Obesity Management

Long-term effectiveness of diet-plus-exercise interventions vs. diet-only interventions for weight loss: a meta-analysis

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Summary

Diet and exercise are two of the commonest strategies to reduce weight. Whether a diet-plus-exercise intervention is more effective for weight loss than a diet-only intervention in the long-term has not been conclusively established. The objective of this study was to systemically review the effect of diet-plus-exercise interventions vs. diet-only interventions on both long-term and short-term weight loss. Studies were retrieved by searching MEDLINE and Cochrane Library (1966 – June 2008). Studies were included if they were randomized controlled trials comparing the effect of diet-plus-exercise interventions vs. diet-only interventions on weight loss for a minimum of 6 months among obese or overweight adults. Eighteen studies met our inclusion criteria. Data were independently extracted by two investigators using a standardized protocol. We found that the overall standardized mean differences between diet-plus-exercise interventions and diet-only interventions at the end of follow-up were −0.25 (95% confidence interval [CI] −0.36 to −0.14), with a *P*-value for heterogeneity of 0.4. Because there were two outcome measurements, weight (kg) and body mass index (kg m^{-2}), we also stratified the results by weight and body mass index outcome. The pooled weight loss was 1.14 kg (95% CI 0.21 to 2.07) or 0.50 kg m^{-2} (95% CI 0.21 to 0.79) greater for the diet-plus-exercise group than the diet-only group. We did not detect significant heterogeneity in either stratum. Even in studies lasting 2 years or longer, diet-plus-exercise interventions provided significantly greater weight loss than diet-only interventions. In summary, a combined diet-plus-exercise programme provided greater long-term weight loss than a diet-only programme. However, both diet-only and diet-plus-exercise programmes are associated with partial weight regain, and future studies should explore better strategies to limit weight regain and achieve greater long-term weight loss.

Keywords: Diet, exercise, intervention, weight loss.

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Introduction

The prevalence of obesity has increased markedly over the past 2 decades. Obesity is a risk factor for type 2 diabetes, cardiovascular disease, postmenopausal breast cancer, colon cancer, pancreatic cancer and all-cause mortality (1–4). Multiple strategies for effective weight loss have been proposed. Diet is an obvious target for intervention, as reduction in energy intake can lead to negative energy balance and weight loss. Different types of diets are proposed to promote weight loss such as low-calorie and fat-restricted diets and low-carbohydrate diets. Although findings from dietary intervention studies suggest that a low-carbohydrate dietary pattern may be most effective in inducing weight loss in the short term, there is no conclusive evidence that one diet is superior to another in the long term (5). Physical activity is another target for weight loss interventions, because energy expenditure is largely influenced by physical activity. If people lose weight through dietary restriction, their energy expenditure is reduced: eating less reduces diet-related thermogenesis, loss of body mass reduces both resting energy expenditure and the amount of energy required for specific activities, and adaptive suppression of thermogenesis may occur (6). This reduction in energy expenditure makes it more difficult to achieve long-term weight loss. Physical activity increases energy expenditure, both directly and through increased metabolic rate (van Baak, 1999 p. 107) and may therefore compensate for the reduction in energy expenditure resulting from diet-induced weight loss. Hence, one would expect that combining dietary restriction with increased physical activity facilitates successful long-term weight loss. For many years, numerous small studies have focused on the effect of different levels of exercise in obese individuals; however, few reviews have directly compared the effect of diet-plus-exercise (D + E) intervention with a diet-only (D) intervention on weight loss. Whether D + E intervention is more effective for weight loss than D intervention has not been conclusively established.

Meta-analysis may be especially useful in summarizing and analysing prior research when the number of subjects per individual study is small. Previous meta-analyses by Curioni *et al.* and Miller *et al.* (7,8) focused on interventions over a short time period (1 year or less), and more information on effects on long-term weight loss is needed. We therefore evaluated the effect of D + E interventions vs. D interventions on long-term weight loss using meta-analysis.

Methods

Study selection

Studies were eligible for inclusion in our review if they were randomized controlled trials, compared a D + E intervention with a D intervention that was administered simultaneously and with the dietary programme being identical in both intervention groups, had a study duration (intervention time plus follow-up time after intervention) of at least 6 months, reported weight and/or body mass index (BMI) before and after the intervention, and were conducted in adults. Dietary interventions included any type of weight loss diet including low-carbohydrate diets and energy-restricted diets. Exercise interventions included any type of exercise programme. We only included articles published in English-language journals. We conducted a comprehensive literature search of Medline (Pubmed) and Cochrane Library from 1966 to 30 June 2007. We used the keywords: 'diet', 'exercise', 'physical activity' and 'physical exertion', and the Medical Subject Headings: 'diet therapy', 'physical fitness', 'exercise', 'exertion' and 'exercise movement techniques' in combination with the keywords: 'weight', 'weight loss', 'obesity' and 'body mass index', and the Medical Subject Headings: 'BMI', 'body weight changes' and 'body mass index'. Additional studies were found via the reference lists of the identified articles. The selection process for studies included in our review is shown in Fig. 1. Our search strategy and exclusion criteria resulted in a total of 18 articles being included in the meta-analysis (9–26). Of these, 10 articles examined weight loss for less than 1 year, 11 for 1–1.9 years, seven for ≥2 years and seven for 6 years (seven studies reported results for more than one time point).

Data extraction

Using a standardized data extraction form, two independent investigators extracted and tabulated all data (T. W. and M. C.). Discrepancies were resolved by group discussions. The data we collected included the last author's name, year of publication, country of origin, sample size, mean age and BMI, gender, duration of the intervention and the follow-up after intervention, type of dietary and exercise intervention and other relevant characteristics of the study population. We extracted baseline and post-intervention means and standard deviations for weight measurements including weight (kg) and BMI (kg m^{-2}).

Statistical analysis

The primary outcome was change in body weight. The effect size for each study was the difference in weight loss between the two intervention groups (the D + E group and the D group). A random effects model was used to pool the results from the individual studies which allows for both sampling error and additional between-study heterogeneity (27). There were two main measures of weight in these studies: weight (kg) or BMI (kg m^{-2}). Because these two measures are on a different scale, we first calculated the standardized mean differences for each study and then pooled the standardized mean differences. Standardized mean differences were obtained using Cohen's d method by dividing the change in body weight by the standard deviation of the change in body weight as expressed in weight or BMI (28). As a result, the standardized mean differences are mean differences on a standard deviation scale and do not have a measurement unit. We also pooled studies separately for weight (kg) and BMI (kg m^{-2}) without using Cohen's method. For some studies, there were different D + E groups because different types of exercise programmes were assigned: we pooled the results of these D + E groups together, weighted by inverse of the variance within each

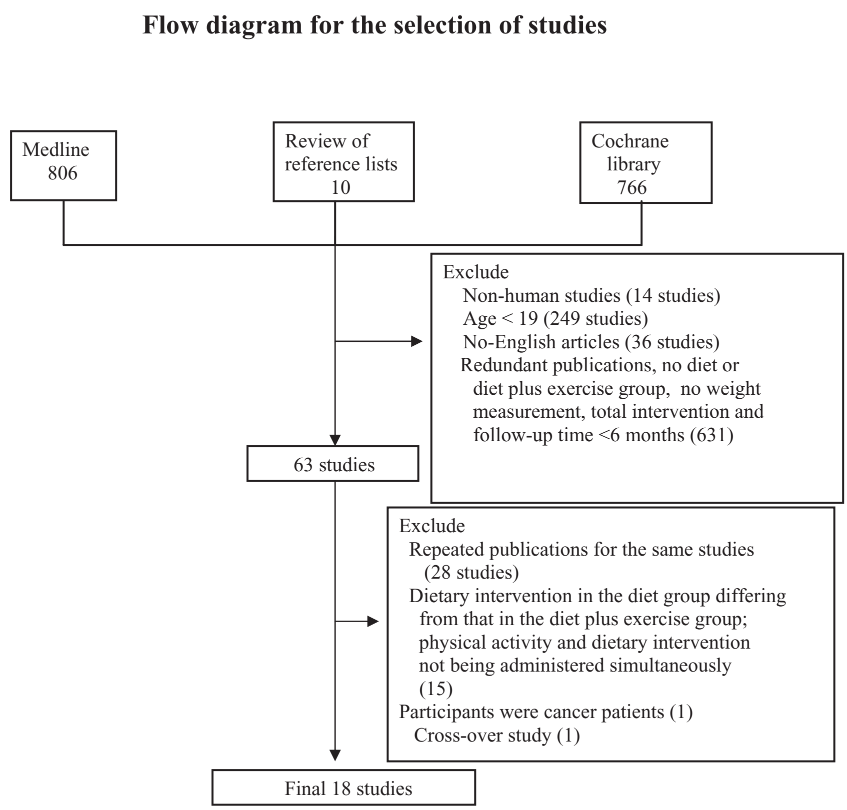

Figure 1 Full text review for 63 studies.

group. As a secondary analysis, we also examined the effects of interventions on percentage of body fat loss.

Using the last time point of weight loss measurement for each study, we also performed a meta-analysis among subgroups by baseline age, BMI, gender, the length of the intervention and the subsequent follow-up without active intervention and comorbidities (as defined by diabetes, cardiovascular risk factors such as elevated LDL-C and impaired glucose tolerance and metabolic syndrome). The *P*-values for differences in effects between strata were obtained using univariate meta-regression (29). To determine the presence of publication bias, we assessed the symmetry of the funnel plots in which mean differences were plotted against their corresponding standard errors, and we used Begg and Egger test for detecting publication bias (30). We further conducted sensitivity analysis by excluding those studies with higher dropout rate (more than 20% in both intervention groups) or the dropout rate between two intervention groups was more than 10% different.

All analyses were conducted using STATA 8.2 (StataCorp, College Station, TX, USA); two-sided *P*-values <0.05 were considered statistically significant.

Results

The baseline characteristics for the studies included in the meta-analysis are presented in Table 1. The mean age of the study population ranged from 36 to 55 years. The mean weight ranged from 70 to 100 kg and the mean BMI from 25 to 38 kg m^{-2}. Ten studies included both men and women, and three included only women (11,21,22), four included only men (13,15,18,23). As a result of our eligibility criteria, the total duration of the study (the duration of active intervention plus subsequent follow-up after intervention) was at least 6 months in all studies. The length of intervention varied from 3 months to 6 years, and the length of the subsequent follow-up without active intervention varied from 0 to 2.5 years.

With regard to randomized intervention studies, there are general criteria for evaluating the quality of clinical trials including randomization procedures, allocation concealment, blinding of outcome measurement, dropout rate and intent-to-treat analysis. However, most of the studies in our meta-analysis failed to mentioned whether they adhered to these rules or conducted the studies according to these guidelines. Only three studies stated their randomization procedures (12,16,20), none of the studies mentioned allocation concealment, one study mentioned that they did have blinding of outcome measurement (12), and only two studies had a 0% dropout rate (12,13), in which intent-to-treat analysis was conducted; the rest of the studies did not conduct intent-to-treat analyses.

Table 2 shows weight loss at the end of follow-up for the D + E groups and D groups for individual studies and for

Table 1 Characteristics of the trials included in the meta-analysis

Reference	Country	*n*	Sex	Mean age	Mean BMI (kg m^{-2})	Dietary intervention	Exercise programme	Duration of the active intervention	Follow-up after intervention	Population
Wing *et al.* (1988) (24)	USA	28	M&F	55.5	38	Calorie-restricted diet (1000 calorie deficit)	Supervised weekly in a group, walked 3 miles each time, four times per week	14.5 months	0	Type 2 diabetics
Leighton *et al.* (1990) (16)	USA	66	M&F	42.5	27	NCEP initial diet*	Supervised weekly in a group. Aerobic exercise (stationary bicycling, walking, jogging, stair climbing or rowing), reached 55% of aerobic capacity for the first 10 weeks and 75% of maximal aerobic capacity after week 10	6.5 months	0	Subjects with elevated LDL-C levels
Svendsen *et al.* (1993) (21)	Denmark	100	F	54	30	4200 KJ d^{-1}, included obligatory diet supplement (NUPO)** plus foods	Supervised three times per week in a group. Combination of aerobic (bicycling, stair walking and treadmill) plus anaerobic exercise (resistance weight training), for a total of 1.0–1.5 h, reaching 70% of maximal oxygen consumption	3 months	6 months	Healthy postmenopausal women
Hellenius *et al.* (1993) (13)	Sweden	79	M	46	25.6	NCEP step 1 diet†	Supervised weekly in a group, aerobic (walking, jogging), reached 60–80% maximum heart rate, 30–40 min, 2–3 time per week	6 months	0	Healthy men with moderate cardiovascular risk
Williams *et al.* (1994) (23)	USA	76	M	37	30.5	NCEP step 1 diet	Aerobic exercise (brisk walking and jogging), 25–45 min, reached 60–80% of the maximal heart rate, three times per week	12 months	0	Obese men
Anderssen *et al.* (1996) (9)	Norway	177	M&F	40	29	Increased fish, fruit and vegetables and fibre, reduced intake of sugar and saturated fatty acids, no heavy evening meals	Supervised weekly, aerobic training (strength, flexibility, circuit training, jogging), reached 60–80% of peak heart rate	12 months	0	Sedentary subjects
Skender *et al.* (1996) (19)	USA	36	M&F	35	35	HYHEP diet§ (low-energy eating plan)	Supervised weekly although group, brisk walking at a level of felt 'vigorous' not 'strenuous', 45 min, 4–5 times per week	12 months	12 months	Obese subjects
Pan *et al.* (1997) (17)	China	155	M&F	44	25.9	Calorie intake at 25–30 kcal kg^{-1} (105–126 kJ kg^{-1}), 55–65% carbohydrate, 10–15% protein and 25–30% of fat. Increased vegetable intake and reduced intake of sugars; using individual goals	Increased the amount of exercise at least 1 U d^{-1}¶ and 2 U d^{-1} for those less than 50 years old with no evidence of heart or arthritis. The rate of increase and type of exercise depending on age, past exercise pattern and existence of heart problem other than impaired glucose tolerance. Physical activity was followed up every 3 months	6 years	0	Subjects with impaired glucose tolerance including diabetes

Table 1 *Continued*

Reference	Country	*n*	Sex	Mean age	Mean BMI (kg m^{-2})	Dietary intervention	Exercise programme	Duration of the active intervention	Follow-up after intervention	Population
Wadden *et al.* (1998) (22)	USA	77	F	42	36.5	Conventional diet with 1200–1500 kcal d^{-1}	Supervised weekly in a group, 1 h, two times per week, included three exercise groups: (1) Aerobic, expended 300–400 kcal per time; (2) strength, expended 150–176 kcal per time; (3) combined (aerobic + strength), 40% aerobic, expended 225–275 kcal per time	12 months	13 months	Obese women
Wing *et al.* (1998) (25)	USA	77	M&F	45.5	36	Low-calorie and low-fat regimen with 20% of calorie plus fat at 800–1000 kcal d^{-1} during week 1–8 and gradually adjusted to 1200–1500 kcal d^{-1} after week 16	Supervised by exercise physiologists weekly in a group. Mainly brisk walking, 3 miles, five times per week, total activity gradually increased to 1500 kcal per week	24 months	0	Non-diabetic subjects with parental history of diabetes
Stefanick *et al.* (1998) (20)	USA	97	M&F	50.5	26.6	NCEP step 2 diet[‡]	Supervised weekly, aerobic exercise = 16 km jogging per week	12 months	0	Men and postmenopausal women with low HDL-C and high LDL-C
Fogelholm *et al.* (2000) (11)	Finland	82	F	35	34	Low-fat diet	Supervised weekly in a group, reached 50–60% of maximal heart rate, included two groups: (1) walking, expended 4.2 MJ per week; and (2) walking, expend 8.4 MJ per week	13 months	11 months	Premenopausal women
Reseland *et al.* (2001) (18)	Norway	101	M	46	27	Increased intakes of fish, vegetables and fibre; reduced intakes of saturated fat and cholesterol	Supervised weekly in group. Aerobic, circuit training, fast walking and jogging, 60 min, three times per week	12 months	0	Men with the metabolic syndrome
Kiernan *et al.* (2001) (14)	USA	152	M&F	35	30 for men 28 for women	NCEP step 1 diet	Supervised programme of aerobic exercise (brisk walking and jogging), three times per week, reached 60–80% of maximal heart rate for 25–45 min per time (by the fourth month)	12 months	0	Overweight subjects
Brekke *et al.* (2005) (10)	Sweden	49	M&F	43	25.5	Nordic nutrition recommendation*** plus low-glycemic index foods	Increased physical activity (walking or other activity), ≥30 min, 4–5 times per week. Supervised intervention was through group discussions. Intensive follow-up was conducted in the first 4 months by a 72-h physical activity recall every 10 d; less intensive follow-up was performed after 4 months (recall every 10 weeks)	12 months	12 months	First degree relatives of type II diabetes

Table 1 *Continued*

Reference	Country	*n*	Sex	Mean age	Mean BMI (kg m^{-2})	Dietary intervention	Exercise programme	Duration of the active intervention	Follow-up after intervention	Population
Kukkonen-Harjula *et al.* (2005) (15)	Finland	90	F	42	33	Two months of very low-energy diet (2 MJ d^{-1}) followed by low-energy diet (5 MJ d^{-1})	Included walking and resistance training, 45 min, three times per week, reached 60–70% of oxygen consumption, expended 1.7 MJ in walking and 1.2 MJ in resistance each time. Participants were supervised weekly during weight reduction and maintenance phase before the intervention	8 months	23 months	Obese men
Heilbronn *et al.* (2006) (12)	USA	36	M&F	37.5	27.5	25% calorie restriction diet based on American Heart association recommendations (≤30% fat)	Supervised weekly in a group, increased 12.5% energy expenditure (walking, running, cycling) 5 d per week	6 months	0	Overweight adults
Messier *et al.* (2004) (26)	USA	158	M&F	69	34.5	The goal of intervention was to produce and maintain an average weight loss of 5% baseline body weight. The intervention was divided into three phases: intensive (months 1–4), transition (months 5–6) and maintenance (months 7–18)	The exercise programme consisted of an aerobic phase, a resistance-training phase, a second aerobic phase and cooling down phase	18 months	0	Overweight and obese individuals with knee osteoarthritis

*NCEP initial diet: less than 30% of energy from total fat, <10% of energy from saturated fat and <300 mg of cholesterol per day.

†NCEP step 1 diet: less than 30% of energy from total fat, <10% of energy from saturated fat, >10% of energy from polyunsaturated fat, up to 10–15% of energy from monounsaturated fat, 50–60% of energy from carbohydrate, 10–20% of energy from protein and <200 mg of cholesterol per day.

‡NCEP step 2 diet: less than 30% of energy from total fat, <7% of energy from saturated fat and <200 mg of cholesterol per day.

§HYHEP diet: help your heart eating plan. A low-cholesterol eating plan with energy intake of 30% from fat, 50% from carbohydrate and 20% from protein.

¶1 U: equals to 30 min of slow walking or shopping.

**NUPO: supplied protein 65 g, carbohydrate 21 g, dietary fibres 30 g, fat 5 g and calcium and phosphorous 800 mg d^{-1}.

***Nordic Nutrition recommendations: 10% of energy from saturated fat, increase intake of monounsaturated fat and *n*-3 fatty acids, 50–60% of energy from carbohydrate and 10–20% from protein, <300 mg of cholesterol per day.

BMI, body mass index; F, female; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; M, male; NCEP, national cholesterol education programme.

Table 2 Weight loss differences between diet-plus-exercise group and diet-only group at the end of follow-up

Study	Intervention (months)	Total duration*	dropout rate†	D + E	D	Differences
Weight (kg)						
Heilbronn *et al.* (2006) (12)	6	6	0% in D + E§ and 0% in D‡	–8.00	–8.00	0
Leighton *et al.* (1990) (16)	6.5	6.5	27% in D + E and 18% in D	–2.00	0	–2.00
Svendsen *et al.* (1993) (21)	3	9	2% in D + E and 2% in D	1.40	1.50	–0.1
Kiernan *et al.* (2001) (14)	12	12	10% in D + E and 18% in D	–8.70	–5.00	–3.70
Wing *et al.* (1988) (24)	14.5	14.5	13% in D + E and 0% in D	–7.90	–3.80	–4.10
Skender *et al.* (1996) (19)	12	24	50% in D + E and 65% in D	–2.20	0.90	–3.10
Wing *et al.* (1998) (25)	24	24	20% in D + E and 5% in D	–2.50	–2.10	–0.40
Fogelholm *et al.* (2000) (11)	13	24	2% in D + E and 3% in D	–7.50	9.70	–2.20
Brekke *et al.* (2005) (10)	12	24	17% in D + E and 4% in D	–1.90	–0.08	–1.82
Wadden *et al.* (1998) (22)	12	25	22% in D + E and D	–9.10	–6.90	–2.20
Messier *et al.* (2004) (26)	18	18	24% in D + E and 23% in D	–5.20	–4.61	–0.59
Pooled mean				–3.60	–1.78	–1.14
95% CI (kg)				–6.74 to –0.46	–4.86 to 1.30	–2.07 to –0.21
BMI (kg m^{-2})						
Hellenius (1993)	6	6	0% in D + E and 0% in D	–0.60	–0.30	–0.30
Williams *et al.* (1994) (23)	12	12	14% in D + E and 13% in D	–2.80	–1.50	–1.30
Anderssen *et al.* (1996) (9)	12	12	3% in D + E and 5% in D	–2.16	–1.63	–0.53
Stefanick *et al.* (1998) (20)	12	12	3% in D + E and 1% in D	–3.10	–2.70	–0.40
Reseland *et al.* (2001) (18)	12	12	0% in D + E and 0% in D	–1.80	–1.30	–0.50
Kukkonen-Harjula *et al.* (2005) (15)	8	31	23% in D + E and 26% in D	–0.87	–1.80	0.93
Pan *et al.* (1997) (17)	72	72	8% in D + E and D	–1.60	–1.10	–0.50
Pooled mean				–1.83	–1.38	–0.50
95% CI (kg m^{-2})				–2.45 to –1.21	–1.92 to –0.84	–0.79 to –0.21

*Total duration, intervention time plus follow-up time after intervention.
†Average dropout rate if not specially indicated.
‡D denotes diet-only group.
§D + E denotes diet-plus-exercise group.
Two measurements for weight were recorded, weight (kg) or BMI (kg m^{-2}).
BMI, body mass index; CI, confidence interval.

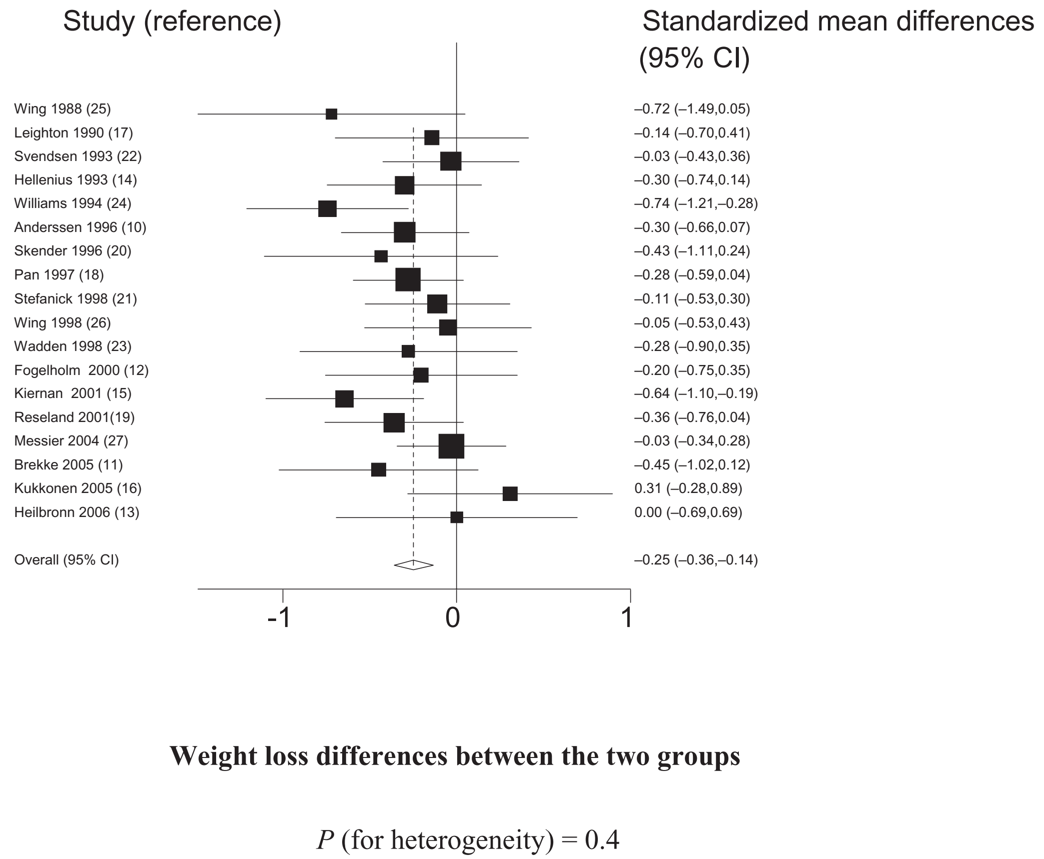

Figure 2 Pooled standardized mean differences of weight loss between diet-plus-exercise and diet-only groups at the end of study. CI, confidence interval.

all studies combined. Ten studies reported results as change in weight (kg) and seven studies as change in BMI (kg m^{-2}). After pooling the data, weight loss was 3.34 kg or 0.87 kg m^{-2} in D + E group and 1.38 kg or 1.48 kg m^{-2} in the D group. The pooled weight loss was 1.24 kg (95% confidence interval [CI] 0.23 to 2.26) or 0.50 kg m^{-2} (95% CI 0.21 to 0.79) greater for D + E group as compared with D group. We did not detect significant heterogeneity in results for either the studies reporting weight change (*P*-value for heterogeneity = 0.2) or the studies reporting change in BMI (*P*-value for heterogeneity = 0.3). In two studies, the interventions were initiated after an intensive weight loss intervention in the weight maintenance phase and did not lead to further weight loss (11,15).

The dropout rates for the interventions were lower than 30% (Table 2), except for the study by Skender *et al.* which had a 50–65% dropout rate (19). The dropout rate in the D + E group was similar to that in the D group in most of the studies. In a sensitivity analysis excluding those with higher dropout rate or highly different dropout rates in two groups, the overall results did not change.

We also pooled the results on weight and BMI separately using the time frame at 1–2 and after 2 years. For the 1–2 year time point, the weighted mean difference between D + E and D groups was –2.29 kg for weight (kg) (95% CI –3.52 to –1.06, *P* for heterogeneity = 0.8; from seven studies) and –0.67 kg m^{-2} for BMI (kg m^{-2}) (95% CI –1.05 to –0.30, *P* for heterogeneity0 = 0.4; from four studies). For the time frame after 2 years, the differences between the two groups was –1.78 kg for weight (kg) (95% CI –3.43 to –0.13, *P* for heterogeneity = 0.9; from five studies) and –0.04 kg m^{-2} for BMI (kg m^{-2}) (95% CI –1.35 to 1.27, *P* for heterogeneity = 0.1; from two studies).

To be able to combine the studies reporting weight change and BMI change, we also expressed results as standardized mean differences between the intervention groups. Using the measurement at the end of each study (Fig. 2), the pooled standardized mean difference between D + E and D groups was –0.25 (95% CI –0.36 to –0.14), with a *P*-value for heterogeneity of 0.4 (pooled standardized mean difference was expressed as mean or standard deviation, thus it does not have a unit). We also calculated standardized pooled mean differences at different time points. The pooled standardized difference was –0.14 (95% CI –0.30 to 0.03; 10 studies; *P* for heterogeneity = 0.9), <1.0 year; –0.32 (95% CI –0.44 to –0.17; 10 studies; *P* for heteroge-

Table 3 Pooled standardized mean differences according to study characteristics (using the last point of measurement)

Group	Mean differences*	95% CI	No of studies	Between-group heterogeneity *P*-value for differences between strata
All studies	–0.25	(–0.36 to –0.14)	18	
Age category				
<45 years	–0.32	(–0.48 to –0.16)	11	0.30
≥45 years	–0.21	(–0.39 to –0.02)	7	
Overweight category				
BMI ≥ 30 kg m^{-2}	–0.29	(–0.56 to –0.02)	8	0.90
BMI < 30 kg m^{-2}	–0.27	(–0.41 to –0.13)	10	
Sex				
Male	–0.31	(–0.68 to –0.07)	4	0.30
Female	–0.13	(–0.41 to 0.16)	3	
Mixed	–0.29	(–0.44 to –0.14)	11	
Intervention time				
≥1 year	–0.35	(–0.48 to –0.22)	13	0.03
<1 year	–0.07	(–0.29 to 0.16)	5	
Follow-up time after active intervention				
0 month	–0.32	(–0.46 to –0.19)	12	0.20
>0 month	–0.15	(–0.37 to 0.07)	6	

*Mean differences are standardized mean differences expressed per standard deviation (without unit).
CI, confidence interval.

neity = 0.3), after 1.0–1.9 years; and –0.20 (95% CI –0.39 to –0.02; seven studies; *P* for heterogeneity = 0.5), after 2.0 or more years. In the trial of Pan *et al.* (17), clinics instead of individuals were randomized to different interventions. We therefore performed a sensitivity analysis excluding this trial and observed a similar pooled difference in weight loss between D + E intervention and D intervention.

As a secondary analysis, we examined effects of interventions on percentage of body fat mass loss based on the six studies for which data on body fatness were reported (11,16,18,21–23). Consistent with our primary analysis, we found that the percentage of body fat loss at the end of the study was greater for the combined D + E intervention as compared with the D intervention (pooled difference 2%; 95% CI 0.65% to 3.5%).

Table 3 shows the results of subgroup analyses. The difference in weight loss between the D + E and the D group was significantly greater in studies with a longer intervention period (*P* = 0.03). Meta-regression did not show statistical significant differences in results by baseline age, obesity, sex, population, comorbidities and duration of follow-up after the active intervention no matter whether they were entered as continuous or categorical variables.

The funnel plot (graph not shown) showed data points symmetrically scattered across the horizontal line indicating a lack of association between study precision and the effects size (i.e. standardized mean differences in weight change between the D + E and D groups). The Begg (*P* = 0.7) and Egger (*P* = 0.9) tests also did not provide evidence for publication bias.

Discussion

In this meta-analysis of 18 randomized trials, we found that interventions including a combined D + E programme produced greater long-term weight loss than interventions that only included a diet programme. This difference in weight loss was significantly greater for interventions with a duration longer than 1 year than that for interventions of shorter duration.

In general, achieving long-term weight loss is difficult. Previous meta-analyses included trials with a maximum of 1-year follow-up (7,8); our analysis included seven trials with a duration of 2 years or longer. The achievement after 2 years may appear small, averaging 1.64 kg or 1.24 kg m^{-2} loss of body weight after a combination of dietary changes and increased physical activity. There may be several reasons for this modest long-term effect. First, poor compliance is often an issue in long-term intervention studies. Other researchers reported that the degree of adherence to weight loss interventions is a strong predictor of weight loss (31,32). Second, we found that intervention time was significantly associated with greater weight loss associated with adding exercise to the intervention programme which is in line with some previous studies (33,34). Our study thus suggests that a prolonged active intervention may be important; this could be accomplished in several ways: by regular clinical visits, at group meetings or through encouragement by telephone or emails. In fact, one study reached 5.6% (1.6 kg m^{-2}) decrease in BMI after 6 years (17) suggesting that substantial long-term weight loss is achievable. It has been reported that 5% loss of body weight is associated with a marked decrease in incidence of type 2 diabetes and other metabolic disturbances (33,34). It should be noted that including exercise in interventions improves various health-related parameters independent of effects on body fatness including blood lipid profile, blood pressure, insulin sensitivity and psychological well-being (14).

Our meta-analysis had several strengths. Meta-analysis provides more precise estimates than individual studies and allows evaluation of potential determinants of heterogeneity in results. We conducted an extensive literature search to retrieve all relevant eligible trials resulting in 18 randomized clinical trials including seven trials with a duration of 2 years or longer. A previous meta-analysis (7,8,35,36) did not include any intervention study longer than 2 years. Anderson *et al.* (37) conducted a meta-analysis on long-term maintenance of weight loss for up to 5 years; however, their results were from observational studies, which lack randomization and are thus prone to confounding.

A number of limitations of the present analysis should also be acknowledged. First, heterogeneity in results may be introduced by differences between trials, including different D + E regimens. However, heterogeneity test using random effect model was not significant. Further, heterogeneity in the amount of additional weight loss associated with adding exercise to the intervention programme appeared to be limited. Our pooled results therefore suggest that D + E intervention is generally more beneficial for long-term weight loss than D intervention, independent of the D regimen and type of exercise used in the included studies. Publication bias cannot be excluded to affect the results on any meta-analysis; however, formal statistical testing did not suggest publication bias for the current analysis. Finally, most studies did not provide information on the quality of the intervention such as randomization method, allocation concealment and blinding of the study assignments to the persons performing the outcome measurements. Although many studies included in our analysis had a substantial dropout rate (see Table 2), intent-to-treat analyses were generally not conducted. However, dropouts were less likely to bias the comparison of the weight loss for D + E intervention as compared with D intervention because dropout rates were generally similar for these intervention groups. Our sensitivity analysis showed that exclusion of studies with high dropout rates or dropout rates that were substantially different for the D + E group and D group did not change the overall results. Future studies on long-term weight loss should clearly report the randomization method, allocation concealment, blinding and the use of intent-to-treat analysis.

In conclusion, the present study confirms the importance of including exercise in addition to diet in long-term weight loss programmes. A combined D + E programme provided greater weight loss even in studies lasting 2 years or longer. However, both D and D + E programmes are associated with partial long-term weight regain, and future studies should explore better strategies to limit weight regain and achieve greater long-term weight loss.

Conflict of Interest Statement

No conflict of interest was declared.

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