake d) 7-week stabilisation phase e) 26-week-maintenance phase: nutritional education and behaviour modification (six – medical examinations, thirteen – exercise units, twenty two – behaviour therapy lessons, five – nutrition counselling) *Control group: N/R*	Weight change from baseline to weight loss phase: −15·2 kg in females and −19·4 kg in males (ITT)	2-year	*Assessment:* Body weight, body height, BMI. Weight change from baseline to weight regain phase: −5·9 kg (all subjects) Weight gain from weight loss phase to – weight regain phase: +15·1 % (all subjects)
Wadden *et al.*[37]	*N* = 5145 BMI = 36·3 ± 6·2 kg/m^2 (females) BMI = 35·3 ± 5·7 kg/m^2 (males)	1-year	*Intensive lifestyle intervention (ILI)* – Weeks 1–2: energy goal 1200–1800 based on initial weight, with <30 % from fat (<10 % from saturated fat) and a min. of 15 % of from protein. The PA goal: 175 min or more per week Weeks 3–19: liquid meal replacement plan (Slim Fast, Glucerrna, Optifast, HMR) Months 7–12: replace one meal and one snack per day with shake and bars; PA >200 min Participants who after 6-months lost: a) <5 % were encouraged to try orlistat b) 10 % >weight loss≥5 % were eligible for orlistat c) ≥10 % not offered the orlistat d. Regained 2 % or more – were allowed to take the orlistat *Diabetes support and education (DSE)* participants were invited to three group sessions each year – standardised protocols	Weight change from baseline to weight loss phase: ILI −8·7 % *v.* DSE −0·8 %	3-year	*Assessment:* Body weight, self-reported energy intake and energy expenditure Weight change from baseline to weight regain phase: ILI: −4·7 % *v.* DSE: −1·1 % Weight gain from weight loss phase to weight regain phase: ILI: +4 % *v.* DSE: −0·3 %
Milsom *et al.*[38]	*N* = 110 BMI = 36·76 ± 5·10 kg/m^2	0·5-year	*Initial 6-month intervention:* twenty-four weekly group sessions (90 min). Dietary goals: reduction in: energy intake by 2092–4184 kJ/d, total fats to 25–30%, and protein to 15 % PA goals: addition of 3000+ steps per day earlier baseline, or 30 min/d of walking, 6 d/week *Control group: N/R*	Weight change from baseline to weight loss phase: −10·17 % during the initial six-month intervention	3·5-year	*Assessment:* Body weight, Weight Management Questionnaire, Weight change from baseline to weight regain phase: N/R Weight gain from weight loss phase to – weight regain phase: +6·95 % from months 6–48
Champagne *et al.*[39]	*N* = 1685 BMI = 25–45 kg/m^2	0·5-year	Intervention included twenty weekly, group sessions led by nutrition and behavioral counselors (moderate energy reduction – 2092 kJ/d and PA – 180 min/week) *Control group: N/R*	Weight change from baseline to weight loss phase: −8·4 kg	2-year	*Assessment:* Body weight, body height, BMI, FFQ Weight change from baseline to weight regain phase: −4·0 kg Weight gain from weight loss phase to – weight regain phase: +4·4 kg
Kuller *et al.*[40]	*N* = 508 BMI = 25–39·9 kg/m^2	0·5-year	*Lifestyle Change group (LC)* – dietary goals – to reduce: the saturated fat to <7 % of total energy or <10 g/d, energy intake to 5439·2 or 6276 kJ; to increase the use of foods high in soluble fibre and nutrient-dense, high-volume, low-energetic foods. *Health Education group (HE)* – six seminars during the first year then several times per year through 36 months.	Weight change from baseline to weight loss phase: LC −7·8 kg *v.* HE −1·2 kg	4-year	*Assessment:* Body weight, body height, WC, PA, SBP, LDL-C, HDL-C, TAG, Insulin, Glc, NMR HDL-P , NMR LDL-P, NMR small LDL-P, changes in coronary calcium and carotid plaque Weight change from baseline to weight regain phase: LC −3·4 kg *v.* HE −0·2 kg Weight gain from weight loss phase to weight regain phase: LC +4·4 kg *v.* HE +1·0 kg

Lantz *et al.*[41]	*N* = 113 BMI = 40·2 kg/m^2	4-year	*Very low energetic group:* twelve initial weeks of very low energetic treatment followed by dietary and behavioural support *non-very low energetic group*: dietary and behavioural support only	Weight change from baseline to weight loss phase: very low energetic group −7·6 kg *v.* non-very low energetic group −6·3 kg (p-ns)	4-year	*Assessment:* Body weight, body height, BMI Weight change from baseline to weight regain phase: N/R Weight gain from weight loss phase to - weight regain phase: N/R The completers (*n* 55) had maintained a weight loss of 3·3 ± 10·7 kg ($P < 0·05$) 8 years after randomisation. After 6 years, the non-completers (*n* 58) had gained 3·2 ± 9·7 kg compared with baseline ($P<0·05$)
Lindstroem *et al.*[42]	*N* = 522 BMI = 31·4 ± 4·5 kg/m^2 (intervention group) BMI = 31·1 ± 4·5 kg/m^2 (control group)	1-year	*The intervention group (IG):* face-to-face consultation sessions (from 30 min to 1 h) with the study nutritionist at weeks 0, 1–2 and 5–6 and at months 3, 4, 6 and 9, i.e. altogether seven sessions during the first year and every 3 months thereafter; individualised dietary counselling from a nutritionist; circuit-type resistance training sessions and advise to increase overall PA. *The control group (CG):* general information about lifestyle and diabetes risk (individually or in one group session – 30 min to 1 h), and some printed material	Weight change from baseline to weight loss phase: IG: −4·5 kg *v.* CG: −1·0 kg	2-year	*Assessment:* Body weight, waist circumference, fasting plasma glucose, 2-h plasma glucose, HbA1c, TC, HDL-C, TAG, 3-d food record, the validated Kuopio Ischaemic Heart Disease Risk Factor Study 12-month leisure-time physical activity questionnaire Weight change from baseline to weight regain phase: IG: −3·5 kg *v.* CG −0·9 kg Weight gain from weight loss phase to - weight regain phase: IG: +1·0 kg *v.* CG +0·1 kg
Svetkey *et al.*[43]	*N* = 1029 BMI = 25·1–46·7 kg/m^2	0·5-year	*Phase 1:* behavioural intervention – twenty weekly group sessions Intervention goals: 180 min/week of moderate PA; reduce energetic intake; adopt the Dietary Approaches to Stop Hypertension dietary pattern. *Phase 2:* Participants randomly assigned to one of three groups: a self-directed comparison condition in which participants received minimal intervention (SD), an interactive technology-based intervention in which participants were encouraged to regularly log on to an interactive Web site; and a personal-contact intervention in which participants had monthly individual contact with an interventionist (PC)	Weight change from baseline to weight loss phase: −8·5 kg	2-year	Assessment: Body weight, self-reported dietary intake and PA Weight change from baseline to weight regain phase: SD: −2·9 kg; interactive Web site: −3·3 kg ; PC: −4·2 kg ($P<0·001$) Weight gain from weight loss phase to weight regain phase: SD: +5·5 kg; interactive Web site: +5·2 kg; PC: +4·0 kg ($P<0·001$)

N/R, not reported; PA, physical activity; ITT, intention to treat; WC, waist circumference; ILI, intensive lifestyle intervention; SBP, systolic blood pressure; HbA1c, glycated haemoglobin; TC, total cholesterol; LDL-C, low-density lipoprotein; HDL-C, high-density lipoprotein; Glc, glucose; NMR HDL-P, NMR LDL-P, NMR small LDL-P – proton NMR spectroscopy method for quantifying plasma lipoproteins.

fruit and vegetable servings (3·5 (SE 0·1)). Other studies[40,42] also included the changes in biomarker concentrations (e.g. LDL-cholesterol, HDL-cholesterol, glucose and insulin). In Lindstroem's study[42] significant improvements were seen at year 1 in fasting plasma glucose (0·2 *v.* 0·0 mmol/l), 2-h plasma glucose (0·9 *v.* 0·3 mmol/l), HbA1c (0·1 *v.* 0·1 %), serum total cholesterol to HDL-cholesterol ratio (0·4 *v.* 0·1), and serum TAG (0·2 *v.* 0·0 mmol/l) in the intervention group compared with the control group. Additionally, Kuller *et al.*[40] found that systolic blood pressure ($P = 0{\cdot}048$), LDL-cholesterol ($P = 0{\cdot}026$), TAG ($P = 0{\cdot}92$), insulin ($P = 0{\cdot}0001$), glucose ($P = 0{\cdot}002$) and HDL-cholesterol ($P = 0{\cdot}0001$) developed significantly differently between the Health Education and the Lifestyle Change group. In the reviewed studies, the weight changes from baseline to weight loss ranged from −4·0 to −0·2 kg; in two studies they were not reported[38,41]. However, the studies with no data on weight loss reported an average weight regain of about 4 kg[36–38] and percentage changes in body weight between 4 and 15·1 %[36–38]. The participants were often re-contacted several times during follow-up, e.g. via emails containing newsletters with information related to weight management.

In the first phase (weight reduction period), the effectiveness of different strategies for weight reduction in obese subjects has been investigated[36–43]. It has been shown that similar responses regarding satiety, hunger and satisfaction exist for diets with different proportion of nutrients[44]. In general, the reduced-energy diets result in clinically meaningful weight losses regardless of which macronutrients they emphasise[36–44]. For long-term weight loss, macronutrient composition should also be considered regarding whether it helps to counteract compensatory mechanisms leading to weight regain after weight loss[45]. Thus, interest has been rising for a comparison of different low energy diets containing different ratios of fat, protein and carbohydrates in relation to long-term weight gain. Particular interest was recently given to protein[36,37] and fat[38–40,43]. It was found by one group that a high carbohydrate and protein breakfast is preventing weight regain by reducing diet-induced compensatory changes in hunger, cravings and ghrelin suppression[45]. High-protein diets may also be related to higher levels of thermogenesis, which can increase energy efficiency during weight loss and help avoiding weight regain[46]. It was shown by one study that body-weight loss and low weight-gain depend on the high-protein content of the diet, rather than the low-carbohydrate component, while it is unrelated to the concomitant fat-content of the diet[47]. Furthermore, the Mediterranean and Dietary Approaches to Stop Hypertension diet, which was recommended by Champagne *et al.*[48] and Svetkey *et al.*[43] for the weight reduction phase, encourages intakes of fruit, vegetables, nuts, and whole grains and discourages intakes of red and processed meats and saturated fat. Unlike the Mediterranean diet, the Dietary Approaches to Stop Hypertension diet, in addition, discourages sodium and sugar-sweetened beverages and encourages the intake of low-fat dairy, and has no specific alcohol recommendation[8]. Indeed, the Dietary Approaches to Stop Hypertension diet was related to a reduction in body weight in a high cardiovascular risk population and also prevented weight gain[49,50].

Taking into consideration the age of the participants, as it was expected, younger participants were more familiar with web-based methods and in their case, implementation of web-based methods was a highly effective strategy than older participants, who prefer the traditional methods for information distribution (e.g. newsletter or telephone conferences) and also a manually and simplified form of contact with nutritionist[6,38,43,51–53]. In both cases, the face-to-face counselling condition obtained the best results[36,37,39–42]. This condition also allowed the study subjects to cope with the new dietary approach in a very short time period. Moreover, the research study should give each of the study participants the opportunity to participate in further behavioural and dietary counselling beyond the scientific study. A key message from the study review is that to build good relations between study subjects and nutritionist, the dietary counselling should be conducted by the same team throughout the study period[36–43]. As mentioned previously, clinicians need to emphasise the role of healthy diet for healthy lifestyle.

In the second phase (weight regain phase), the key point seems to be the self-regulation of dietary intake which stays in close connection with changes in dietary habits. It was found in general that individuals who had used a self-guided approach maintained their initial weight loss with great success, even better than those individuals who had used a very low energy diet[36,42]. The involvement of study participants in the process of preparing healthy meals might be an important step for obese people, especially in the case when they are losing the motivation to stay slim[54]. The study conducted by ter Bogt *et al.*[55] did not indicate differences in preventing weight gain between structured lifestyle counselling by nurse practitioners compared with usual care by general practitioners in overweight and obese subjects. For the future, it seems to be important not only to record the mean value of weight loss after the intervention period but also focusing on the long-term body weight gain including a more comprehensive documentation of the data during follow-up. In view of the role of dietary changes and their determinants, the documented long-term data on changes in body weight in the studies had been unsatisfactory, particularly in regard to changes in the self-estimation by the study participants[37,38]. The available evidence from clinical trials suggests that obese subjects used to perceive themselves as less obese and have a tendency to declare less food intake than actually eaten[56].

Physical activity and weight regain

The selected studies which integrate the PA into the changes of lifestyle are presented in Table 3. The majority of the studies focused on obese subjects, with the exception of Hunter *et al.*[49] and Nakade *et al.*[57] who included both obese and overweight subjects. The studies

https://doi.org/10.1017/S0029665114000718 Published online by Cambridge University Press

Table 3. Physical activity in long-term weight status

Authors	Population	Duration of intervention	Lifestyle modification	Results	Follow up	Weight status and used measurements
Hunter *et al.*[49]	*N* = 208 BMI = 27–30 kg/m^2	Time needed to reach the goal of a 25 kg/m^2 (154 (SE 61) d)	I group: diet and aerobic exercise, II group: diet and resistance exercise, III group: diet only (Diet: 3347·2 kJ/d :20–22 % fat, 18–22 % protein, and 58–62 % carbohydrate, Exercise: three per week during weight loss and two per week during the 1-year following weight loss	Weight change from baseline to weight loss phase: –12·3 kg – no differences between the exercise groups was found (P = 0·2).	1- year	Assessment: Body weight, visceral fat Weight change from baseline to weight regain phase: N/R Weight gain from weight loss phase to weight regain phase: I group: +3·1 kg, II group: +3·9 kg, III group: +6·2 kg
Nakade *et al.*[57]	*N* = 235 BMI = >28·4 kg/m^2	1-year	Intervention group (IG): individual counselling (30 min) and group sessions about effective exercise (20 min) at baseline, 1, 3, 6 and 9 months CG: did not receive support	Weight change from baseline to weight loss phase: IG –5·0 kg *v.* CG +0·1 kg form men and −4·0 kg *v.* −0·2 kg for women, respectively	1-year	Assessment: Body weight, body fat, visceral fat, WC, BMI, self-administered diet history questionnaire, questionnaire about stages of change to improve lifestyles Weight change from baseline to weight regain phase: IG –3·6 kg in men *v.* −2·5 kg in women Weight gain from weight loss phase to weight regain phase: IG +1·4 kg in men *v.* +1·5 kg in women
Borg *et al.*[58]	*N* = 90 BMI >30 kg/m^2	0·67-year	I Phase: 0–2 months: low-energy diet (5020·8 kJ/d) based on a meal-exchange system, and VLED (2092 kJ/d, Nutrilett,), meetings in groups led by a nutritionist II Phase: 2–8 months: weight maintenance two exercise groups trained 45 min three times weekly (energy expenditure (EE): 1255·2–1673·6 kJ/session). The subjects were randomised into three groups: a control group (C) with no increase in habitual exercise and two exercise groups (walking, W or resistance training, R) training 45 min three times weekly	Weight change from baseline to weight loss phase: −14·3 kg (all subjects between 0 and 2 months) The subjects in C and W group gained : +1·6 kg and 1·8 kg, respectively, the subjects in R group maintained their weight (+0·3 kg) between 2 and 6 months	1·9-year	Assessment: Body weight, body composition, exercise diaries and dietary records Weight change from baseline to weight regain phase: N/R Weight gain from weight loss phase to weight regain phase: C group: +6·8 kg, W group: +8·3 kg, R group: +8·8 kg
Jeffery *et al.*[59]	N = 202 BMI = 31·7 (SE 2·6) kg/m^2	0·5-year	SBT: an EE goal of 4184 kJ/week, HPA the goal was an EE of 10·46 MJ /week included encouragement to recruit one to three exercise partners into the study, personal counselling from an exercise coach, and small monetary incentives	Weight change from baseline to weight loss phase: SBT: −8·1 kg *v.* −9·0 kg in HPA group	1-year	Assessment: Body weight, PA level – Paffenbarger Physical Activity Questionnaire and dietary intake – the 60-item version of the Block Diet Questionnaire Weight change from baseline to weight regain phase: SBT: −4·1 kg *v.* −6·7 kg in HPA group Weight gain from weight loss phase to weight regain phase: SBT: +4·0 kg *v.* +2·3 kg in HPA group

CG, control group; HPA, high physical activity; N/R, not reported; SBT, standard behaviour therapy; WC, waist circumference; VLED, very-low-energy diet.

were different in PA by demographic characteristics. Participants younger than 50 years, male, non-African American or overweight are more active than those who are older than 50 years, female, African American or obese[60]. Moreover, only 2 % of participants are active for 60 or more minutes daily. It should be underlined that sex differences between energy expenditure related to PA, appetite ratings and energy intake may lead to different patterns of energy intake and subsequent weight maintenance[61].

Very few reviewed intervention studies have explored whether the programmes based on diet and exercise gave better results regarding anthropometry than the use of one method alone[49,57–59]. Often the PA is much more difficult to perform by obese subjects, because performance is related to public places. Public places are perceived negatively by this group of subjects, and they are spending 'extra'-money or finding 'extra' time for exercises[62]. In sedentary and obese subjects, it was also found that a supervised exercise-based programme appears to be more efficacious in promoting and maintaining weight loss and improvements in markers of health and fitness compared with an individual counselling and group sessions focused on exercises[57,58]. It was also observed that both aerobic and resistance training prevented regain of potentially harmful visceral fat[49]. Most likely daily self-monitoring of PA can be one of the feasible and effective approaches for low long-term weight regain. Even 12-months of small-changes of PA due to intervention can be successful in sustaining initial weight loss[63]. Thus, the literature clearly indicates that increased PA is one of the main predictors of low weight status after weight reduction[64]. Increasing PA with increased weight loss might help to maintain weight loss itself[65]. It should be noted that often even moderate weight losses, induced by energy restriction, lead to a large decrease in PA. However, the decrease in PA returns to baseline levels when weight loss is maintained[66]. Thus, clinicians should remind all patients that without maintenance of an active lifestyle, the risk of weight regain is highly increased. The American College of Sports Medicine recommends 150–250 min/week PA to prevent weight gain which should be increased up to 200–300 min/week for prevention of weight gain after weight loss[67].

Similarly, as in Table 2, in the studies with intervention of PA, only the basic anthropometrical measurements and the energy expenditure during follow-up were assessed, based upon self-administered questionnaires[57–59]. An implementation of easy to use tools, e.g. accelerometers can be an appropriate mean to favour the maintenance of PA in obese or older adults[68]. In the studies, an intensive lifestyle intervention including high volume of PA resulted in favourable changes in CVD risk factors and eating behaviours in subjects with severe obesity[69]. The lifestyle counselling by either nurses or general practitioners obtained similar results after 3 years intervention in terms of higher PA and healthier diet[70]. Although the studies used different study designs, diet programme and exercise duration, even with a shorter term follow-up, all measures of an increase of PA can be recommended due to its evident beneficial effect on health status.

Conclusions and challenges

In the strategy of successful long-term weight loss among the obese the main role should be given to a diet with self-regulation of dietary intake. This measure should be combined with behaviour therapy and PA and tailored to the individual situation. In addition, the psychosocial condition of the obese subjects stays in close relation to their motivation. However, after having analysed the papers, it is difficult to arrive at a conclusion regarding unambiguous measures related to low long-term weight regain in obese subjects and to recommend a specific dietary intervention.

From the present literature, it appears that more standardised measurements of determinants of weight changes and low weight regain will provide more comparable data and will allow for a better interpretation of the study results. The challenges are seen to harmonise and standardise the data collected in the follow-up period of long-term weight loss studies. The standardised format of data collected in different countries with different languages could give an opportunity for more extensive analysis of existing datasets. Moreover, it appears useful to build up easily accessible programmes for obese subjects after weigh loss by an interdisciplinary team that would include nutritional education, individual well-balanced diet, promotion of PA and measures to keep a high motivation of behavioural changes. Regular use of interactive web-sites and potential contact with nutritionist could bring an additional benefit for participants in the follow-up period. Therefore in the process of development of such programmes for obese subjects, all details of the studies conducted so far could be important and should be considered.

Acknowledgements

The authors would like to thank the committee members of the Belgian Nutrition Society, The Nutrition Society and Société Française de Nutrition for allowing the corresponding author to present this paper at the Joint Conference: Sustainable Diet and Food Security, 28–29 May 2013, Lille, France.

Financial Support

None.

Conflicts of Interest

None.

Authorship

M. S. M. and H. B. were the lead authors and involved in all aspects of the review. M. M. and J. W. contributed to writing and editing the article.

https://doi.org/10.1017/S0029665114000718 Published online by Cambridge University Press

References

1. World Health Organization (2013) Obesity and overweight; available at http://www.who.int/mediacentre/factsheets/fs311/en/index.html
2. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults the evidence report. 1998 NIH publication no. 98-4083 National Institutes of Health; available at http://www.nhlbi.nih.gov
3. Byrne S, Cooper Z & Fairburn C (2003) Weight maintenance and relapse in obesity: a qualitative study. *Int J Obes Relat Metab Disord* **27**, 955–962.
4. Visram S, Crosland A & Cording H (2009) Triggers for weight gain and loss among participants in a primary care-based intervention. *Br J Commun Nurs* **14**, 495–501.
5. Phelan S, Hill JO, Lang W *et al.* (2003) Recovery from relapse among successful weight maintainers. *Am J Clin Nutr* **78**, 1079–1084.
6. Neve MJ, Morgan PJ & Collins CE (2011) Behavioral factors related with successful weight loss 15 months post-enrolment in a commercial web-based weight-loss programme. *Public Health Nutr* **15**, 1299–1309.
7. Furst T, Connors M, Bisogni C *et al.* (1996) Food choice: a conceptual model of the process. *Appetite* **26**, 247–266.
8. Connors M, Bisogni CA, Sobal J *et al.* (2001) Managing values in personal food systems. *Appetite* **36**, 189–200.
9. Bisogni CA, Jastran M, Shen L *et al.* (2005) A biographical study of food choice capacity: standards, circumstances, and food management skills. *J Nutr Educ Behav* **37**, 284–291.
10. Jabs J & Devine CM (2006) Time scarcity and food choices: an overview. *Appetite* **47**, 196–282.
11. Reyes NR, Oliver TL, Klotz AA *et al.* (2012) Similarities and differences between weight loss maintainers and regainers: a qualitative analysis. *J Acad Nutr Diet* **112**, 499–505.
12. Kayman S, Bruvold W & Stern JS (1990) Maintenance and relapse after weight loss in women: behavioral aspects. *Am J Clin Nutr* **52**, 800–807.
13. Manzoni GM, Pagnini F, Gorini A *et al.* (2009) Can relaxation training reduce emotional eating in women with obesity? An exploratory study with 3 months of follow-up. *J Am Diet Assoc* **109**, 1427–1432.
14. Sarlio-Lähteenkorva S, Rissanen A & Kaprio J (2000) A descriptive study of weight loss maintenance: 6 and 15 year follow-up of initially overweight adults. *Int J Obes Relat Metab Disord* **24**, 116–125.
15. Kaholokula JK, Townsend CT, Sinclair K *et al.* (2013) Socio-demographic, behavioral, and biological variables related to weight loss in native Hawaiians and other Pacific Islanders. *Obesity* (Silver Spring) **21**, E196–E203.
16. Rissanen A, Lean M, Rössner S *et al.* (2003) Predictive value of early weight loss in obesity management with orlistat: an evidence-based assessment of prescribing guidelines. *Int J Obes Relat Metab Disord* **27**, 103–109.
17. Teixeira PJ, Silva MN, Coutinho SR *et al.* (2010) Mediators of weight loss and weight loss maintenance in middle-aged women. *Obesity (Silver Spring)* **18**, 725–735.
18. Johnston CA, Tyler C & Foreyt JP (2007) Behavioral management of obesity. *Curr Atheroscler Rep* **9**, 448–453.
19. Dennis KE & Goldberg AP (1996) Weight control self-efficacy types and transitions affect weight-loss outcomes in obese women. *Addict Behav* **21**, 103–116.
20. Cotton JR, Burley VJ, Weststrate JA *et al.* (2007) Dietary fat and appetite: similarities and differences in the satiating effect of meals supplemented with either fat or carbohydrate. *J Hum Nutr Diet* **20**, 186–199.
21. Swinburn BA, Caterson I, Seidell JC *et al.* (2004) Diet, nutrition and the prevention of excess weight gain and obesity. *Public Health Nutr* **7**, 123–146.
22. Massey A & Hill AJ (2012) Dieting and food craving. A descriptive, quasi-prospective study. *Appetite* **58**, 781–785.
23. Anton SD, Gallagher J, Carey VJ *et al.* (2012) Diet type and changes in food cravings following weight loss: findings from the POUNDS LOST Trial. *Eat Weight Disord* **17**, 101–108.
24. Martin CK, Rosenbaum D, Han H *et al.* (2011) Change in food cravings, food preferences, and appetite during a low-carbohydrate and low-fat diet. *Obesity (Silver Spring)* **19**, 1963–1970.
25. Harvey J, Wing RR & Mullen M (1993) Effects on food cravings of a very low calorie diet or a balanced, low calorie diet. *Appetite* **21**, 105–115.
26. Batra P, Das SK, Salinardi T *et al.* (2013) Relationship of cravings with weight loss and hunger. Results from a 6 month worksite weight loss intervention. *Appetite* **69**, 1–7.
27. Thomas EA, Bechtell JL, Vestal BE *et al.* (2013) Eating-related behaviors and appetite during energy imbalance in obese-prone and obese-resistant individuals. *Appetite* **65**, 96–102.
28. Weiss A, Xu F, Storfer-Isser A *et al.* (2010) The association of sleep duration with adolescents' fat and carbohydrate consumption. *Sleep* **33**, 1201–1209.
29. Piaggi P, Krakoff J, Bogardus C *et al.* (2013) Lower "awake and fed thermogenesis" predicts future weight gain in subjects with abdominal adiposity. *Diabetes* **62**, 4043–4051.
30. St-Onge MP, O'Keeffe M, Roberts AL *et al.* (2012) Short sleep duration, glucose dysregulation and hormonal regulation of appetite in men and women. *Sleep* **1**, 1503–1510.
31. Labayen I, Ortega FB, Ruiz JR *et al.* (2011) Role of baseline leptin and ghrelin levels on body weight and fat mass changes after an energy-restricted diet intervention in obese women: effects on energy metabolism. *J Clin Endocrinol Metab* **96**, E996–E1000.
32. Calvin AD, Carter RE, Adachi T *et al.* (2013) Effects of experimental sleep restriction on caloric intake and activity energy expenditure. *Chest* **144**, 79–86.
33. Nedeltcheva AV, Kilkus JM, Imperial J *et al.* (2009) Sleep curtailment is accompanied by increased intake of calories from snacks. *Am J Clin Nutr* **89**, 126–133.
34. Markwald RR, Melanson EL, Smith MR *et al.* (2013) Impact of insufficient sleep on total daily energy expenditure, food intake, and weight gain. *Proc Natl Acad Sci USA* **110**, 5695–700.
35. Greer SM, Goldstein AN & Walker MP (2013) The impact of sleep deprivation on food desire in the human brain. *Nat Commun* **4**, 2259.
36. Bischoff SC, Damms-Machado A, Betz C *et al.* (2012) Multicenter evaluation of an interdisciplinary 52-week weight loss program for obesity with regard to body weight, comorbidities and quality of life-a prospective study. *Int J Obes (Lond)* **36**, 614–624.
37. Wadden TA, Neiberg RH, Wing RR *et al.* (2011) Four-year weight losses in the Look AHEAD study: factors associated with long-term success. *Obesity* (Silver Spring) **19**, 1987–1998.
38. Milsom VA, Middleton KM & Perri MG (2011) Successful long-term weight loss maintenance in a rural population. *Clin Interv Aging* **6**, 303–309.
39. Champagne CM, Broyles ST, Moran LD *et al.* (2011) Dietary intakes associated with successful weight loss and maintenance during the Weight Loss Maintenance trial. *J Am Diet Assoc* **111**, 1826–1835.

https://doi.org/10.1017/S0029665114000718 Published online by Cambridge University Press

40. Kuller LH, Pettee GKK, Kinzel LS *et al.* (2012) The Women on the Move Through Activity and Nutrition (WOMAN) study: final 48-month results. *Obesity* (Silver Spring) **20**, 636–643.
41. Lantz H, Peltonen M, Agren L *et al.* (2003) A dietary and behavioural programme for the treatment of obesity. A 4-year clinical trial and a long-term posttreatment follow-up. *J Intern Med* **254**, 272–279.
42. Lindström J, Louheranta A, Mannelin M *et al.* (2003) The Finnish Diabetes Prevention Study (DPS): lifestyle intervention and 3-year results on diet and physical activity. *Diab Care* **26**, 3230–3236.
43. Svetkey LP, Stevens VJ, Brantley PJ *et al.* (2008) Comparison of strategies for sustaining weight loss: the weight loss maintenance randomized controlled trial. *JAMA* **12**, 1139–1148.
44. Sacks FM, Bray GA, Carey VJ *et al.* (2009) Comparison of weight-loss diets with different compositions of fat, protein, and carbohydrates. *N Engl J Med* **26**, 859–873.
45. Jakubowicz D, Froy O, Wainstein J *et al.* (2012) Meal timing and composition influence ghrelin levels, appetite scores and weight loss maintenance in overweight and obese adults. *Steroids* **10**, 323–331.
46. 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.
47. Sørensen TI, Boutin P, Taylor MA *et al.* (2006) Genetic polymorphisms and weight loss in obesity: a randomised trial of hypo-energetic high- versus low-fat diets. *PLoS Clin Trials* **1**, e12.
48. Martin CK, Rosenbaum D, Han H *et al.* (2011) Change in food cravings, food preferences, and appetite during a low-carbohydrate and low-fat diet. *Obesity* (Silver Spring) **19**, 1963–1970.
49. Hunter GR, Brock DW, Byrne NM *et al.* (2010) Exercise training prevents regain of visceral fat for 1 year following weight loss. *Obesity* (Silver Spring) **18**, 690–695.
50. Berz JP, Singer MR, Guo X *et al.* (2011) Use of a DASH food group score to predict excess weight gain in adolescent girls in the National Growth and Health Study. *Arch Pediatr Adolesc Med* **165**, 540–546.
51. Department of Health and Human Services. Expanding the Reach and Impact of Consumer E-health Tools. 2006. [www document]. URL http://www.health.gov/communication/ehealth/ehealthTools/default.htm (accessed 27 April 2014).
52. Brug J, Oenema A & Campbell M (2003) Past, present, and future of computer-tailored nutrition education. *Am J Clin Nutr* **77**, 1028S–1034S.
53. Hebden L, Balestracci K, McGeechan K *et al.* (2013) 'TXT2BFiT' a mobile phone-based healthy lifestyle program for preventing unhealthy weight gain in young adults: study protocol for a randomized controlled trial. *Trials* **18**, 14, 75.
54. Sabinsky MS, Toft U, Raben A *et al.* (2007). Overweight men's motivations and perceived barriers towards weight loss. *Eur J Clin Nutr* **61**, 526–53160.
55. ter Bogt NC, Bemelmans WJ, Beltman FW *et al.* (2011) Preventing weight gain by lifestyle intervention in a general practice setting: three-year results of a randomized controlled trial. *Arch Intern Med* **28**, 306–31361.
56. Quick V, Nansel TR, Liu D, *et al.* (2014) Body size perception and weight control in youth: 9-year international trends from 24 countries. *Int J Obes* **38**, 988–994.
57. Nakade M, Aiba N, Suda N *et al.* (2012) Behavioral change during weight loss program and one-year follow-up: Saku Control Obesity Program (SCOP) in Japan. *Asia Pac J Clin Nutr* **21**, 22–34.
58. Borg P, Kukkonen-Harjula K, Fogelholm M *et al.* (2002) Effects of walking or resistance training on weight loss maintenance in obese, middle-aged men: a randomized trial. *Int J Obes Relat Metab Disord* **26**, 676–68365.
59. Jeffery RW, Wing RR, Sherwood NE *et al.* (2003) Physical activity and weight loss: does prescribing higher physical activity goals improve outcome? *Am J Clin Nutr* **78**, 684–689.
60. Young DR, Jerome GJ, Chen C *et al.* (2009) Patterns of physical activity among overweight and obese adults. *Prev Chronic Dis* **6**, A90.
61. Harrington DM, Martin CK, Ravussin E *et al.* (2013) Activity related energy expenditure, appetite and energy intake: potential implications for weight management. *Appetite* **67**, 1–7.
62. Hagberg LA & Lindholm L (2005) Is promotion of physical activity a wise use of societal resources? Issues of cost-effectiveness and equity in health. *Scand J Med Sci Sports* **15**, 304–312.
63. Zinn C, Schofield GM & Hopkins WG. (2012) A "small-changes" workplace weight loss and maintenance program: examination of weight and health outcomes. *J Occup Environ Med* **54**, 1230–1238.
64. Phelan S, Wing RR, Loria CM *et al.* (2010) Prevalence and predictors of weight-loss maintenance in a biracial cohort: results from the coronary artery risk development in young adults study. *Am J Prev Med* **39**, 546–554.
65. Bonini M, Fioretti D, Sargentini V *et al.* (2013) Increased nerve growth factor serum levels in top athletes. *Clin J Sport Med* **23**, 228–231.
66. Ebbeling CB, Swain JF, Feldman HA *et al.* (2012) Effects of dietary composition on energy expenditure during weight-loss maintenance. *JAMA* **27**, 2627–2634.
67. Donnelly JE, Blair SN, Jakicic JM *et al.*; American College of Sports Medicine (2009) American College of Sports Medicine Position Stand. Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults. *Med Sci Sports Exerc* **41**, 459–471.
68. Bélanger-Gravel A, Godin G, Bilodeau A *et al.* (2013) The effect of implementation intentions on physical activity among obese older adults: a randomised control study. *Psychol Health* **28**, 217–233.
69. Danielsen KK, Svendsen M, Mæhlum S *et al.* (2013) Changes in body composition, cardiovascular disease risk factors, and eating behavior after an intensive lifestyle intervention with high volume of physical activity in severely obese subjects: a prospective clinical controlled trial. *J Obes* **325**, 1–12.
70. Driehuis F, Barte JC, Ter Bogt NC *et al.* (2012) Maintenance of lifestyle changes: 3-year results of the Groningen Overweight and Lifestyle study. *Patient Educ Couns* **88**, 249–255.

https://doi.org/10.1017/S0029665114000718 Published online by Cambridge University Press