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NARRATIVE REVIEW

The Efficacy of Exercise in the Treatment of Established Obesity

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Abstract

Objective: The objective of this narrative review was to examine cross-sectional empirical data on the efficacy of adequate doses of daily physical activity in the treatment of established obesity. **Methods:** Information obtained from Ovid/Medline and Google Scholar through to June 2019 was supplemented by a search of the author's extensive personal files. **Results:** Randomized controlled trials have shown a small but consistent effect of exercise programmes in reducing the body mass and body fat content of the obese. Some non-randomized trials have adopted larger volumes of exercise (2-4 MJ/d), and weight losses of 10 kg or more have then been observed. Dieting has generally given a greater weight loss than exercise, but some of this apparent advantage has reflected a greater loss of lean tissue. Changes in lean tissue mass have under-estimated the beneficial impact of exercise programmes by 2-3 kg, while exaggerating the benefits of dieting by 2-3 kg. Fat loss seems to occur a little more easily in men than in women, and it is also easier to mobilize abdominal fat than subcutaneous fat. The minimal dose of physical activity recommended by public health authorities seems insufficient to deal with established obesity; adults need 150-250 min of exercise per week, incurring an additional weekly energy expenditure of 4.8-8.0 MJ, and children may require even larger doses of activity to counter obesity. High intensity programmes save time and may be somewhat more effective for any given energy expenditure than longer periods of moderate activity. A combination of dietary restraint and heavy exercise can cause an 8.5 kg loss of fat over 8 weeks. However, long-term adherence to high intensity programmes is more problematic. It may be helpful to split a single session of aerobic activity into several shorter segments. Causes of a limited response to exercise include an insufficient exercise prescription, poor programme adherence, and a compensatory increase of food intake, compounded by reductions in resting metabolic rate, spontaneous leisure activity and NEAT. Meta-analyses have typically shown weight and fat losses of around 10 kg with 3 months of combined dieting and exercise, but in a few instances much greater weight losses have been reported. Moderate exercise sessions have sometimes added little to dieting alone, but it remains unclear whether more rigorous physical activity programmes might lead to a greater fat loss. Exercise is helpful in preserving lean tissue; it also confers many ancillary health benefits such as enhanced cardio-respiratory fitness, and it may limit the regain of weight after the completion of formal treatment. Resistance exercise is particularly helpful in conserving lean tissue. In a long-term perspective, lifestyle activities may be more effective than a formal exercise programme. Much of initial weight loss is often regained within a year, but continued exercise and dieting conserve at least 3 kg of the initial weight reduction. **Conclusions:** Moderate exercise alone has less effect upon obesity than rigorous dieting, but benefits are larger if the exercise dose can be increased. Exercise helps to conserve lean tissue, and plays an important role in weight maintenance. The challenges to health professionals are to develop safe methods of reaching an effective dose of exercise in those who are obese, and in sustaining the enthusiasm of such individuals for an active lifestyle once initial weight goals have been attained. **Health & Fitness Journal of Canada 2019;12(3):93-165.**
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Introduction

Evidence from a variety of sources points strongly towards the efficacy of an increase in physical activity as a means of preventing the development of obesity throughout the human lifespan (Shephard, 2019a, b, c). On the other hand, many investigators have argued that dieting is much more effective than an increase of physical activity as a method of treating established obesity. Nevertheless, this latter conclusion has often been based on the relative changes in total body mass achieved by the two types of intervention, rather than on a determination of the respective decreases in body fat content. Drastic dieting inevitably lead to a substantial loss of body mass, but much of this loss is lean tissue rather than fat. In contrast, exercise programmes tend to maintain and may even increase lean tissue mass; this is a much preferable outcome, even though it leads to a smaller change in total body mass following an intervention.

The present narrative review looks critically at the treatment of established obesity in terms of the immediate and longer-term benefits conferred by exercise versus stringent dieting or a combination of exercise and dieting, considering the potential impact of the weekly physical activity levels proposed in most public health recommendations and the likely additional benefits resulting from participation in a more vigorous regimen. We also explore compensatory mechanisms that seem to have impeded a clinically useful fat loss in many trials, and discuss what an exercise programme can add to a seemingly effective treatment based upon dieting. Comment is made on the respective merits of aerobic and resistance exercise programmes, and on the benefits that result from encouraging an active lifestyle relative to participation in formal exercise classes. Finally, we examine concerns about long-term programme adherence and underline the value of regular physical activity in maintaining and appropriate body mass once immediate weight-loss objectives have been met.

Can exercise induce a significant reduction of body fat content in those who are obese?

In seeking an answer to this question, we will look at meta-analyses of existing randomized controlled trials, noting the methods of assessing fat loss that have been used and the extent of benefit resulting from exercise programmes, commenting on possible differences in response dependent upon the individual's sex and pattern of fat distribution.

Meta-analyses of randomized controlled trials.

One reviewer found at least 16 randomized controlled studies that had looked at the influence of exercise alone upon individuals who, in the main, were overweight rather than obese. Trials had continued over periods of 4 to 16 months, with nine of the investigations continuing for 11-16 months (Catenacci & Wyatt, 2007). Fifteen of the 16 reports had noted a trend to benefit from the exercise intervention in terms of weight loss, and 11 of the 16 studies had demonstrated a statistically significant decrease of body mass relative to the control group, although sometimes the change had been relatively small. Typically, weight losses had ranged from 1 to 3 kg, and changes of lean tissue mass were often not recorded. Three of the 5 trials where no significant benefit was seen lasted for 4 months or less, and one of these trials had provided only resistance exercise, presumably with a relatively limited increase in daily energy expenditure. Moreover, the available evidence is often unsatisfactory in terms of the efficacy of exercise as a means of fat loss, since the primary goal of investigators has commonly been to enhance cardiovascular fitness, and the volume of exercise undertaken (60-180 min/wk) was sub-optimal in terms of correcting obesity. The negative energy balance thus induced would necessarily have had only a small effect in terms of fat metabolism.

Catenacciand Wyatt (2007) noted that in contrast to most of the randomized controlled investigations, some uncontrolled studies had used much larger volumes of exercise, sufficient to achieve a negative energy balance of 2-4 MJ/d, and that such programmes had led to a much larger decreases of body mass, often of around 12.5 kg (Hadjiolova, Minscheva, Dunev, & Doleva, 1982; Lee, Kumar, & Leong, 1994). Specific examples of substantial benefit from more vigorous exercise programmes are discussed below. Plainly, exercise can have an immediate clinically useful effect in reducing obesity, provided that the volume of added physical activity is sufficiently large. However, Catenacci and Wyatt (2007) have questioned whether severely obese individuals have the motivation and the physical ability to persist with such demanding programmes until a significant fat loss had been achieved.

Thorogood et al. (2011) identified 14 trials of exercise alone, involving 1467 patients, studied through to January 2010. The intensity of prescribed effort was sometimes as low as 40% of maximal oxygen intake, and the total duration of the added physical activity ranged from 120 to 240 min/wk. Dietary intake was often uncontrolled. Data after interventions of 6 and 12 months showed decreases in body mass averaging 1.6 and 1.7 kg, and decreases in waist circumference of 2.1 and 2.0 cm. Despite the small size of these benefits, Thorogood et al. (2011) noted that there were ancillary beneficial changes in blood pressure and blood lipids.

The report of Garrow and Summerbell (1995) assembled data from 28 reports of randomized controlled trials published between 1968-1993, where exercise had been compared with control groups or alternative treatments for obesity (Table 1). This article is particularly helpful in specifying not only the decreases in body mass that were observed, but also changes in fat-free mass. Often, as also noted by Catenacci and Wyatt (2007), the investigators concerned had prescribed only a limited and rather inadequate additional weekly volume of exercise, but nevertheless the adoption of an exercise programme without deliberate dieting had generally achieved a modest weight loss, without the undesired metabolism of lean tissue that was a typical side-effect of stringent dieting. In the first grouping of papers, control participants had been given what would have been a weight-maintenance diet without any change in their level of weekly physical activity. Over a weighted trial duration of 30 weeks in the men and 14 weeks in the women, aerobic exercise had decreased body mass by 2.6 kg in the men and 3.0 kg in the women relative to the controls, but there had been little change of fat free mass. A few of the trials included in this report had evaluated resistance exercise (12 and 8 week programmes in men and women, respectively); this regimen had increased lean tissue mass relative to controls (by 2.6 and 1.1 kg), but had brought about little change of total body mass. In a second group of trials, exercise with a weight-maintenance diet had been compared with rigorous dieting. Over periods of 32 weeks for men and 10 weeks for women, findings for aerobic exercise were much as in the first group of reports, with decreases in body mass of 2.8 and 3.0 kg in men and women respectively, but little change of lean tissue mass in either sex. Dieting over similar periods produced much greater decreases of body mass (7.6 and 7.8 kg), but at the expense of a substantial loss of lean tissue. The third and fourth groups of trials examined the effects of adding exercise to periods of moderate (>4 MJ/d) and severe (<4MJ/d) dietary restriction. Severe dieting alone (a food intake <4 MJ/d) led to a substantially larger decrease in body mass than the other interventions, but there was also a greater decrease of fat-free mass. The addition of an exercise programme to either of the dietary interventions led to a further small increase in weight loss, but there was some attenuation of the decrease in fat-free mass.

Shaw, Gennat, O'Rourke, and Del Mar (2009) collected information from 43 randomized controlled trials covering a total of 3476 participants. All subjects were initially overweight or obese, and the average loss of subjects at follow-up was less than 15%. Exercise led to small decreases in body mass and body mass index, relative to no treatment, with the size of this effect increasing if a greater volume and intensity of exercise was prescribed. Dieting plus exercise led to a small increase in weight loss relative to dieting without exercise (a weighted mean benefit of 1.0 kg) . However, data on changes in fat-free mass or body fat content were not analyzed in this report.

Methods of assessing the extent of fat loss.

The extent of the improvement in body composition following exercise interventions has generally been assessed in terms of overall weight loss rather than as a decrease of body fat content, and on this criterion changes relative to controls or to dieting alone have commonly been in the range 1-3 kg. However, some reports have also indicated the loss of lean tissue mass, allowing one to make a more accurate estimation of actual fat loss. For exercisers, the fat loss has been 2-3 kg greater than the total weight loss,

Table 1: Meta-analyses of 28 randomized controlled trials of exercise as a means of treating established obesity (Garrow & Summerbell, 1995), arranged to show the change in fat mass achieved by various therapeutic options.

Participants	Treatment	Change in body mass	Change in fat-free mass	Change in fat mass
192 M, 56 F	Sedentary Aerobic ex. Resistance ex.	+0.4, -0.7 kg .-2.6, -3.0 kg 0.0, +0.5 kg	-0.3 , +0.3kg +0.1, +0.3 kg +2.1, +1.1 kg	+0.7, -0.4 kg -2.7, -3.3 kg -2.1, -0.6 kg
158 M, 45 F	Dietary restriction Aerobic ex.	-7.6, -7.8 kg -2.8, -3.0 kg	-1.9, -1.6 kg 0.0, -0.4 kg	-5.7, -6.2 kg -2.8, -2.6 kg
176 M, 530 F	Diet >4 MJ/d Aerobic ex.	-7.9, -6.1 kg -9.0, -6.9 kg	-2.3, -0.9 kg -1.9. -0.5 kg	-5.6., -5.2 kg -7.1, -6.4 kg
84 M, 176 F	Diet <4 MJ/d Aerobic or res. ex.	-12.2, -11.6 kg -14.1, -12.8 kg	-3.8, -2.9 kg -1.7, -2.7 kg	-8.4, -8.7 kg -12.4, -12.1 kg

whereas for dieters the fat loss has been correspondingly smaller than might have been inferred from changes in total body mass (Table 1).

Verheggen et al. (2016) made a meta-analysis of 117 studies covering 4815 participants, and they underlined the point that total weight loss was a poor indicator of changes in the visceral fat content of the body. Although dieting tended to cause a larger overall weight loss than exercise, an exercise programme often induced a larger decrease in visceral fat stores than dieting. Indeed, exercise could lead to as much as a 6.1% decrease in visceral adipose tissue without causing any change in overall body weight.

Likely extent of benefits from exercise programmes.

The extent of fat loss achieved during an intervention is influenced in essence by the size of the energy deficit created by the exercise and/or dietary programme and the initial body fat content of the individual. In the case of exercisers, an individual's body mass also influences the energy deficit created by any given exercise prescription.

Ideally, an exercise-based treatment regimen should restore the overall body mass and the body fat content of an obese individual to "ideal" values, but this is not always practicable, and indeed is quite rarely achieved in clinical practice. Nevertheless, it is important to recognize that exercise programmes can yield clinically significant health benefits in terms of physical ability, blood pressure and the risk of diabetic complications, even if the decreases in body mass and body fat content are quite small.

A person's relative aerobic power and effective muscular strength increase in almost direct proportion to any decrease in body mass that they achieve. Moreover, the ability to undertake many types of physical activity is enhanced by the favourable effect of programmes on peak oxygen intake and lean tissue mass.

Bravata, Smith-Spangler, and Sunduram (2007) further reported a small decrease of blood pressure in studies where the average decrease of BMI had been only 0.38 kg/m^2. Likewise, Thorogood et al. (2011) noted beneficial changes in blood pressure and blood lipids, despite decreases in body mass that averaged only 1.6 -1.7 kg, and decreases in waist circumference in the range of 2.0-2.1 cm.

Again, Wing, Venditti, Jakicic, Polley, and Lang (1998) found that the risk of developing diabetes mellitus diminished if the body mass was reduced by an average of only 4.5 kg, provided that this loss was maintained for at least 24 months. Likewise, Boulé, Haddad, Kenny, Wlls, and Sigal, (2001) demonstrated the effectiveness of exercise programmes in reducing $haemoglobin_{1c.}$ Based on 11 randomized and 3 non-randomized trials, the decrease in this marker was of sufficient magnitude to reduce diabetic complications, even though the exercised subjects showed little greater weight loss than control groups

Possible sex differences in response to weight loss programmes.

Sex differences in response to a weight loss programme might be anticipated, in part because of female hormonal regulation of body fat stores to meet the energy needs of pregnancy and lactation, and in part because of gender-related differences in attitudes to exercise, sources of knowledge and nutritional beliefs, and what is regarded as a desirable body image (Davy, Bemes, &

Driskell, 2006 ; Lovejoy, Sainsbury, and Stock Conference Working Group, 2009). Many investigations have found men losing body fat more easily than women. However, not every investigator has found a sex difference in response, perhaps in part because the subjects of fat-loss programmes have often been older adults, where the influence of sex hormones is waning.

Ballor and Keesey (1991) noted that the weight loss achieved with exercise was generally greater for men than for women, and Wood, Stefanik, and Dreon (1988) reached similar conclusions. The meta-analysis of Vissers et al. (2013) concluded that an aerobic exercise programme without dietary restriction reduced visceral adipose tissue of women by 30 cm^2, and that of men by 40 cm^2. Redman, Heilbronn, and Martin (2007) also found slightly more effect from dietary restriction or a combined exercise plus dietary restriction in men than in women (a 27% versus a 22% loss of fat over 6 months of treatment).

Meijer et al. (1991) compared responses of 16 men and 16 women who were preparing themselves for participation in a half-marathon run over a period of 5 months training. Both sexes increased their habitual physical activity by some 62%. However, doubly-labeled water studies found an increase of average daily metabolic rate in the men that was not seen in the women; the authors hypothesized that in the men, exercise stimulated habitual physical activity and diet-induced thermogenesis, whereas the women did not show such a response.

Possible impact of fat distribution upon efficacy of fat loss programmes

Okura, Nakata, Lee, Ohkawara, and Tanaka (2005) found that the benefits of adding exercise to a simple dieting programme were somewhat greater in the treatment of intra-abdominal fat versus subcutaneous fat. Moreover, with either type of regimen, it seemed substantially easier to reduce the amount of abdominal fat relative to subcutaneous fat. Given that men are more prone to accumulate abdominal fat (Power and Schulkin, 2008), this may influence sex differences in the response to treatment programmes.

Decreases of body mass and body fat content among obese adults following public health recommendations for volume, intensity and pattern of physical activity

Although uncontrolled observations suggest that a substantial volume of moderate to vigorous physical activity can do much to correct obesity, it is less clear how far the necessary regimen can be tolerated by a person who has already developed a substantial obesity. There is thus interest in the possibility of achieving clinically useful results by persisting with a less demanding exercise programme. The minimum physical activity recommendation of public health groups calls for adults to engage in at least 30 min of moderately vigorous aerobic activity on most days of the week, and to undertake systematic resistance exercise at least twice per week. This level of exercise is generally considered sufficient to confer benefits in many areas of health, but unfortunately several substantial studies suggest that it is insufficient to correct established obesity (Table 2).

Table 2: Decrease of body mass and/or body fat content seen in overweight or obese individuals who have followed the minimal public health recommendations for weekly physical activity.

Author	Sample	Regimen	Response	Comments
Church et al. (2010)	162 sedentary M & F aged 39.7 yr, BMI 31.8 kg/m^2	3-5 sessions/wk of supervised exercise vs. unchanged regimen for 4 months	Wt. -0.6 kg vs. + 0.1 kg DEXA fat mass -0.6 kg vs. +0.2 kg	Peak O_2 intake + 0.17 L/min with intervention; no mean benefit in terms of c-reactive protein
Church et al. (2007)	464 overweight or obese post-menopausal women	Aerobic exercise at 0, 50, 100, or 150% of min. public health recommendation (energy exp. 0, 16, 32 or 48 kJ per kg of body mass per week)	No inter-group differences of body mass or body fat at 4-6 months, but waist circumference reduced 2.6-3.1 cm in most active group	Peak oxygen intake increased 0.11 L/min in most active group
Donnelly et al. (2000)	22 overweight or obese individuals aged 49-54 yr.	30 min exercise at 60-75% max. ox. intake 3 times/wk, vs. walking 2 x 15 min/d, 5 times/wk	Aerobic activity reduced body weight 1.7 kg in 16 months, walking reduced it 0.8 kg	Similar changes in fat weight for 2 interventions
Duncan et al. (1991)	102 sedentary women, aged 20-40 yr	Walking 4.8 km/d, 5 d/wk at speeds of 8, 6.4 or 4.8 km/h vs. control	24 weeks; little change of body mass, decrease of body fat (4, 5, 6%) similar for 3 interventions	
Kraus et al. (2002)	111 sedentary and overweight men and women aged ~ 52 yr.	8 months, 32 km/wk at 65-80% peak ox. intake vs. 19.2 km/wk at 65-80% or 40-55% peak ox. intake vs. control	Body mass -1.52 kg, -0.17 kg, -0.55 kg vs. + 0.95 kg for 4 groups.	Beneficial effects on lipid profile related to volume of exercise undertaken
Sigal et al. (2007)	251 adults aged 39-70 yr with type 2 diabetes mellitus.	6 months aerobic and/or resistance training vs. control	Body mass relative to control, aerobic - 2.2 kg, resistance -0.7 kg, combined aerobic/resistance -2.2 kg	Either aerobic or resistance exercise improves glycaemic control, but best results with combined regimen

Influence of the volume of physical activity upon fat loss

Church, Earnest, and Thompson (2010) focused on the ability of moderate exercise to modify levels of c-reactive protein in a sample of 162 sedentary and obese men and women. Subjects were randomly divided between a group that undertook the volume of physical activity commonly recommended by consensus public health advisory groups (3-5 supervised sessions of moderate-to-vigorous physical activity per week, totaling 150-210 min of activity at 60-80% of maximal oxygen intake) and a control group that maintained their previous lifestyle. At the end of 4 months, the intervention group showed a negligible advantage in terms of both weight change (a loss of 0.6 kg. versus a gain of 0.1 kg), and a DEXA estimate of body fat content (a loss of 0.6 kg versus a gain of 0.2 kg). There was a small increase of peak oxygen intake (0.17 L/min) in the experimental group, but no inter-group difference in c-reactive protein levels was seen. The same group of investigators (Church et al., 2007) decided to compare the effectiveness of 3 different volumes of aerobic exercise (50, 100 and 150% of the minimum public health recommendation, implying added energy expenditures of 16, 32 or 48 kJ per kg of body mass per week). The subjects for this second trial were 464 overweight or obese post-menopausal women aged an average of 57.3 yr. At the end of 4-6 months, there were no inter-group differences in decreases of body mass or body fat, but the waist circumference decreased in proportion to the volume of exercise that had been undertaken (2.6 cm after 4 months of exercise in the most active group). Increases in peak oxygen intake (4.2%, 6.0% and 8.2%) were also graded in terms of the volume of exercise that had been undertaken.

Donnelly et al. (2000) assigned 22 subjects between a light aerobic exercise programme (30 min of physical activity, 3 times per week, at 60-75% of maximal oxygen intake) and a programme of light intermittent walking (15 min, twice a day, 5 d/wk). Over 16 months, there was a small but statistically significant decrease of body mass in the aerobic exercise group (1.7 kg), but no significant change of body mass in the intermittent walking group.

Duncan et al. (1991) compared body mass and fat percentages between controls and 3 groups of women who undertook more than the minimal recommendation (covering a distance of 4.8 km/d at different speeds of 8, 6.4 and 4.8 km/h). After 24 weeks; changes of body mass were quite small in all 3 groups, but there were useful and clinically similar losses of body fat (4%. 5%, and 6%) relative to the control group for aerobic walkers, brisk walkers and strollers.

Kraus et al. (2002) compared the impact of 3 volumes of exercise over a 6-month period. A sample of 111 sedentary and overweight men and women with an average age of 52 yr was divided among a control group and 3 groups undertaking differing patterns of exercise (running 32 km/week at 65-80% of peak oxygen intake, versus running 19.2 km/week at the same intensity, or walking 19.2 km at 40-55% of peak oxygen intake). After 8 months, the respective changes of body mass for the 3 interventions relative to control were -2.47 kg, -1.12 kg and -1.50 kg. There were also beneficial changes in the lipid profile, and these were related to the volume of exercise that had been undertaken.

Sigal et al. (2007) compared aerobic and resistance training with a combination of the 2 interventions in 251 middle-aged adults with type 2 diabetes mellitus. After 6 months, the decreases of body mass relative to the control, group were 2.2 kg for the aerobic programme (3 times per week, 15-20 minute sessions at 60% of maximal heart rate, rising to 45 min at 75% of maximal heart rate), 0.7kg for the resistance programme (7 exercises, rising to 2-3 sets at 7-9 RPM loads), and 2.2 kg for a full combination of aerobic and resistance programmes. Either aerobic or resistance exercise improved glycaemic control, but the best results in this context were obtained with the combined regimen.

We may conclude that if obese individuals do no more than follow the minimum public health physical activity recommendations for weekly physical activity, they are unlikely to realize more than a 2 kg decrease in body mass over a period of 4-6 months. If a greater reduction in body mass and/or body fat content is to be achieved by moderate exercise within this time frame, the physical activity programme must be supplemented by dietary restriction, and even then exercise makes only a modest addition to the weight loss created by dieting. Nevertheless, ancillary health benefits are likely to be realized from quite modest programmes of aerobic activity, including an increase of cardio-respiratory fitness, a reduction of systemic blood pressures, a better control of blood glucose and lipids, an enhanced quality of life, and an increased life expectancy. Even if the obesity remains largely uncorrected, individuals who increase their cardio-respiratory fitness substantially attenuate the adverse impact of fat accumulation upon life expectancy (Katzmarzyk, Church, & Blair, 2004).

However, most of those who are involved in the treatment of obesity are now agreed that programmes should adopt a greater weekly volume of physical activity than the minimal general public health recommendation. A consensus meeting held in Bangkok (Saris, Blair, & Van Baak, 2003) argued that adults needed a volume of at least 45-60 min/d of moderate physical activity in order to avoid obesity, and that maintenance of weight loss by those who were formerly obese required a daily minimum of 60-90 min of physical activity. Likewise, the U.S. Institute of Medicine called for 60 min/d of moderate physical activity to maintain body mass (U.S. Institute of Medicine, 2002). Further to these recommendations, an official "Position Statement" from the American College of Sports Medicine recommended that in order to prevent obesity and/or to maintain current weight, adults should engage in 150-250 min of moderate to vigorous exercise per week, incurring an added a weekly energy expenditure of 4.8- 8.o MJ (Donnelly, Blair, & Jakicic, 2009), and that more than 250 min/wk of moderate physical activity was needed in order to achieve a substantial loss of body weight. Finally, there is evidence that even greater weekly volumes of physical activity are needed to prevent and to treat obesity in children than those that are needed by adults.

Influence of a higher intensity or a larger volume of physical activity upon fat loss

The intensity of physical activity may have a significant influence upon the efficacy of an exercise programme as a means of reducing body fat content (Boutcher, 2011), with high intensity Intermittent exercise causing a greater loss of subcutaneous fat than steady-state aerobic activity of more moderate intensity (Trapp, Chisholm, & Freund, 2008; Tremblay, Simoneau, & Bouchard, 1994). Possible reasons why intensive activity has greater efficacy include a catecholamine-induced mobilization of fat, a continuing post-exercise fat oxidation, and a post-exercise inhibition of appetite (Boutcher, 2011). Catecholamine secretion certainly increases with the intensity of effort that is undertaken. High intensity exercise is also likely to increase the post-exercise stimulation of oxygen consumption, thus prolonging the metabolism of fat (Warren, Howden, Willaims, Fell, & Johnson, 2009). Further, vigorous exercise may have a greater immediate appetite suppressant effect than a more moderate bout of physical activity. Finally, the relative proportions of fat and carbohydrate that are metabolized by the working muscles depend upon the intensity of effort that is undertaken (Gonzalez & Stevenson, 2012), with a maximal utilzation of fat when the intensity of exercise is ~70% of maximal oxygen intake.

De Feo (2013) debated the pros and cons of recommending high intensity effort in weight control, noting that while such programmes increased aerobic fitness and led to a more rapid loss of body fat, they also tended to be plagued by poorer adherence than more moderate exercise interventions, so that in the long term a high intensity regimen might yield a smaller total volume of physical activity than a more modest approach. However, Gillen and Gibala (2014) argued that in addition to saving time, repeated bursts of high intensity interval training were more enjoyable than continuous exercise, at least for young and middle-aged men, and that intense interval work could produce favourable changes in fitness and body composition within a few weeks.

Bryner, Tuffle, Ullrich, and Yeater (1997) compared the impact of high intensity (163 heart beats/min) versus low intensity (132 heart beats/minute) bouts of exercise in a small sample of 14 women aged 18 to 34 yr. Diet was kept unchanged, and both groups exercised for 40-45 min/wk for a total of 11 weeks. The total body mass of the high heart rate group did not change, but they showed a small (3.5%) decrease in their percentage of body fat. In contrast, the low heart rate group (who also performed a smaller total volume of exercise) showed only a statistically insignificant (1.2%) decrease of body fat.

Gutin, Barbeau, Owens, Lemmon, and Baumann (2002) studied obese adolescents aged 13-16 yr for a period of 8 months.. A sample of 80 students was divided between programmes offering lifestyle education alone, lifestyle education plus moderate intensity physical activity (55-60% of maximal oxygen intake), and lifestyle plus high intensity activity (75-80% of maximal oxygen intake). Training took place 5 d/wk, with a matched total energy expenditure of 1.05 MJ/d for both groups of exercisers. In this study, exercise intensity had no clear effect on the metabolism of either visceral or total body fat.

Heydari, Freund, and Boutcher (2012) compared a high-intensity interval training programme (20-minute sessions of intermittent sprinting, performed three times per week) to controls in a group of 46 young overweight men. Over a 12-week intervention, the exercisers showed small favourable changes in body mass (a decrease of 1.5 kg) and body fat (a decrease of 2.0 kg), accompanied by reductions in visceral fat and waist circumference, and increases in lean tissue mass.

Irving, Davis, Brock, Weltman, and Swift (2008) worked with a small sample of middle-aged women (average age ~51 yr) who undertook equal volumes of physical activity of differing intensities for a total of 16 weeks, They found no significant decrease of body fat content if the intensity of effort was less than the lactate threshold (60-70% of maximal heart rate, or 45-55% of maximal oxygen intake). In contrast, in individuals who had been assigned to a programme involving exercise above the lactate threshold 3 d/wk, with light exercise on the other 2 week-days, body mass decreased by 3.5 kg, body fat by 1.7%, and waist circumference by 5.6 cm. The high intensity exercisers also showed significant reductions in sub-cutaneous, visceral and total abdominal fat.

Keating et al. (2014) compared the efficacy of moderate continuous exercise with high intensity interval training in a group of 38 previously inactive overweight adults aged 18-55 yr. Over a 12-week intervention (3 exercise sessions per week), the continuous training (rising progressively to 45 min of exercise at 65% of maximal oxygen intake per session) yielded a 3.1% decrease of trunk fat, as measured by dual energy x-ray absorptiometry, but in contrast the high intensity intermittent exercise group (which apparently performed a smaller total volume of exercise, 6 one-minute periods per session at 120% of maximal oxygen intake) experienced an 0.8% increase of body fat.

Nicklas et al. (2009) compared dieting alone (a 1.6 MJ/d decrease of energy intake) with dieting supplemented by tri-weekly exercise sessions involving equal energy expenditures on either moderate exercise (at 45-50% of heart rate reserve, with session duration progressing to 55 min) or high intensity exercise (at 70-75% of heart rate reserve, with sessions progressing to a duration of 30 min). Over a 20-week intervention, losses of abdominal fat in a sample of 112 overweight and obese women were only marginally greater for those with the high intensity activity (diet alone, -7.4 kg, moderate exercise, 8.2 kg, vigorous exercise 8.5 kg), but both exercise programmes conserved lean tissue relative to those who engaged in dieting alone.

Slentz, Duscha, and Johnson (2004) examined the relative efficacy of volume and intensity of exercise in an 8-month randomized controlled trial on 120 sedentary and overweight men and women aged 40-65 yr. Respective losses of body mass and fat mass were -2.9 and -4.8 kg for the high intensity/high volume group, -0.6 and -2.5 kg for the high intensity/moderate volume group, -0.9, -2.0 kg for the low intensity/moderate volume group, and +1.0, +0.4 kg for the controls. This study underlined that although a substantially larger amount of fat was mobilized if a programme demanded a high total volume of exercise, the weight loss achieved by a walking programme was similar to that seen with vigorous jogging for any given distance of weekly travel.

Tjønna, Stølen, and Bye (2009) compared aerobic interval training (12 months of biweekly 4 x 4 minute sessions of uphill treadmill running at 90% of maximal heart rate) with a standard programme of aerobic exercise (tri-weekly sessions, progressing from 15-20 min at 60% of maximal heart rate to 45 min at 75% of maximal heart rate), combined with bimonthly dietary and psychological advice (21 hours of various forms of treatment over 3 months) in 54 adolescents aged ~14 yr. Over the year of observation, both treatment options decreased body fat content by a similar amount of ~2 kg.

The same group of investigators (Tjønna, Lee, & Rognmo, 2008) examined 32 middle aged patients (aged ~ 52 yr) with the metabolic syndrome, randomizing them to a tri-weekly programme of moderate exercise (47 min of continuous activity at 70% of maximal heart rate), an equal volume of aerobic interval training (4 x 4-minute periods of exercise at 90% of maximal heart rate), and a control group. Over a 16-week study, the two treatment options again led to rather similar decreases in body mass (-2.3 kg, -3.6 kg) and waist circumference (-6.0 cm, -5.0 cm).

Trapp et al. (2008) assigned 45 young non-obese women between a control group, a group undertaking 15 weeks of tri-weekly continuous exercise (progressing to sessions of 40 min at 60% of peak oxygen intake), and a group that engaged in high-intensity interval exercise (60 repeats of 8-second high intensity sprinting per session). Only the high intensity exercise programme yielded a small but statistically significant 2.7 kg decrease of fat mass.

Tremblay et al. (1994) compared a 20-week endurance-training programme (progressing to five 45 minute sessions per week at an intensity demanding 85% of the individual's heart rate reserve) with a 15-week programme where 20-30 min of aerobic exercise was supplemented by short and long bouts of interval training. Neither group showed much change of body mass over the 20 weeks, but the interval training regimen yielded a much larger decrease in the summed thickness of 6 skin-folds than did the aerobic training (13.9 versus 4.5 mm).

Influence of accumulating repeated bouts of exercise upon fat loss

Attention has recently focused on the approach of accumulating repeated relatively brief bouts of exercise in order to attain a sufficient volume of physical activity to induce weight loss. Thus, Schmidt, Biwer, and Kiascheuer (2001) found that over a 20-week trial, the accumulation of short daily bouts of exercise (2 x 15 minute, or 3 x 10 min) had similar effects on weight loss to a continuous daily volume of 30 min of aerobic activity in a group of overweight female university students (Table 3).

Summary

In summary, it is important to underline that many studies purporting to compare the efficacy of exercise relative to dieting as a means of weight loss have fallen far short of the minimum volume and/or intensity of physical activity currently advocated for this purpose. Examples of the response to more intensive programmes of physical activity are summarized in the section below. Some studies have suggested that for any given energy expenditure, high intensity programmes save time and tend to be more effective. However, other investigators have argued that in the longer term programme adherence may be reduced if a high intensity of effort is chosen. For those who are severely obese, it may also be advantageous to split a single 30-min session of aerobic activity into two or three shorter segments.

Decreases of body mass possible with large exercise-induced increases in weekly energy expenditures

The adoption of larger weekly training volumes generally leads to some increase in the loss of body mass and fat mass achieved by exercise alone (Table 4), although this apparently has not always occurred (Irwin, Yasui, Ulrich, Bowen, & Rudolph, 2003; McTiernan, Sorensen, Irwin, Morgan, & Yasui, 2007). Vissers et al. (2013) suggested that this apparent paradox may have arisen because investigators relied on self-reports of adherence to the exercise programme, and that the intended high energy expenditures may not actually have been achieved in all patients.

Table 3: Comparison of the response to continuous aerobic exercise (30 min/day for 12 weeks) with two 15-minute sessions or three 10-minute sessions per day. Based on data of Schmidt et al. (2001).

Measure	30 min continuous/day	Two 15-min sessions/day	Three 10 min sessions/day	Control group
Body mass	-2.7 kg	-3.0 kg	-4.4 kg	0.1 kg
Sum of skin-folds	-3.7 mm	-3.4 mm	-3.9 mm	3.6 mm
Sum of circumferences	-7.2 cm	-8.4 cm	-7.6 cm	2.1 cm

Carels, Darby, and Cacciapaglia (2004) achieved a 6.5% decrease of body mass (7.8 kg) and a 7.4% decrease of fat mass in 44 post-menopausal women aged ~55 yr through a 6-month 24-wession lifestyle intervention that included both provision of dietary information and encouragement of a 40% increase of physical activity (as confirmed by Caltrac accelerometer recordings). Unfortunately, 63% of the weight-loss achieved in this study had already been regained within one year of completing the intervention, although study participants were still maintaining a higher level of daily activity than before the intervention.

In an uncontrolled 12-week experiment, Caudwell, Hopkins, and King (2009) involved 58 overweight or obese men and women aged ~40 yr in a programme that demanded an additional 2.1 MJ of energy expenditure per exercise session, 5 d/wk. The resulting weight loss averaged only 3.2 kg, but the authors noted that individual responses varied widely, from 0 to 15 kg, apparently because some participants elected to increase their food intake substantially when they began the exercise programme. Responders showed a 6 cm decrease in waist circumference over the 12-week trial.

Gutin et al. (2002) used a sample of 80 obese adolescents aged 13-16 yr to compare lifestyle education with education supplemented by moderate (55-60% of maximal oxygen intake) or high intensity (75-80% of maximal oxygen intake) exercise 5 d/wk. Over an 8 month intervention, both of the exercise programmes increased the daily energy expenditure by 1.05 MJ. The exercise decreased fat mass by a limited 0.73 kg, compared with a gain of 1.62 kg with education alone. However, the intensity of exercise had no clear differential effect on total or visceral adiposity.

Jeffery, Wing, Sherwood, and Tate (2003) examined the impact of increasing the daily volume of aerobic exercise from a standard 4 MJ/wk to 10 MJ/wk in a sample of 202 overweight men and women. At 18 months, actual weekly energy expenditures for the two groups were 6.8 and 9.6 MJ. The greater nominal weekly volume of exercise was associated with a greater decrease in body mass (6.7 versus 4.1 kg). However, the high volume group also sustained slightly more injuries and exercise-related illnesses, and both groups had regained a substantial proportion of the weight losses that had been observed at 6 months (9.0 and 8.1 kg).

Irving et al. (2008) compared the effects of exercise sessions below the lactate threshold 5 d/wk with a programme combining such exercise 2 d/wk with 3 d/wk exercising at an intensity above the lactate threshold. The subjects were 27 obese women aged ~51 yr. The high intensity programme reduced total, subcutaneous, abdomianl

Table 4: Decreases of body mass and/or body fat achieved by participation of overweight and obese individuals in high intensity and/or high volume exercise programmes.

Author	Sample	Intervention	Findings	Comment
Carels et al. (2004)	44 post-menopausal women, aged 55 yr	Lifestyle intervention increasing daily physical activity by 40%	Body mass - 6.5% (-7.8 kg). Fat mass -7.4% over 6 months	63% of weight loss regained at 1 yr
Cauldwell et al. (2009)	58 overweight or obese men and women aged ~39.6 yr	Exercise 2.1 MJ/d (70% of max. heart rate) 5 d/wk	Decrease of body mass averaged 3.2 kg over 12 weeks.	Uncontrolled experiment. Weight loss varied 0-15 kg because some individuals increased food intake
Gutin et al. (2002)	80 obese adolescents aged 13-16 yr	Lifestyle ed. vs. lifestyle ed. + mod. exercise vs. lifestyle + high-intensity	No clear effect of ex. intensity on visceral or total adiposity.	Both exercise progs. added 1.05 MJ/d
Irving et al. (2008)	27 obese women aged ~51 yr	Ex > lactate threshold 3/wk + light es 2/wk vs. light ex. 5/wk vs. control	High int. ex. reduced total, subcut. and visc. abdom. fat	No change in controls or light ex.
Jeffery et al. (2003)	202 overweight men and women	10 vs. 4 MJ/wk exercise energy expenditure	At 6, 12 & 18 months, wt loss 9.0, 8.5, 6.7 kg. vs. 8.1, 6.1, 4.1 kg	
Kirby et al. (2011)	104 subjects, aged 46 yr	Moderate exercise, 1 h/d, 6.3 MJ/d (women), 7.5 MJ/d (men)	-2.9 kg body mass, 0.9 kg fat mass over 1 yr	
Niklas et al. (2009)	112 overweight & obese postmenopausal women	1.6 MJ/d diet restriction, vs. diet + 45-50% or 70-75% HRR ex.	wt. loss at 20 wks 7.4 kg. vs. 8.2 kg. vs. 8.5 kg.	Ex. programmes conserved lean tissue
Nindl et al. (2007)	50 M soldiers aged 24.6 yr	US Army Ranger training course, energy deficit 4 MJ/d	13% decrease of body wt, 6% decrease of fat-free mass, 50% decrease of fat mass (8.5 kg) over 8 wks	Programme included 7-10 day periods of underfeeding
O'Donovan et al. (2005)	64 previously sedentary men	Mod. or equi-caloric vig. ex. 3/wk vs. controls	At 24 wk, wt. loss -1.1 kg vs. -0.5 kg	

and visceral fat, but no changes were seen either in the
controls or in thoes undertaking only light exercise.

Kirby et al. (2011) compared the response to an hour of moderate exercise per day (6.3 MJ/d in women, 7.5 MJ/d in men) with controls in a sample of 104 subjcts aged ~ 46 yr. Controls showed no change of body mass at 6 or 12 months, but the intervention group showed a 2.9 kg decrease of body mass and an 0.9 kg loss of fat mass over 1 year.

Niklas et al. (2009) imposed a 1.6 MJ/d dietary resriction on all of 112 overweight and obese postmenopausal women, with two added tri-weekly exercise sessions (55 min at 45-50% or an equi-caloric 55 min at 70-75% of heart rate reserve (total energy cost 2.8 MJ/wk). At 20 weeks, the respective losses of body weight were 7.4 kg, 8.2 kg and 8.5 kg; the main benefit from the exercise programmes was some conservation of lean tissue relative to controls (respective losses 4.1 kg, 3.4 kg and 3.3 kg). O'Donovan, OPwen, and Bird (2005) considered that the key factor in decreasing body fat content was the volume of additional energy expended rather than the intensity of exercise. Thus, the decrease of body mass over 6 months (-0.5 kg vs. -1.1 kg) was similar whether subjects pursued a high-intensity programme (80% of maximal oxygen intake) or a moderate-intensity programme (60% of maximal oxygen intake) that demanded the same total energy expenditure. Nevertheless, the high-intensity programme had the health advantage of yielding larger gains in aerobic fitness than the moderate aerobic regimen.

Ross et al. (2010) assigned 52 obese men aged 42-46 yr between 4 groups. The food intake of one group was reduced by 2.8 MJ/d, a second engaged in an exercise programme demanding an energy expenditure of 2.8 MJ/d without dieting, a third followed free exercise and the fourth served as a control. The first two groups both sustained a 7.5 kg decrease of body mass over 3 months, but the loss of fat mass was 1.3 kg greater with exercise than with dieting. Moreover, the exercise load of 2.8 MJ/d seemed well tolerated by their group of obese middle-aged men, with a programme adherence of 98%. The same group of authors (Ross et al., 2004) carried out an analogous study on 54 premenopausal women aged 41-44 yr. The respective 14-week weight losses for the 2 active interventions were 5.2 and 6.1 kg and the corresponding losses of body fat were 4.1 and 6.7 kg. This exercise programme was again well tolerated by the women, with an average class attendance of 96%.

In an extension of the study of Kraus et al. (2002), Slentz et al. (2004) examined the impact of the volume and intensity of exercise that was performed upon changes in body composition. An 8 month randomized controlled trial was conducted on 120 sedentary and overweight men and women aged 40-65 yr. The effects of 32 km or19 km of vigorous (65-80% maximal aerobic power) jogging per week were compared with19 km of moderately paced walking and with a control group. The respective losses of body mass and fat mass were for the high intensity/high volume group -2.9 and -4.8 kg, for the high intensity/moderate volume group -0.6 and -2.5 kg, for the low intensity/moderate volume group -0.9, -2.0 kg, and for the control group +1.0, +0.4 kg. This study underlined that although a substantially larger amount of fat was mobilized by a high volume exercise programme, the weight loss achieved by a walking programme was similar to that seen with vigorous jogging for any given distance of weekly travel. The minimum effective dose in the study of Slentz et al. (2004) (19 km of walking per week) was less than others had estimated using doubly-labeled water techniques, and was achieved easily by 79% of the subjects that were recruited.

We may note finally the responses seen with two more extreme exercise programmes, although it seems unlikely that the average obese person would tolerate such physically demanding initiatives. Nindl et al. (2007) followed 50 soldiers who were participating in an 8-week US Army Ranger training programme. This course demanded prolonged bouts of heavy exercise and 7-10 day periods of underfeeding with an average energy deficit of 4 MJ/d. The programme led to substantial changes of body composition (a 13% decrease of body mass, a 6% decrease of lean tissue, and a 50% decrease of body fat (8.5 kg).

Pulfrey and Jones (1985) also evaluated a very rigorous regimen in 5 men and 1 woman. Their study involved 7 d of mountain climbing at an altitude of 6000-8000 m. The average energy expenditure was very high (13.8 MJ/d), and substantial losses of both body mass (3.6 kg) and body fat (0.9 kg) were incurred over the week, although (as in the study of Nindl et al. (2007), at the expense of a substantial decrease in fat-free mass.

Reasons for a poor response to weight loss initiatives.

Sometimes the apparent absence of programme response has reflected inappropriate methodology (reliance on body weight measurements rather than determinations of body fat content) or the use of homeopathic doses of exercise. But many observers have also been puzzled why people who are involved in what appears to be a demanding programme of physical activity and/or restricted food intake appear to lose much less body mass than would be anticipated from the nominal weekly energy deficit that has been imposed upon them (Thomas, Bouchard, & Church, 2012). Such individuals have been termed "weight compensators" (Swift, Johannsen, & Lavie, 2014).

In a randomized controlled trial with 464 postmenopausal overweight or obese women, Church et al. (2007) provided what seemed a clear example of this phenomenon. They compared the effectiveness of 3 different volumes of training corresponding to 50%, 100% and 150% of the minimum public health recommendation for aerobic exercise (added energy expenditures of 16, 32 or 48 kJ per kg of body mass per week). Over a 6-month intervention, they saw no inter-group differences in the losses of either body or fat mass. They thus suggested that exercise initiated one or more compensatory mechanisms, and that such effects were most marked in individuals who undertook a major increase in their weekly volume of vigorous exercise. Given the absence of dietary controls in this study, an

Table 5: Possible reasons why body mass decreases less than predicted from the energy cost of prescribed exercise.

- An increased intake of food
- An inadequate exercise prescription
- Poor adherence to the prescribed activity
- Fat loss is masked by an exercise-induced increase of lean tissue mass
- A compensatory reduction of leisure activity during the rest of the day
- A decrease of incidental activity ("NEAT")
- A decrease of resting metabolic rate
- An increase of metabolic efficiency (reduced proton leakage)
- An increase of food consumption in response to the added exercise
- Genetic factors

increased food intake seemed the most likely explanation of failure to decrease body weight.

In a long-term perspective, the increase of food intake or the decrease in daily energy expenditure needed to negate a weight-loss programme is quite small, perhaps as little as 0.4-0.8 MJ/d (Hill, Wyatt, Reed, & Peters, 2003). Among other potential causes (Table 5), we may note a reduction of spontaneous and incidental physical activity, a reduction of metabolic rate, and at the individual level possible genetic factors.

Exercise-induced increase of food intake

It might be thought that vigorous exercise would stimulate appetite, and thus increase the intake of food in an obese person who was poorly disciplined. However, the immediate response usually seems to be just the opposite, with vigorous exercise at least having an appetite suppressant effect.

Many reports have looked at the effects of moderate exercise. Finlayson, Bryant, Blundell, and King (2009) observed a very variable response of healthy young women to 50 min of cycle ergometry at 70% of maximal heart rate. About a half of their subjects their food intake, but the remainder had a greater hedonic desire for food and increased their intake of nutrients following exercise.

Kissileff, Pi Sunyer, Segal, Meltzer, and Foelsch (1990) examined the intake of a liquefied test meal following 40 min of moderate (30 W) or strenuous (90 W) cycle ergometry. in women who were not obese, intake of the test meal was less following the strenuous bout of activity (620 vs. 754 g), but the impact of physical activity did not differ significantly between those who were obese and those who were not (532 vs. 581 g).

Ueda et al. (2009) had 7 obese and 7 non-obese adults undertake 60 min of cycling at 50% of their maximal oxygen intakes. Over the next hour energy intake relative to seated rest was decreased in both groups, by 1.37 and 0.61 MJ respectively.

Unick, Otto, Helsel, and Dutton (2010) found feelings of hunger an *ad libitum* energy intake were unchanged in overweight and obese women following 40 min of moderate walking. Possibly, the outcome depends on whether the intensity of effort is enough to stimulate catecholamine secretion and thus blood glucose levels.

Westerterp-Plantegna, Verwegen, Ijedema, Wijckmans, and Saris (1997) evaluated the impact of cycling for 2 hours at 60% of maximal power output in both obese and non-obese men. The intake of a buffet-style meal 10 min after exercise decreased from the resting value of 3.1 MJ to 2.3 MJ after completion of the exercise bout.

In all, 10 of fourteen reports exploring this question found a decrease of hunger and appetite during and for 2 hours following a bout of exercise (Shephard, 2019a)**.** Nevertheless, there are some empirical data suggesting that *ad libitum* food intake can increase in response to exercise.

Unfortunately, the question of food intake has not been considered very carefully in many of the experiments looking at the effectiveness of exercise in the control of obesity. Dietary studies have generally covered a longer post-exercise period than subjective ratings of appetite, and for this reason they have given a somewhat different impression of human responses to an exercise-induced increase of energy expenditures than the subjective data. In most investigations, exercise has induced little change in the ingestion of food, but in some situations (particularly when lean adults have engaged in bouts of high intensity exercise), increased eating has compensated for as much as 30% of the energy expenditure added by the exercising. In one uncontrolled experiment, Caudwell et al. (2009) enrolled 58 obese men and women in an exercise programme demanding 2 MJ per session, with classes held five times per week for 12 weeks. On average, this produced a 3.2 kg decrease of body mass, but the response varied widely, from -14.7 to + 2.7 kg, and Caudwell et al. (2009) suggested that those with a poor response had increased their food intake to match the added energy cost of the exercise sessions, verifying this assumption by observing the amounts of food that participants took from a table in the metabolic laboratory following their exercise session. The same research group (King, Hopkins, & Caudwell, 2008) studied the response of 35 overweight or obese men to a 12-week exercise initiative, finding an average weight loss of 3.7 kg, but again there was wide inter-individual variation in final body weights, ranging from a loss of 14.7 kg to a gain of 1.7 kg. Some of these inter-individual differences were due to changes in resting metabolic rate (which showed an average decrease of 287 kJ/d in compensators, as compared with a decrease of only 59 kJ/d in non-compensators), but there were also apparently large inter-individual differences in alterations of food intake (ranging from an increase of1.11 MJ/d to a decrease of 0.54 MJ/d).

Estimates of food intake in many studies were based upon diary records, which are notoriously unreliable. More definitive conclusions can be drawn from studies that have used the doubly-labeled water technique (Thomas et al., 2012). Westerterp et al. {1998) suggested that if there was little or no loss of body mass, the likely explanation was an increased food intake, and that women were particularly liable to increase their food intake if they exercised (Westerterp, 1998 ; Westerterp, Meijer, & Janssen, 1992). Thomas et al.(2012) also noted that in 12 of 13 studies with a poor response to exercise there was an increase in food intake as assessed by the metabolism of doubly-labeled water.

Inadequate exercise prescription

The obese individual is self-conscious about exercising, the excess body weight may have predisposed to the development of osteo-arthritis in the knees or hips, heat dissipation is inevitably more difficult than in a slimmer person, and at least initially any type of sustained vigorous physical activity may seem hard. Further, supervisors of exercise classes are often fearful of persuading obese individuals to engage in prolonged sessions of vigorous exercise that could cause heart attacks or injuries to bones and joints. For all of these reasons, the energy expenditures prescribed and achieved in many weight-reduction programmes fall short of the minimum volume where substantial benefit may be anticipated.

Thomas et al. (2012) noted that in 13 of 15 studies of exercise programmes for obese individuals, the energy deficit achieved was much less than the 2 MJ/d typical of dieting programmes, so that inevitably the response to exercise initiatives fell short of what was achieved by dietary programmes, often with reductions in body mass that were so small as to be difficult to demonstrate experimentally.

We have noted above that where investigators have been successful in stimulating substantial energy expenditures, clinically useful decreases in body mass and body fat content have usually been observed.

Poor adherence to weight loss programmes

Poor long-term adherence is a major problem in weight loss programmes, whether exercise or diet-based, in the case of exercise programmes compounding the issue of initially inadequate prescriptions, and often accounting for poor outcomes in terms of fat loss.

In one 16-month intervention with 131 young overweight and obese adults (Donelly et al., 2003), the programme (involving mainly substantial volumes of treadmill walking 5 d/wk, with energy expenditures averaging 2.77 MJ/session in the men and 1.83 MJ/session in the women) was sufficient to induce a fat loss of 4.9 kg in the men, and to prevent further fat accumulation in the women. However, only 41 of 87 subjects completed the exercise arm of the study (where at least 85% attendance was required), despite being compensated financially for the time involved.

Likewise, Ross et al. (2004) reported that only 50% of their sample of post-menopausal women completed a 14-week intervention that involved either a 2 MJ/d energy expenditure (treadmill walking or jogging) or a 2 MJ/d restriction of food intake.

Perri, McAdoo, McAllister, Lauer, and Yancey (1986) reported that 42% of patients assigned to an exercise programme (brisk walking or cycle ergometry) were performing no exercise at 18 months, and the average amount of exercise still being undertaken by the remainder of their sample averaged only 46 of the prescribed 80 min/wk.

Van Dale, Saris, and ten Hoor (1990) had an even poorer adherence experience, with 72% of their exercisers discontinuing physical activity after only 12-14 weeks of treatment. Nevertheless, the adherence to their dietary programme was even poorer. Thus, after 18-42 months of follow-up, the dietary group had regained 90% of their initial weight loss, whereas the weight regain with a combination of dieting plus exercise was only 60% of the initial loss.

Wadden, Vogt, Foster, and Anderson (1998) found that during weeks 25-40 of a long-term study, attendance at exercise (aerobic and/or resistance) sessions had dropped to 57%. In the year following formal sessions, weight regain was however smaller in those who reported that they had continued to undertake some exercise.

Wing et al. (1998) treated 154 diabetic individuals who were initially 30-100% above their ideal weight. A quarter of the group was set the goal of 6 MJ/wk of moderate physical activity. They attended weekly meetings for 6 months, and then biweekly for a further 6 months, with refresher courses during year 2, aiming to achieve their exercise target primarily through brisk walking. A second group attended a similar schedule of regular meetings, and were asked initially to follow a 3.2-4 MJ/d diet, tapering to 4.8-6 MJ/d by week 16. A third group undertook both the exercise and the dietary interventions, and a control group simply received written advice on exercise and dieting. Although generally

Table 6: Data of Wing et al. (1998) illustrating loss of adherence to exercise and/or dietary programming over 2 years of observation.

Programme duration (months)	Exercise alone	Dieting alone	Exercise + diet	Control
Exercise achieved (MJ/wk)				
6	2.73	0.74	4.28	0.37
12	1.61	1.03	2.13	-0.65
24	1.20	1.71	2.39	0.51
Dieting achieved (MJ/d)				
6	0.38	2.88	2.66	1.38
12	0.30	2.60	2.04	0.89
24	0.36	2.55	1.52	0.54

falling short of weight-loss targets, at 6 months all interventions had achieved positive results. However, by 12 months, participants were attending only about 30% of classes, and at 2 yr the increase in physical activity had decreased markedly, and initial weight loss had been largely regained (Table 6).

Observational and cross-sectional data underline the importance of continued exercise to the maintenance of weight loss. Fogelholm and Kukkonen-Harjula (2000) found that in 12 of 13 studies with a follow-up of longer than one year, weight regain was less in individuals who persisted with a substantial level of habitual physical activity. Further, the daily step count was an independent predictor of success in weight maintenance (Fogelholm, Kukkonen-Harjula, Nenonen, & Pasanen, 2000). Wing et al. (1988) classified subjects into 3 exercise categories on the basis of their estimated continuing weekly energy expenditures after 1 year of follow-up, finding respective persistent weight losses of 2.3 kg, 5.9 kg and 9.1 kg for levels of <2.5 MJ/wk, 2.8-5.0 MJ/wk and 5-16.5 MJ/wk, respectively.

The U.S. National Weight Control Registry maintains a roster of over 6000 individuals who have maintained an average weight loss of 30.4 kg for a mean of 5.5 yr; nearly 90% of this group report regular exercise, with an average weekly energy expenditure of 11.8 MJ (Klem, Wing, & McGuire, 1997). Studies using the metabolism of doubly labeled water have estimated that the minimum weekly energy expenditure needed to prevent a recurrence of obesity approaches 80 min/d of moderate intensity exercise (Schoeller, Shay, & Kushner, 1997; Weinsier, 2002).

Techniques of improving adherence require a consideration of motivations and barriers to greater physical activity, including a changing of attitudes and generation of feelings of self-efficacy (Biddle & Fox, 1998). One of the barriers to continued exercise is the opportunity cost involved in driving to and from a relatively distant gymnasium, and adherence may be improved by the provision of home-based exercise prescriptions and even personal exercise equipment such as a moderate-cost treadmill (Jakicic, Winters, Lang, & Wing, 1999). Long-term adherence may also be enhanced if the pattern of exercise is modified. As noted above, some studies have found a better response to accumulating multiple10-minute bursts of exercise than to a prolonged constant effort (Jakicic, Wing, Butler, & Robertson, 1995; Pate, Pratt, & Blair, 1995). Better results may also be achieved by a gradual progression of intensities; attempts to introduce too stringent a regimen too quickly can have a negative impact upon long-term adherence (Fogelholm & Kukkonen-Harjula, 2000).

Masking of fat loss by an increase of lean tissue.

If a fat loss programme is exercise-centred, one obvious explanation for the phenomenon of an apparent weight compensation is that individual's lean tissue mass has increased, thus masking the full extent of weight loss due to the metabolism of body fat (Table 1). Unfortunately, many studies have failed to assess programme-induced changes in fat-free mass.

However, as noted above, a demanding exercise programme can easily increase lean mass by 2 kg, this effect being particularly marked if the required activities include a substantial component of resistance exercise.

Reduction of spontaneous physical activity.

There is at least a theoretical possibility that following recruitment to an exercise programme a client who is feeling fatigued may make a compensatory reduction of leisure activity outside of the prescribed regimen (Epstein & Wing, 1980), although any incidental reduction of normal leisure activity seems eventually to be reversed if the individual persists with the exercise programme (Donnelly & Smith, 2005). But in practice, this may not be a major issue, since many of the obese are initially so sedentary that little metabolic compensation of this type is possible. One review concluded that there was no evidence of a significant decrease in incidental leisure activity when subjects entered an exercise programme, except possibly in the case of the frail elderly (Westerterp, 1998).

Accelerometer data obtained on middle-aged adults generally support the conclusion that spontaneous leisure activity remains unchanged (Church, Martin, & Thompson, 2008; Gipson, 2012 ; Van Dale, Saris, Schoffelen, & ten Hoor, 1987; Van Dale, Schoffelen, ten Hoor, & Saris, 1989), although one study using the doubly-labeled water technique did find some decrease (Kempen, Saris, & Westerterp, 1995).

The situation of compensatory changes in leisure activities is less clear with regard to children. Wilkin (2011) found that when children were required to undertake an additional 64% of physical education at school, accelerometer data indicated a corresponding reduction of voluntary physical activity at home. Ridgers, Timperio, and Cerin (2014) reached similar conclusions in a study of primary school students. On the other hand, diary records from the Trois Rivières regional study provided little evidence that non-obese primary school students made any compensatory decrease in their leisure activity when an hour of specialist-taught physical education per day was added to their daily classroom programme (Shephard & Lavallée, 1993). Likewise, compensatory reductions of leisure activity were not seen in middle school girls in response to spontaneous increases of physical activity at school (Baggett, Stevens, & Catellier, 2010). Blaak, Westerterp, Bar-Or, Wouters, and Saris (1990) applied the doubly-labeled water technique to a small group of obese boys; over a 4-week programme of cycling 5 times per week for 45 min per session at 50-60% of maximal oxygen intake, overall energy expenditure increased by 12%, double the energy demanded by the imposed exercise programme. Paravidino, Mediano, and Hoffman (2016) concluded that although there often seemed to be some compensatory curtailment of active leisure, nevertheless in their experience an exercise programme was effective in increasing the weekly energy expenditure of overweight boys.

Reduction of incidental physical activity ("NEAT").

For most investigators, the concept of non-exercise activity thermogenesis ("NEAT") embraces energy expended on everything other than sleeping, eating or sports-like exercise. It is potentially the most variable component of total daily energy expenditure. In early experiments with a metabolic chamber, Widdowson, Edholm, and Mccance (1954) set the energy cost of NEAT in military cadets at 1.45 MJ/d, but others have suggested it can account for much as 8 MJ/d of the total daily expenditure (Levine & Kotz, 2005).

Some reports have argued that (perhaps through a hypothalamic mechanism), NEAT shows a compensatory increase with over-feeding and a corresponding decrease with under-feeding, thus making it an important factor regulating obesity, especially in sedentary individuals (Kotz & Levine, 2005; Kotz, Perez-Leighton, Teske, & Billingon, 2017; Levine, 2004 ; Villablanca et al., 2015). Frühbeck (2005) argued that it was possible for a person to remain lean without increasing NEAT, but in contrast King et al. (2007) suggested that changes in NEAT could explain much of inter-individual differences in the response to exercise programmes, with mediation occurring through the hypothalamus and changes in secretion of multiple appetite regulating hormones including orexin, neuromedin U, ghrelin, and the agouti-gene related protein (Villablanca et al., 2015).

However, Alahmadi, Hills, King, and Byrne (2011) found no increase of NEAT as assessed by an accelerometer in 16 overweight or obese adults for 3 d following a single 60 minute bout of either moderate or vigorous walking, although there was some increase on the third day. Likewise, a recent meta-analysis of 10 randomized controlled trials (Fedewa, Hathaway, Williams, & Schmidt, 2017) demonstrated that in most studies NEAT did not change significantly in response to exercise training.

Reduction of resting metabolic rate with a negative energy balance.

There may be some reduction in resting metabolic rate (RMR) in response to a negative energy balance, in part due to a decrease of lean tissue mass. Severe dietary restriction can reduce RMR by as much as 20-30%. A reduction of RMR was seen in 13 of 16 dieting trials, with no investigations where the RMR was increased. Typically, the decrease of RMR from dieting was in the range 10-15% (Shephard, 2019a).

There was a partial or a complete reversal of this trend if additional exercise was incorporated into the treatment programme. Exercise alone has also sometimes induced a small (5-10%) decrease of RMR, even after allowing for any reduction of tissue mass (Shephard, 2019a). However, the reduction of RMR is less marked in exercisers than in dieters (Wilmore, 1998), and is less apparent in those who were obese than in those with a normal body mass. In 9 of 30 trials of exercise interventions there was an increase of RMR of up to 10%, in a further 9 studies there was no change of BMR, and RMR was decreased in only 12 of 30 studies where exercise was increased (Shephard, 2019a). Possible mechanisms whereby exercise might help to sustain RMR during a period of negative energy balance are summarized in Table 7.

Table 7: Possible mechanisms whereby regular vigorous exercise might help to sustain metabolism during a period of negative energy balance and fat loss.

- Sustained post-exercise increase of oxygen consumption
- Increase of lean tissue mass
- Increase of fidgeting and incidental movements (NEAT)
- Shortened duration of sleep
- Increased energy expenditures on tissue growth and repair
- Hormonal adaptations
- Thermic effect of foods; change in relative proportions of metabolites
- Alterations in proton leakage have a familial component (Zurlo et al., 1992).

Comparisons of aerobic vs. resistance exercise have found either no difference between the 2 modes of activity in terms of RMR, or a greater conservation of RMR among those adopting a resistance regimen. Moreover, in at least one trial the maintenance of RMR was helped by the administration of a protein supplement. However, in 14 of 15 aerobic interventions, initially obese subjects showed little or no loss of fat-free mass during treatment, probably because the energy demands of their programmes were met from the depletion of body fat stores (Shephard, 2019a).

The difference in RMR response between exercise alone and dieting plus exercise can be quite striking, with the latter type of programme tending to show a much larger decrease of RMR. One may suppose that the combined treatment has created too large a negative energy balance, leading to a substantial breakdown of lean tissue. The extent of such lean tissue loss probably depends on the client's initial reserves of body fat relative to the imposed energy deficit, and the amount and quality of any amino acid supplements that are made available during the period of treatment.

Increase in metabolic efficiency with negative energy balance

When protons are transported across cell membranes in the process of ATP synthesis, a proportion normally leak back across the membrane via uncoupling proteins (Jastroch, Divakaruni, Mookerjee, Treberg, & Brand, 2010). Such leakage can account for as much as 25% of the resting metabolic rate (Rolfe & Brand, 1996). However, if there is a negative energy balance, this leakage is usually reduced (Asami et al., 2008), a change that is possibly mediated by a reduction in levels of circulating thyroid hormone.

Genetic influences upon interest in sport

Genetic factors could influence a person's interest in sport and other forms of leisure activity and thus the accumulation of fat, as well as modifying hormonal mechanisms of adaptation to a negative energy balance such as a depression of resting metabolic rate.

Interest in sport and physical activity

With one exception, several authors have commented on inheritance as influencing a person's willingness to engage in regular physical activity (Bauman et al., 2012; Rankinen, 2010), and indeed Cai, Cole, and Butte (2006) identified a specific genetic location on chromosome 18q regulating this characteristic. Joosen, Gieken, Vlietnick, and Westerterp (2005) conducted a small study on 20 twin-pairs (12 of them monozygotic); using doubly-labeled water to assess active and total energy expenditures. They concluded that genetic characteristics accounted for 72% and 78% of these two variables.

Maia, Thomis, and Beunen (2002) examined sports participation and leisure activity in a larger sample of 411 Portuguese twin-pairs aged 12-25 yr, using the Baecke questionnaire. They estimated that the contribution of genetic to total variance was greater in males than in females (for sports participation, 68% versus 40%, and for leisure activity 63% versus 32%).

Carlsson, Andersson, Lichtenstein, Maichaëlson, and Ahlbom (2006) exploited the Swedish twin registry to identify 5334 monozygotic and 8028 dizygotic twin-pairs. About a third of this group exercised regularly, and a comparison of data for the monozygotes and dizygotes suggested that inherited characteristics accounted for 57% of the observed physical activity in males and 50% in females.

Stubbe, Boomsma, and Vink (2006) estimated the heritability of a self-reported significant interest in habitual physical activity (a commitment to >60 min/wk at an intensity >4 METs) at 62%, on the basis of data for 37051 twin-pairs from 7 countries..

Franks et al. (2005) evaluated 38 dizygotic and 62 monozygotic twin-pairs aged 4-10 yr. Using doubly-labeled water data, they found no significant influence of genetics on active energy expenditure.

Choh et al. (2009) exploited data from the South-west Ohio Family Study; 521 adults were aged 18-86 yr. The Baecke questionnaire provided data on work and leisure activity. Weak genetic effects were found for 26% of involvement in sport and 25% of participation in leisure activity.

Santos, Katzmarzyk, Seabra, and Maia (2012) summarized the various reports through to 2011; almost all were based on twin and family studies, and most found some genetic influences, with suggestive linkages to a number of specific genes. However, the respective estimates of heritability ranged widely from 0 to 84% and 0 to 60%.

Weight compensation

At the individual level, genetic factors may also be involved in weight compensation. Bouchard, Tremblay, and Després (1994) found that the variance in weight change was 6.8 times greater between than within identical twin-pairs over a period of 93 d. In a weight-loss study where they attempted to control both physical activity and food intake very closely, they also found that decreases of weight varied from 5-12% of initial body mass (from 3 kg to 12 kg)(Bouchard, Tremblay, & Nadeau, 1990 ; Rankinen & Bouchard, 2008).

Wood et al. (1988) also underlined that weight loss was more readily achieved in men than in women.

Summary

In summary, the main causes of a limited response to an exercise-based weight loss programme are an insufficient added volume of daily physical activity, poor adherence to the prescribed regimen, and a compensatory increase of food intake. These negative influences are sometimes compounded by reductions in resting metabolic rate, spontaneous leisure activity and NEAT.

Does exercise add to the fat loss achieved by dieting alone?

Many of the studies where a substantial weight loss has been achieved have involved a combination of vigorous exercise and quite stringent dieting. This immediately poses the question, how much has the exercise programme added to the fat loss that could have been achieved simply by dieting? The answer seems to depend on the degree of dietary restriction that is imposed. If food intake is severely limited, then the addition of an exercise programme may do little to augment the individual's total weight loss, although it should help to protect individual against a loss of lean tissue, and it is also likely to confer more general health benefits that are not anticipated with dieting alone, such as increased cardio-respiratory fitness and a decreased risk of overall mortality. On the other hand, if a less severe dietary regimen is imposed, then the addition of regular exercise sessions can contribute significantly to the total weight loss and fat loss.

Several authors have completed systematic reviews and/or meta-analyses of this question, sometimes covering reports from different years, but often using a rather similar database and in general substantiating the conclusions summarized in the previous paragraph (Table 8). Milstein (2014) commented that the response to interventions was sometimes reported as a decrease in body mass or BMI, and sometimes as a decrease in fat mass or percentage of body fat. However, where both weight and fat loss were presented, the 2 data sets often agreed surprisingly well. Ballor and Poehlman (1994) completed a meta-analysis of this issue, finding that the average decrease in body mass (10 kg) and body fat (8 kg) did not differ greatly either from each other or between diet-based programmes and combinations of dieting plus exercise. On the other hand, the average loss of lean tissue was only 50% as great if exercise was included in the programme.

Catenacci and Wyatt (2007) found that smaller weight losses generally resulted from exercise than from dietary programmes, although they commented that the exercise interventions that were evaluated usually induced a much smaller energy deficit than that introduced by dietary restriction. In their view, if an equivalent energy deficit had been induced, then the weight loss would have been comparable with that achieved by dieting. Catenacci and Wyatt (2007) further emphasized the important contribution that a continued interest in exercise made to the process of weight maintenance once the desired amount of body fat had been metabolized. The same report (Catenacci & Wyatt, 2007) described 17 randomized controlled trials where dietary restriction alone had been compared with diet plus exercise; although the addition of exercise tended to increase weight loss by about 1.5 kg, in only 2 of the 17 reports cited was the added weight loss statistically significant.
Curioni and Lourenco (2005) compared 6 randomized trials of 12 to 52 weeks duration in a total of 265 subjects. The average weight loss achieved in the diet plus exercise programmes was 13 kg, compared with a 9.9 kg loss achieved with dieting alone. Not only did the inclusion of exercise sessions enhance the immediate response to dieting, but one year later the sustained weight loss was 20% greater for those who had undertaken a combination of exercise and dieting (6.7

Table 8: Systematic reviews and meta-analyses examining the added contribution of exercise to dietary programmes for the obese.

Author	# of papers included	Period covered	Conclusions
Catenacci and Wyatt (2007)	17	1990-2005	Exercise usually induced less weight loss than dieting, but similar response seen if equal negative energy balance achieved
Curioni and Lourenco (2005)	9	1993-2000	Dieting alone gave weight loss 9.9 kg, combined programme 13 kg loss; also, combined programme gave 20% greater sustained weight loss at 1 yr
Garrow and Summerbell (1995)	28	1968-1993	Exercise alone gave modest weight loss without loss of lean tissue
Ho et al. (2012)	15	1975-2010	In obese children and adolescents, exercise slightly increased weight loss, but also improved HD cholesterol, fasting glucose and insulin levels relative to dieting alone
Johns et al. (2014)	8	2009-2012	In short term, dieting better than exercise alone. In long-term, optimal results from combination of diet + exercise
Miller et al. (1997)	493	1972-1999	Weight loss with dieting 10.7 kg, with exercise 2.9 kg, with combined intervention 11.0 kg
Miller et al. (2013)	15	Studies to May 2013	Diet more effective than exercise, but best response from combined treatment
Schaar et al. (2010)	13	2003-2006	Weight loss greater for diet + exercise than dieting alone; some if the exercise programmes very light (e.g. only 10 min/d)
Schwingshackl et al. (2014)	22	1996-2014	Greater loss of body mass with diet than with exercise, but combination boosted wt loss and fat loss by 1.38 kg and 1.65 kg respectively
Wu et al. (2009)	18	1966-2008	Diet plus exercise better than diet alone, but partial weight regain following both treatments

versus 4.5 kg). Changes in body fat were not assessed, but one may presume such an analysis would have shown an even greater advantage to the exercisers.

Garrow and Summerbell (1995) found 28 articles published during the period 1968-1993 that had compared the weight or fat loss achieved by exercise with and without dieting. Often, only a limited weekly volume of exercise had been prescribed, but nevertheless if an exercise programme had been adopted without deliberate dieting, a modest weight loss was usually achieved, without the undesired effect of metabolizing lean tissue. On average, aerobic exercise without dieting led in men to a weight loss of 3.0 kg over 30 weeks, and in women to a loss of 1.4 kg over 12 weeks. In both sexes, the exercisers showed little loss of fat-free mass, and indeed when aerobic activity had been supplemented by resistance exercise, the fat-free mass had actually increased, by 2 kg in men and by 1 kg in women. In contrast, if 10 kg of weight loss had ben achieved by dieting alone, the loss of fat-free mass amounted to 2.9 kg in the men and 2.2 kg in the women.

Ho et al. {2012} focused on 15 randomized controlled trials in obese children and adolescents. Both diet alone and diet plus exercise resulted in a significant weight loss. However, the addition of exercise to the treatment greatly improved metabolic benefits, including increases in HDL cholesterol, and decreases in fasting blood glucose and insulin levels. Resistance exercise also led to greater reductions in body fat content, but surprisingly (at least in the short-term) this benefit was not seen when aerobic exercise was added to dieting.

Johns et al. (2014) conducted a review of 8 long-term (>12 month) programmes involving 1022 overweight or obese participants, mainly women. They found that in the short term (3-6 months), dieting gave a greater weight loss than exercise alone (a 6.7 kg advantage). However, in the longer-term (12 months) behavioural management programmes that combined exercise and dieting were more effective than dieting alone, with an optimal weight loss being achieved by a combination of the two approaches to therapy.

Based on an extensive meta-analysis of 493 studies that had been conducted over a period of 25 yr, Miller et al. (1997) concluded that most trials to that point had focused rather narrowly on a middle-aged population who were only moderately obese. At 15 weeks, the decrease of body mass with dietary restriction averaged 10.7 kg, and a 6.6 kg loss was maintained at 1 year, with exercise giving a somewhat superior response to dieting at this stage. Moreover, an evaluation that focused simply on body mass ignored the conservation of lean tissue and the enhancement of cardio-respiratory fitness seen in the exercisers, as well as the important contribution of continuing exercise to weight maintenance after the formal intervention had been completed. Even at 15 weeks, the fat loss with dieting plus exercise was 9.0 kg, as compared to 7.8 kg with dieting alone.

In a more recent report, Miller et al. (2013) summarized the findings from 14 randomized controlled studies. These articles again showed that dieting alone was generally more effective than exercise alone if considered simply in terms of immediate, short-term weight loss, but that exercise generally augmented the response found with dieting alone, and in terms of the decrease in total body mass the response was almost invariably greatest for a combination of the two treatments.

Schaar et al. (2010) completed a meta-analysis of 13 randomized trials conducted between 1993 and 2006. As in other analyses, dieting alone was found to have produced a significantly greater weight loss than exercise alone, although some of the exercise interventions on which this conclusion was based had required as little as 10 min of physical activity per day from their subjects. The end-result of these various trials, in terms of a decrease in total body mass, was almost invariably greatest for a combination of exercise plus dieting.

Schwingshackl et al. (2014) analyzed the results from 22 trials. They observed a significant advantage of dieting alone relative to exercise alone in terms of reductions in both body mass (2.93 kg) and fat mass (2.20 kg) as well as in other anthropometric outcomes. Nevertheless, exercise boosted the effects of dieting alone by 1.38 and 1.65 kg in terms of decreases in total body mass and fat mass respectively.

Wu et al. (2009) summarized 18 randomized controlled trials. In their analysis, exercise plus dieting gave marginally better results than dieting alone (an advantage of 1.1 kg), but there was a partial weight regain following both treatments. Seven trials with a duration of more than 2 yr all showed a final weight loss of only 1.6 kg even with the combined treatment. This reversal of benefits underlined the need for further study of techniques of weight maintenance. One factor in effective weight maintenance seemed a prolongation of the active intervention, with one study showing a persistent 5.6% (3.3 kg) decrease in weight loss of diabetic individuals after 6 yr of treatment (Pan et al., 1977).

In summary, almost all meta-analyses to date have shown only a small additional decrease of body mass when dietary programmes have been supplemented by regular exercise sessions, but in general rather modest exercise prescriptions have been used, and it remains unclear whether more stringent exercise programmes might have increased fat metabolism. Most studies have also found exercise helpful in conserving lean tissue, and where evaluated exercise programmes have conferred other health benefits. Some investigators have also found continuing exercise to be useful in reducing the extent of weight regain after the completion of formal treatment.

Individual studies where a substantial weight loss was developed

Individual studies where substantial weight loss was achieved are summarized in Table 9**.** The largest responses were seen by Goodpaster, Delaney, and Otto (2010) and by Hall (2013). Goodpaster and associates studied 191 adults with Class II or Class III obesity. Participants were randomized to either a group following a 5.0-8.7 MJ/d diet for 6 months, followed by a combined diet plus exercise programme for a further 6 months, or to a group that combined dieting with exercise (60 min of brisk walking 5 d/wk) for the entire 12 months. At 6 months, the respective average weight losses for the two groups were 8.2 kg and 10.9 kg, with fat losses of 5.9 kg and 8.7 kg, and at 12 months, the respective weight losses were 9.9 and 12.1 kg.

Hall (2013) had grossly obese subjects attend a fat-treatment ranch for up to 13 weeks. Their dietary intake was decreased to 5.2 MJ/d, and an average of 3.1 hours/day was spent in various forms of vigorous exercise demanding an average energy expenditure of 11.8 MJ/wk. On returning home, subjects followed a less closely supervised 17-week programme, with food intake increased to an average of 7.8 MJ/d, and vigorous physical activity decreased to 1.1 h/day. At the end of this time, the average weight loss was estimated at 34 kg for dieting alone, 27 kg for exercise alone, and 58 kg for a combination of the two interventions. There was still a sustained loss of 13.6 kg at 5 yr. Thirty min of moderate exercise 5 d/week or 20 min of vigorous exercise 3 d/wk for 36 weeks was enough to add substantially to the weight and fat loss achieved by simply adhering to a 6 MJ/d diet in a sample of 206 overweight and obese women (Andreou, Philippou, & Papandreou, 2011). Respective losses of 15.5 and 6.1 kg in body mass, 8.2% and 0.5% in body fat and 11.2 versus 5.5 cm in waist circumference at 18 weeks, and of 17.3 and 8.4 kg, 10.0% and 1.2%, and 14.2 and 8.0 cm at 36 weeks.

Table 9: Responses of obese subjects to dieting alone versus dieting plus exercise, as seen in individual trials where substantial weight losses were observed.

Author	Sample	Intervention	Response	Study duration	Comments
Andersen et al. (1999)	40 obese women, mean age 42.9 yr	Aerobic programme building to 45 min stepping 3/week or 30 min lifestyle exercise most days, Diet 4.8 MJ/d	Aerobic 8.3 kg Lifestyle 7.9 kg weight loss at 16 wk	16 wk programme, 1yr follow-up	Loss of lean tissue for aerobic exercise (0.5 kg) less than for lifestyle activity (1.4 kg)
Andreou et al. (2011)	206 overweight & obese women	Diet 6 MJ/d, plus exercise (3 d/wk vigorous 20 min/d or 5 d/wk moderate 30 min/d)	Diet + exercise -17.3 kg vs. diet alone -8.4 kg; at 36 wk BMI -5.1 (diet + exercise) vs. -3.2 kg/m² (diet); waist circumference -14.2 vs. -8 cm	18 wk intervention + 18 wk maintenance	
del Corral et al. (2009)	141 healthy overweight premenopausal women	3.2 MJ/d diet, aerobic or resistance exercise 3 d/wk	weight loss ~12.5 kg for all 3 groups; fat loss aerobic 91 g/d, resistance 89 g/d, diet alone 85 g/d	Target BMI reached in 151 d	Adherence to diet 73%, aerobic ex 81%, resistance ex 79%
Foster-Schubert et al. (2012)	399 overweight or obese postmenopausal women aged 58 yr	Diet (4.8-8 MJ/d), exercise progressing to 45 min at 60-70% max heart rate 5 d/wk), diet + exercise vs. control	Weight loss relative to control diet 8.5%, exercise 2.4%, diet + exercise 10.8%	12 months	Low fat diet
Geliebter et al. (1997)	65 moderately obese adults aged 19-48 yr	5.2 MJ/d diet, or diet + aerobic or diet + strength exercises 3/wk	-9.0 kg (no difference between 3 groups)	8 weeks	Strength training lost less fat-free mass
Goodpaster et al. (2010)	101 adults class II or III obesity	5.0-8.7 MJ/d diet vs. diet + brisk walking 60 min 5d/wk	Diet- 8.2kg Diet + ex.-10.9 kg	6 months	body fat loss 5.9 kg, 8.7 kg
Hall (2013)	16 obese adults	5.2 MJ/d diet, 3.1 h/d vigorous exercise, or combination	Diet -34 kg exercise -27kg diet + exercise -58.2 kg	Up to 30 wks	On returning home, diet increased to 7.9 MJ/d, exercise dropped to 1.1 h/d
Hammer et al. (1989)	26 premenopausal obese women	3.2 kJ/d diet vs. exercise sufficient to increase maximal oxygen intake	Body mass significantly reduced by 9.5 kg (diet), 6.7 kg (exercise), 12.9 kg (combined) Fat loss 5.0, 5.0, 7.1, 3.7%	16 wk	Neither intervention altered fat-free mass
Hill et al. (1989)	32 moderately obese women (130-160% of ideal weight)	4.8 MJ/d or 2.4-7.2 MJ/d diet, with or without walking 6.5 km 5 d/wk	-8.6 kg vs. -6.5 kg, 7.0 vs. 4.7 kg reduction in body weight & body fat if exercise added to dieting	12 wk	No advantage in diet alternating 2.4-7.2 MJ/d; 86% loss is fat with exercise, 73% is fat with diet alone

Table 9 Continued

Author	Sample	Intervention	Response	Study duration	Comments
Kempen et al. (1995)	20 obese women aged 25-50 yr	Diet 2.0 MJ/d for 4 wks, 3.6 MJ/d for 4wks with or without ex. 3 d/wk	Fat mass -7.8 kg (exercise + diet) vs. -5.5 kg (diet)	8 wk	No increase of total energy expenditure with exercise- ? decrease of leisure activity
Klem et al. (1997)	155 M, 629 F overweight	Diet 5.8 MJ/d physical activity 11.8 MJ/wk	Body weight - initial -30 kg, maintained -15.6 kg	5 yr	
Layman et al. (2005)	48 women aged ~46 yr	Diet 7.1 MJ/d with differing protein content, 5d/wk walking, 2 day/wk resistance exercise	-9.8 kg (protein diet + exercise), -6.7 kg (CHO diet + exercise) -8.7 kg (protein alone) -7.8 kg (CHO alone)	4 months	Controls undertook public health recommended weekly ex. Parallel improvements in fat mass.
Leutholtz et al. (1995)	40 obese adults, age 41 yr	Diet 1.7 MJ/d, training volume 1.2 MJ/session, 3/wk	-14.9 kg (0.3 kg loss of lean mass)	12 weeks	Response similar if exercise at 40% or 60% of heart rate reserve
Racette et al. (1995)	23 obese women	Aerobic exercise 0.8 MJ/d, 5 MJ/d low fat or low CHO diet	Fat loss 8.8 kg with added exercise, 6.1 kg with diet alone	12 weeks	Greater loss on low CHO (-10.6 kg) than low fat diet (-8.1 kg)
Ross et al. (2010)	52 obese men	Aerobic exercise vs. diet vs. exercise without weight loss vs. control	7 kg weight loss with either diet or exercise	3 months	Exercised group had bonus of increased cardio-respiratory fitness
Strasser et al. (2007)	20 women	Reduction of diet by 2.1 MJ/d or dietary restriction -1.4 MJ/d + aerobic exercise 5.9 MJ/wk (3 times/wk)	Weight -2.0 kg diet, -2.2 kg diet + exercise	8 weeks	Weight loss depends simply on negative energy balance
Van Aggel-Leijssen et al. (2001)	40 obese men aged 39 yr	Diet vs. diet + light exercise (40% max. ox, intake)	-14.7 kg diet, -15.2 kg diet + exercise	12 weeks (10 weeks diet)	Exercise counters decline in fat oxidation post-dieting
Van Dale et al. (1989)	12 obese women	Diet (2.9-3.5 MJ/d) or diet +exercise 4 h/wk at 55% max. ox. intake	-12.2 kg diet, -13.4 kg diet + ex.	12 weeks	Fat loss 9.4, 10.9 kg
Wood et al. (1998)	131 overweight and sedentary men	Running vs. dieting vs. controls	Total, fat and fat-free weight exercise -4.6, -3.8, -0.7 kg, diet -7.8 , -5.6, -2.1 kg	1 yr	Exercise avoids loss of fat-free mass; equal impact on blood lipids

del Corral et al. (2009) compared dieting (a restriction of food intake to 3.2 MJ/d) with both aerobic and resistance exercise in the treatment of 141 healthy but overweight premenopausal women. The weight loss was ~12.5 kg for all 3 groups, and the target BMI of 25 kg/m^2 was met in a similar time of ~151 d for all 3 options. Programme adherence was a little better for aerobic exercise (81%) and for resistance training (79%) than for the dietary programme (73%).

Foster-Schubert et al. (2012) compared dieting (a food intake of 4.8-8.0 MJ/d, aiming at a 10% weight reduction), aerobic exercise (progressing to 45 min, 5 d/wk at 70-85% of maximal heart rate)) or a combination of the two treatments versus controls. Their sample consisted of 399 post-menopausal overweight-to-obese women who completed a 12-month trial. Respective changes in body mass were -8.5%, -2.4%, - 10.8% and -0.8%, and losses of body fat were 4.8%, 1.8%, 6.3% and 0.1%, with a somewhat greater programme response in those with an initial BMI <30 kg/m^2.

Geliebter et al. (1997) studied 65 moderately obese adults, aged 19-48 yr, assigning their sample between a 5.2 MJ/d diet, the same diet plus aerobic exercise (upper and lower body cycle ergometry at 55% of the subject's initial peak oxygen intake), or the same diet plus an isoenergetic strength training programme 3 d/wk. All three groups showed a rather similar weight loss of ~9 kg and a similar fat loss of ~7 kg over an 8-week trial, although the group receiving the strength training had a smaller loss of fat-free mass than the other 2 groups (1.1 kg versus 2.3 kg for aerobic exercisers and 2.7 kg for those dieting alone).

Goodpaster et al. (2010) recruited 101 adults with class II or class III obesity, allocating these individuals between a dietary programme (food intake limited to 5.0-8.7 MJ/d) and the same diet supplemented by the equivalent of 60 min of brisk walking 5 d/wk, with a pedometer goal of 10,000 steps/day. Over 5 months of treatment, the dieting produced a weight loss of 8.2 kg, and this increased to 10.9 kg with the combined programme; respective decreases in body fat content were 5.9 and 8.7 kg.

Hammer et al. (1989) recruited a small group of 26 premenopausal women, comparing the responses to a 3.2 MJ/d diet. an aerobic exercise programme sufficient to increase the individual's maximal oxygen intake (progressing to 4.8 km of walking/jogging at 70-85% maximal heart rate 5 d/wk) or a combined programme. Over 16 weeks, respective weight losses were 9.5 kg (dieting), 6.7 kg (exercise), 12.9 kg (combined treatment), and 5.8 kg (controls), and the corresponding changes in body fat were 5.0%, 5.0%, 7.1% and 3.7%.

In the study of Hill et al. (1989), the effects of exercise on 32 moderately obese women was compared between the options of a constant 4.8 MJ/d diet, or a diet that alternated between an energy intake of 2.4 and 7.2 MJ/d. The pattern of dieting did not change the response, but losses of body mass and body fat were greater if either regimen was supplemented by walking 5 d/wk (20 increasing to 50 min per session at 60-70% of maximal oxygen intake). Over 12 weeks, the addition of walking increased weight loss (8.6 kg versus 6.5 kg) and fat loss (7.0 kg versus 4.7 kg).

Kempen et al. (1995) imposed severe dietary restrictions (a food intake of 2.0 MJ/d for 4 weeks, then 3.5 MJ/d for a further 4 weeks) on 20 obese women aged 25-50 yr. A half of the group also undertook programmed physical activity (90 min of aerobic exercise at 50-60% or maximal oxygen intake 3 times per week). The combined treatment yielded a larger fat loss than dieting alone (7.8 kg. versus 5.5 kg over a 4-week programme), although there was apparently some compensation for the added exercise by a reduction of leisure activity.

Klem et al. (1997) described findings on 629 women and 155 men in a U.S. registry who had initially reduced their body mass by an average of 30 kg, and had maintained a weight loss of 13.6 kg for at least 5 yr. Only about a half of this group had entered formal weight-loss programmes. Most of those concerned had used a combination of diet and exercise to achieve their weight loss, and they currently reported an exercise energy expenditure averaging a surprisingly large and possibly over-reported 11.8 MJ/wk.

Layman et al. (2005) compared the response to various diets providing a food intake of 7.1 MJ/d in 48 women aged ~46 yr, both when they adopted the normal public health exercise recommendation (probably leading to about 100 min/wk of aerobic exercise) and when combined with a more demanding routine requiring at least 30 min of aerobic activity 5 d/wk plus 2 d/wk of resistance exercise. Over a period of 4 months, weight losses were 8.7 kg with a protein diet, 7.8 kg with a carbohydrate diet, 9.8 kg with the protein diet plus the demanding exercise routine, and 6.7 kg with the carbohydrate diet plus the demanding exercise, with fat mass showing parallel changes.

Leutholtz et al. (1995) combined a severely restricted diet of 1.7 MJ/d with a tri-weekly training volume demanding 1.2 MJ/session. Over a 12-week trial, this regimen induced a 14.8 kg weight loss, with a lean tissue loss of only 0.3 kg.; the response was similar whether a given volume of exercise was performed at 40% or 60% of the heart rate reserve.

Racette et al. (1995) provided 26 women with a low fat or a low carbohydrate diet (5 MJ/d, corresponding to about 75% of their basal metabolic rate). The addition of tri-weekly 45 min sessions of aerobic exercise demanding an energy expenditure of 0.8 MJ/d improved compliance with the dietary regimen. Over a 12-week trial, the fat loss was 6.1 kg with dieting alone, and 8.8 kg with the added exercise. The response was also better with a low carbohydrate than with a low fat diet (respective losses of 10.6 and 8.1 kg).

Ross et al. (2010) enrolled 52 obese men in a trial comparing aerobic exercise (energy cost 2.8 MJ/d) with dieting (a 2.8 MJ/d decrease of food intake), exercise with sufficient food to prevent weight loss and controls. Both the dieting and the exercise programmes yielded a weight loss of about 7 kg over a 3-month programme, but the exercisers enjoyed the bonuses of a slightly greater fat loss (6.1 versus 4.8 kg) and an increased cardio-respiratory fitness.

Strasser et al. (2007) compared the impact of a reduction in food intake of 2.1 MJ/d with a dietary restriction of 1.4 MJ/d, supplemented by tri-weekly exercise sessions generating a weekly energy expenditure of 5.9 MJ. Dieting produced a 2 kg weight loss over 8 weeks, and the combined dieting plus exercise caused only a slightly larger loss of 2.2 kg, with corresponding fat losses of 1.5% and 1.6%.

Van Aggel-Leijssen et al. (2001) compared the impact of severe dieting (a food allowance of 2.1 MJ/d, rising to 3.5

MJ/d) versus dieting supplemented by light exercise (40% of maximal oxygen intake) in 40 obese men aged ~39 yr. Over a 12-week trial, dieting induced a 14.7 kg wright loss, and the addition of exercise (cycle ergometry, 60 min/d, 4 d/wk at 40% of maximal oxygen intake) increased the loss marginally, to 15.3 kg. The addition of exercise nevertheless had the advantage of increasing post-exercise fat oxidation.

Van Dale et al. (1989) compared stringent dieting (2.9-3.5 MJ/d) with a similar programme supplemented by exercise (4 one-hour sessions at 55% of maximal oxygen intake per week). Over a 12-week period, responses were relatively similar for the two groups (weight losses of 12.2 and 13.4 kg, fat losses of 9.4 and 10.9 kg).

Wood et al. (1988) compared the impact of a running-based exercise programme versus a dietary programme designed to reduce body fat by one third over 9 months. The sample comprised 131 sedentary and overweight men, who were followed over a one-year period. Respective losses were for total weight 4.6 kg versus 7.8 kg, for fat loss 3.8 kg versus 5.6 kg, and for lean tissue 0.7 kg versus 2.1 kg. They concluded that running (an average of 19 km/week) achieved a slightly smaller fat loss and had an equal impact upon blood lipids, but led to a much smaller loss of lean tissue than dieting.

The food intake allowed in the various trials ranged from a modest restriction (to 7.1 MJ/d) to a drastic limitation (1.7 MJ/d). Most of the studies were of rather short duration (8-18 weeks), although the study of Wood et al. (1988) continued for a full year. In many instances, the level of exercise undertaken was also quite modest, and less than recent recommendations for the treatment of obesity. However, exercise was also seen as increasing the proportion of fat consumed in metabolism (Kempen et al., 1995), and in countering the decline of fat oxidation post-dieting (Van Aggel-Leijssen et al., 2001). On the other hand, performing 30 min of exercise 3 times per week did not add substantially to the weight loss realized by a drastic 3.2 MJ/d diet (del Corral et al., 2009).

Abbenhart et al. (2013) compared the effects of various combinations of dieting (4.8-8.0 MJ/d, <30% fat) and moderate to vigorous exercise (45 min, 5 d/wk) on adiponectin and leptin levels in 439 initially obese post-menopausal women. Adiponectin was increased by dieting (+9.5%) and diet + exercise (+6.6%0), and leptin was decreased by dieting + exercise (-40.1%), dieting (-27.1%) and exercise (-12.7%). Changes in the levels of these hormones are important not only because of their implications for appetite, but also because they may mediate the adverse effect of obesity upon the risk of certain forms of cancer.

In summary, weight and fat losses of around 10 kg have commonly been reported with dieting or exercise treatment periods of around 3 months., and in a few instances much greater fat losses have been realized (Klem et al., 1997). Most studies have shown a larger response to dieting alone than to exercise alone, but the weight loss achieved by a dietary regimen alone has generally been augmented 1-2 kg by the inclusion of regular sessions of vigorous exercise, and sometimes this has also boosted fat loss. Moreover, the combined regimen has carried the added benefits of conservation of lean tissue, improved eating behaviour (Jakicic, 2002), enhanced cardio-respiratory fitness and improvements in lipid profile, sometimes with a lesser regain of weight following the intervention (Jakicic, 2012).

Aerobic or resistance exercise in the treatment of obesity?

Most studies on the value of exercise in the treatment of obesity have focused upon moderate aerobic activity, but public health recommendations for healthy but sedentary individuals have stressed the need to include also resistance exercises in order to maintain and develop the main muscle groups of the body; according to these recommendations, systematic training of the main muscle groups should be practiced at least twice per week. The energy expenditure developed by such exercise (perhaps 0.5 MJ/d), is relatively low compared with dieting (where there is commonly a 2-3 MJ/d reduction of food intake), so that the inclusion of resistance activity would not be expected to contribute much to the reduction in total body mass or the metabolism of excess body fat. On the other hand it seems logical that resistance training would be more effective than aerobic activity as a means of maintaining lean tissue mass during a period of negative energy balance, and it could in this way counter the reduction of resting metabolic rate that is associated with severe dieting and to a lesser extent with vigorous aerobic activity. A resistance training programme may have the further advantage of increasing fat oxidation in the period following a bout of exercise. As in the exercise recommendations that have been developed for the healthy individual, resistance activities should thus be a regular component of an exercise regimen for those who are obese.

Several authors have commented specifically on the value of a resistance programme as a means of conserving lean tissue during weight-reduction programmes (Geliebter et al., 1997; Wood et al., 1988). A review by Garrow and Summerbell (1995) concluded that aerobic exercise without dietary restriction caused a weight loss relative to sedentary controls of 3 kg over 30 weeks in men, and of 1.4 kg over 12 weeks among women. However, such exercise apparently caused little decrement of fat-free mass. Resistance exercise contributed little to the decrease in total body mass, but it actually increased lean tissue mass, by about 2 kg in men and 1 kg in women.

Resistance exercise

A number of authors have focused specifically upon the benefits of a resistance exercise programme, practiced alone or in combination with dieting (Table 10). Such investigations have confirmed that resistance exercise adds little to the weight loss achieved by dieting alone. There remains some disagreement as to how far a resistance exercise programme reduces body fat content, but often there seems to be a small loss of body fat, with a matching increase of lean body mass.

In a study of 40 obese women, Ballor, Katch, and Becque (1988) found similar decreases of body mass over 8 weeks, whether study participants were treated by dieting alone (4.5 kg) or by dieting plus resistance exercise (3.9 kg), whereas the body weight of those practicing resistance exercise without dieting actually increased by 0.5 kg over the 8-week study. On the other hand, the 2 groups who performed resistance exercise showed substantial gains of lean

Table 10: Effects of resistance exercise, practiced either alone or in combination with dieting.

Author	Sample	Intervention	Findings	Comments
Ballor et al. (1988)	40 obese women	Resistance vs. dieting vs. resistance exercise + dieting	Resistance alone, wt. gain of 0.5 kg; loss of wt 4.0 kg, 3.9 kg in other 2 groups.	Groups performing resistance exercise increased muscle cross-section 10-11 cm^2
Bryner et al. (1999)	20 middle-aged adults aged ~37 yr	3.2 MJ/d liquid diet vs. diet + resistance ex.	Both groups lost fat. 4 kg loss of lean mass with diet, not seen if resistance ex. Added	Resistance ex. also increased resting met. rate, whereas controls showed decrease of resting metabolism
Hunter et al. (2000)	Elderly, 8 M, 7 F aged 61-77 yr	26 weeks of resistance training	Body mass unchanged, lean mass +2kg, fat mass - 2 kg.	12% increase in total energy expenditure
Ibanez et al. (2005)	9 older men with type 2 diabetes	16 wks resistance training	No change of body mass, but 10% decrease of abdominal and sub-cutaneous fat	
Lemmer et al. (2001)	19 young, 22 older adults	24 wks strength training	No change of body wt. in men, women 1.9 kg wt. gain; also 1.5 kg fat loss, 1.5 kg increase of lean mass in men only	Men increased resting metabolism, women did not
Olsen et al. (2007)	28 overweight women, aged 28-44 yr	1 yr moderate resistance training	2.2 kg gain of lean mass in experimental group	
Polak et al. (2005)	12 obese men, average aged ~ 47 yr	6 months dynamic strength training	No change of body mass, trends to 0.9% decrease of fat, 1.9 kg increase of fat-free mass	
Schmitz et al. (2003)	68 middle-aged women	38 weeks of strength training	Experimental group lost 0.98 g fat, gained 0.89 kg lean tissue relative to controls	

tissue, as shown by large increases of muscle cross-sectional area in the upper arms (11.2 and 10. 4 cm^2), when compared with the increases of 2.7 and

2.0 cm^2 seen in the controls and those who dieted without exercise respectively.

Bryner et al. (1999) imposed severe dietary restriction (a 3.2 MJ/d liquid diet) on middle-aged adults. Over 12 weeks, this intervention led to a 4 kg decrease in lean tissue mass. However, the decrease was not seen if the dieting was supplemented by resistance training (exercises at 10 stations, 3 d/wk). Both subject groups lost body fat over the 12-week trial (7.4% versus 8.6%). Those performing resistance exercise showed an increase in their resting metabolic rate, in contrast with those who only dieted (where resting metabolism showed a substantial decrease).

Hunter, Wetzstein, and Fields (2000) had 8 men and 7 women aged 61 to 77 yr engage in 26 weeks of resistance training. Doubly-labeled water was used to estimate energy expenditures. The response to the resistance exercise was a 12% increase of total daily energy expenditure, with a 6.8% increase of resting expenditures supplementing a 38% increase of active energy expenditures. Body mass remained unchanged throughout the trial, but fat-free mass increased by 2 kg, implying that the resistance programme had induced a 2 kg loss of fat.

Ibanez, Izquierdo, and Arguelles (2005) had 9 older men with type 2 diabetes mellitus participate in a twice-weekly programme of progressive resistance exercise for 16 weeks. There was no change of body mass over this time, but abdominal and subcutaneous fat stores decreased by some 10%.

Lemmer, Ivey, and Ryan (2001) reported the response of 10 young men and 9 young women, 11 older men and 11 older women to a strength-training programme. There was a sex difference in response to this intervention, in that the men increased their resting metabolic rate, whereas the women did not. This was reflected in the impact upon body composition; the men showed no change of body mass, whereas the women gained an average of 1.9 kg over the study. Moreover, the men lost 1.5 kg of body fat but gained 1.5 kg in lean tissue mass.

Olsen et al. (2007) studied 28 overweight women aged 28-44 yr; 12 served as controls, and 16 as an intervention group, who undertook 1 year of moderate resistance training. With the exception of a 2.2 kg increase of lean tissue mass, the body composition of the intervention group did not differ significantly from that of the controls.

Polak et al. (2005) applied 6 months of dynamic strength training to a group of 12 obese men of average age 47 yr. There was no change of body mass over the course of the study, but there were trends to a 0.9% decrease of fat mass and a 1.9 kg increase of fat-free mass.

Schmitz et al. (2003) evaluated 39 weeks of strength training in 60 middle-aged women. They noted that the experimental group lost 0.98 kg more fat and gained 0.89 kg more fat-free mass than the control group.

In summary, the findings that are cited conform with our predictions. Resistance exercise did little to reduce body mass, but in most studies it increased lean tissue mass, commonly with an associated increase of resting metabolism, and several studies also showed a significant loss of excess body fat.

Comparisons of response to aerobic and resistance exercise.

Ismail, Keating, Baker, and Johnson (2011) undertook a systematic review and meta-analysis of randomized controlled studies through 2010, comparing the effectiveness of aerobic and resistance exercise programmes in terms of their effectiveness in reducing visceral fat stores. Nine studies had compared the two approaches, with a non-significant trend to aerobic programmes being more effective than resistance training in this regard. Interestingly, even doses of aerobic exercise below current recommendations had some beneficial effect on levels of visceral fat.

Marzolini , Oh and Brooks (2012) analyzed 12 randomized controlled trials involving 504 participants, all comparing aerobic exercise with a combination of aerobic and resistance exercise. They concluded that the combined treatment was more effective as a means of improving body composition, muscle strength, and some measures of cardiovascular fitness, without compromising trial safety or trial completion.

A review by Thomas et al. (2012) focused on the issue of lean tissue loss, noting that in 14 of 15 studies of aerobic exercise programmes there was little evidence that a decrease in total body weight had been accompanied by a decrease in lean tissue mass. However, they were cautious about attributing the conservation of lean tissue to the exercise regimen. In most reports, food intake had been determined only by dietary records, and an undetected increase in the intake of protein and other key nutrients could have contributed at least in part to the preservation of lean tissue. Forbes (2000) supported this hypothesis, arguing that if dietary intake was held constant, the losses of lean tissue in an aerobic exercise programme were often as large as those seen when a corresponding negative energy balance was created by dieting. Church et al. (2010) also saw a loss of lean tissue in 51% of subjects who were following an aerobic regimen. In contrast, Bouchard et al. (1994) were able to achieve a substantial 5 kg weight loss without a significant reduction of lean tissue mass in response to a negative energy balance that totaled 244 MJ over 93 d. Individual studies of aerobic and resistance exercise are summarized in Table 11.

Aminilari et al. (2017) divided 60 middle-aged overweight women with type 2 diabetes mellitus between a regimen of light aerobic exercise (25 min per session at 50-55% of maximal heart rate), a resistance exercise programme (3 times per week, 8 repetitions of 3 sets for each of the major muscle groups, at 50-55% of 1 repetition maximum force), a combined exercise programme (without an increase in total exercise dosage) and a control group. Over a 12-week intervention, they found similar losses of body fat with the 3 interventions (10.2%, 11.0% and 12.0%, versus a 5.2% loss in controls). The combined exercise programme also induced favourable changes in serum omentin-1 levels.

Arciero, Gentile, and Martin-Pressman (2006) looked at the benefits of combining aerobic and resistance activity with dieting in 63 subjects. Over 12 weeks, changes in body fat (15.6%) and abdominal fat (15.8%) were more favourable with a combination of aerobic and resistance training plus dieting than with dieting plus aerobic training (6.9%) or with dieting alone (0.8%).

Banz et al. (2003) compared the response to aerobic training (three 40 min sessions per week on a ski simulator, at 60-85% of maximal heart rate) and to resistance exercise (3 sessions per week on a commercial resistance training apparatus, eight different muscle groups, with 10 submaximal lifts per set) in a sample of 26 adults with android obesity. After a 10-week intervention, both groups showed a decrease in the waist-hip ratio, but the resistance exercise group also showed a 3.9% decrease of body fat not seen with aerobic exercise.

Table 11: Comparisons of responses to aerobic and resistance exercise programmes in the treatment of obesity.

Author	Sample	Intervention	Findings	Comments
Aminilari et al. (2017)	60 overweight middle-aged women with type 2 diabetes	Aerobic vs. resistance vs. combined ex. vs. control	12 wk fat loss aerobic 10.3%, resistance 11.0%, combined 12.0%, control 5.2%	Combined regimen gave favourable changes in omentin
Arciero et al. (2006)	63 overweight or obese adults	Diet + aerobic + resistance training vs. diet + aerobic vs. diet alone, over 12 wk	First intervention gave greatest reductions of body fat (15.8%) and abdominal fat (15.6%)	First intervention also improved blood lipid profile
Banz et al. (2003)	26 adults with android obesity	10 wk aerobic or resistance training	Decrease of wait-hip ratio in both groups, resistance ex. & 3.9% decrease of body fat	
Bateman et al. (2011)	86 overweight, dyslipidaemic adults, aged 18-70 yr	8 months of resistance and/or aerobic training	Increase of lean tissue 0.7kg with resistance, decrease of 1.54 kg with aerobic, decrease of 1.90 kg with combined	
Church et al. (2010)	262 M & F with type 2 diabetes mellitus	9 months resistance ex.	1.4 k fat loss with resistance; 1.7 kg fat loss with aerobic + resistance ex. Greatest increase of lean mass with resistance alone	Combined training improved Hb A1c levels, no change with resistance or aerobic training alone
Delecluse et al. (2004)	105 healthy men aged 55-75 yr	20 wks endurance training vs. ET + moderate or intensive resistance exercise	All 3 interventions reduced waist circumference 2.1-2.6 cm relative to control	
Fenkei et al. (2006)	60 obese women not on diets	Aerobic vs. resistance ex. vs. controls	At 12 wk, decreases of weight (3.1, 3.7 kg), waist circumference (1.9, 2.7 cm)	Aerobic regimen improved lipid profile
Ferrara et al. (2006)	39 older men	Aerobic or resistance training, 3 d/wk for 6 months	Body mass 2% decrease (aerobic), 2% increase (resistance)	16% gain of aerobic power (aerobic), 45% gain of muscle strength (resistance)
Geliebter et al. (1997)	29 M, 40 F	Diet + resistance vs. diet + aerobic training vs. diet alone	No inter-group difference in mean weight loss, but resistance training conserved lean tissue	
Ho et al. (2012)	64 overweight or obese adults	Aerobic vs. resistance vs. combined ex. vs. control	Over 12 weeks, weight loss 0.9, 0.1, 1.2 kg, fat loss 0.7, 0.4, 1,6 kg	Best results from combined ex.
Kraemer et al. (1997)	31 overweight women, aged 35 yr	12 wk diet vs. diet +aerobic vs. diet + aerobic + resistance training	No differences in weight loss or fat loss between interventions	

Table 11 Continued

Author	Sample	Intervention	Findings	Comments
Kraemer et al. (1999)	35 overweight men	12 wk diet vs. diet +Aerobic vs. diet + Aerobic + Resistance training	Decrease of body mass: diet 9.6 kg, diet + aerobics 9.0 kg, diet + aerobics + resistance ex 9.9 kg	
Lee et al. (2012)	45 obese adolescent boys, no dietary restrictions	Aerobic vs. Resistance ex. vs. Control	At 3 months body mass -0.04, -0.6 kg; waist circ. -2.0, 3.2 cm, total fat -3.0. -2.5 kg	Insulin sensitivity improved by resistance ex.
Lucotti et al. (2011)	47 patients with type 2 diabetes mellitus	Diet plus aerobic or diet + aerobic + resistance training	At 21 d, wt loss 3.4 kg both interventions, fat loss 1.9 and 2.8 kg	Both interventions improved insulin sensitivity
Mohammadi et al. (2018)	47 men aged 40-60 yr	Aerobic vs. strength vs. combined training vs. control	At 12 wk, body mass -5.4 kg, +1.0 kg, -3.0 kg; body fat -3.8%, -1.7%, -4.5%; lean mass 0, +5.4 kg, +8.6 kg	All 3 interventions had favourable impact on intercellular adhesion molecules 1 and 2 and on C reactive protein
Park et al. (2003)	30 obese women	24 wk, 1 h Aerobic exercise 6 d/wk vs. Aerobic 3 d/wk + Resistance 3 d/wk	Decreased 2.8 kg of body mass 4.7 kg aerobic, 6.4 kg combined; fat loss similar for 2 interventions (9.2, 10.3%)	
Rice et al. (1999)	20 Obese men	Diet, or diet with aerobic or resistance exercise	At 16 wks wt loss 12.1, 11.5 and 13.6 kg, waist circumf. -8.8, -12.9, -11.9 cm, Fat loss 8.5, 9.7 and 10.8 kg	Both exercise interventions enhance effect of diet on insulin levels
Sarsan et al. (2005)	60 obese women	Aerobic or resistance exercise or control	At 12 wk, wt. loss 3.5, 2.8 kg waist circumf. -5.8, -2.2 cm	Aerobic programme improved max. ox. intake and mood state, resistance programme enhanced strength
Sigal et al. (2007)	251 adults with diabetes mellitus, aged 39-70 yr	6 months aerobic, resistance or combined training	Weight loss relative to control aerobic 2.6 kg, resistance 1.1 kg, combined 2.6 kg	All interventions improved glycaemic control (best with combined treatment)
Sweeney et al. (1993)	30 obese women	Severe or moderate diet with aerobic or aerobic + resistance exercise	No significant added effects from aerobic (walking) or circuit training	Group sizes very small
Villareal et al. (2017)	160 obese older adults	Diet plus aerobic ex, resistance ex. or both or control	6 months wt loss 9.0, 8.5, 8.5 kg, fat mass 6.3, 7.3, 7.0 kg, lean mass loss 2.7, 1.0, 1.7 kg	Bone mineral density better conserved by resistance or combined ex.

Table 11 Continued

Author	Sample	Intervention	Findings	Comments
Wadden et al. (1997)	128 obese women	Diet vs. diet + aerobics vs. diet + resistance vs. diet + aerobic + resistance exercise	Weight loss 16.5 kg at wk 24, 15.1 kg at wk 48, with no difference between 4 interventions	
Weinstock et al. (1998)	45 obese women	Diet vs. diet + aerobic ex. vs. diet + strength training	At 44 wks, wt loss 13.8 kg (similar for 3 programmes)	5.3 kg regain of weight at week 96
Willis et al. (2012)	119 sedentary overweight or obese adults	Aerobic vs. resistance vas. combined training	At 8 months, loss of weight 1.8, 0.8, 1.6 kg, fat loss 1.0, 0.7, 2.0%, lean mass -0.1, +1.1, +0.8 kg	

Working with a sample of 86 overweight and dyslipidaemic adults aged 18-70 yr, Bateman, Slentz, and Willis (2011) found that after an 8-month programme there was an 0.70 kg increase of body mass with resistance training (3 sessions per week, with 3 sets of 8-12 repetitions per set) , as compared to a loss of 1.54 kg with aerobic training (running a distance of 198.3 km/week at 65-80% of peak oxygen intake), and a loss of 1.90 kg with combined aerobic and resistance training. The combined regimen also induced a 2.5 cm decrease of waist circumference.

Church, Blair, Cocreham et al. (2010) tested 262 patients with type 2 diabetes mellitus. They found only an 0.3 kg decrement of body mass after 9 months of resistance exercise (3 d/wk); with aerobic exercise (demanding an added energy expenditure of 12 kcal/kg per week) the loss was 0.8 kg, and there was a loss of 1.5 kg with the combined treatment. However, the reduction of fat mass was 1.4 kg with resistance training, 0.6 kg with aerobic exercise, and 1.7 kg with a combination of aerobic (10 kcal/kg) and resistance training (twice per week). Moreover, the final lean tissue mass was greater for those undertaking resistance exercise (+0.8 kg) than for either the aerobic exercise (-0.5 kg) or the combined aerobic + resistance exercise regimen (0 kg).

Delecluse, Colman, and Roelants (2004) compared endurance exercise alone (rising to 40 min of exercise per session at 70-80% of heart rate reserve), endurance exercise with moderate to vigorous or light resistance exercise and controls in a sample of older men (aged 55-75 yr). They concluded that neither moderate nor light resistance training increased the fat loss obtained from 20 weeks of aerobic training alone. Over 20 weeks, all three intervention groups showed a decrease in waist circumference of 2.1-2.6 cm relative to controls, and changes in the percentage of body fat were very small throughout.

Fenkei, Sarsan, Rota, and Ardic (2006) studied 60 obese women, none of whom were dieting. The effects seen in those undertaking 12 weeks of aerobic exercise (cycle ergometry, rising to 0-45 min at 50-85% of the heart rate reserve 5 d/wk) or resistance exercise (6 stations, 3 times per week) were compared to a control group. Both interventions reduced body mass (3.1 and 3.7 kg), and the aerobic exercise also improved the lipid profile significantly.

Ferrara, Goldberg, and Ortmeyer (2006) involved 39 older men in either aerobic or resistance training programmes, practiced 3 d/wk for 6 months. The 2 groups showed similar improvements in glucose metabolism. However, there were also gains of maximal aerobic power of 16% in the first group, and gains of muscle strength of up to 45% in the second group. The aerobic group showed a 2% decrease of body mass, whereas body mass increased by 2 kg in the resistance-trained group.

Geliebter et al. (1997) compared dietary restriction with resistance training (3 times per week), diet plus iso-energetic aerobic training, and dieting alone (an energy intake restricted to 70% of resting metabolism) in a sample of 25 men and 40 women. Over 8 wk, the mean decrease in body mass of 9 kg did not differ significantly between groups, but the group receiving resistance training showed a significantly smaller average loss of lean tissue than the other two groups.

Ho et al. (2012) made a four-way comparison between responses to aerobic exercise (30 minute sessions of treadmill running at 60% of heart rate reserve), resistance exercise (4 sets at each of 5 stations, with 10 RM contractions over30 min), combined exercise (15 min of aerobic and 15 min of resistance activity) and a control group in 64 overweight or obese adults. Over 12 wk of tri-weekly training, the active interventions induced decreases in body mass of 0.9, 0.1, and 1.2 kg, and fat losses amounted to 0.7, 0.4, and 1.6 kg.

Kraemer et al. (1997) studied 31 overweight women aged ~35 yr, assigning subjects between control, diet, diet plus aerobic exercise, and diet plus aerobic exercise plus strength training. At the end of 12 weeks of tri-weekly training sessions, they observed no inter-group differences in body mass or fat mass between the 3 interventions. Kraemer et al. (1999) also examined responses in 35 overweight men, with similar results to those found in female subjects. At 12 weeks, decreases of body mass (diet, 9.6 kg; diet plus aerobics 9.0 kg, diet plus aerobic plus resistance exercise 9.9kg) were relatively similar, but there was a substantial loss of fat free mass in those who only dieted (3.0 kg), as compared with losses of 2.0 kg with diet plus aerobics, and 0.3 kg with diet plus aerobics plus resistance training..

Lee et al. (2012) compared responses to aerobic and to resistance exercise in 45 adolescent boys who were not undergoing any type of dietary restriction. Neither aerobic exercise (progressing to 60 minute sessions at 60-75% of peak oxygen intake 3 times per week) nor resistance exercise (60 minute rotations around 10 stations, 3 times per week) had any great effect on total body mass over a period of 3 months, but both interventions decreased waist circumferences and total body fat content substantially (aerobic programme -2.6 cm, -2.6%, resistance programme -2.5 cm, -2.6%). Only the resistance programme was effective in decreasing insulin resistance.

Lucotti et al. (2011) compared aerobic exercise alone (30 min, twice per day, 5 d/wk of ergometry at 70% of maximal heart rate) with aerobic plus resistance exercise (the same aerobic activity, followed by 15 min of resistance training at each session) over a rather short period of 21 d. At this stage, both interventions had caused a 3.4 kg decrease of body mass, and respective decreases of fat mass were 1.9 and 2.8 kg. Both interventions had also improved insulin sensitivity.

Mohammadi et al. (2018) divided 47 men aged 40-60 yr between 4 groups (aerobic exercise, 3 times per week, rising to 60 minute sessions at 75% of maximal heart rate; strength training, rising to 3 d/wk at 75-80% of 1 repetition maximum force; combined training (20-30 min of aerobic training and a reduced volume of strength training; and a control group. After a 12-week intervention, respective changes associated with the 3 interventions were: for body mass -5.4, +1.0 and -3.0 kg, for body fat -3.8, -1.7 and - 4.5%, and for lean tissue mass 0, +5.4 and +8.6 kg. All three interventions induced favourable changes in intercellular adhesion molecules 1 and 2, and in C-reactive protein.

Park, Park, and Kwon (2003) studied 30 obese women; 10 followed a programme requiring 60 min of aerobic training 6 d/wk for 24 weeks at 60-70% of maximal heart rate, and another 10 subjects substituted resistance training for the aerobic training on 3 of the 6 d. Body mass decreased by 4.7 kg with aerobic training and by 6.4 kg with the combined regimen; however, the decrease of body fat was very similar for the 2 approaches to treatment (9.2% and 10.3%).

Rice et al. (1999) examined the benefits of adding either aerobic exer4cise (progressing to 60 min at 50-85% of maximal heart rate) or resistance exercise (three 30-minute sessions per week, with an energy expenditure of ~0.5 MJ/session) to dieting in 20 obese men. After 16 weeks, decreases in body mass (12..5 and 13.6 kg), waist circumference (8.87, 12.9 and 11.9 cm) and total body fat (8.5, 9.7 and 10.8 kg) did not differ greatly between the 3 interventions, but the addition of either type of exercise improved plasma insulin levels.

Sarsan et al. (2006) assigned 60 obese women to aerobic exercise (rising to 30-45 minute sessions at 50-85% of heart rate reserve for 5 d/wk) or resistance exercise (3 d/wk at 6 stations, rising to 75-80% of 1 repetition maximum force) or a control group. At 12 weeks, respective weight losses for the two interventions were 3.5 and 2.8 kg, and decreases in waist circumference averaged 5.8 and 2.2 cm. The aerobic programme also increased maximal oxygen intake and reduced symptoms of depression, while the resistance programme increased the strength of various muscle groups.

Sigal et al. (2007) compared aerobic and resistance training with a combination of the 2 interventions in 251 diabetic adults aged 39-70 yr. Over a 6-month trial, the decreases of body mass relative to control were 2.6 kg for the aerobic programme, 1.1 kg for the resistance programme, and 2.6 kg for the combined regimen. Respective decreases in fat mass were 1.6, -0.2 and 1.9 kg. Either aerobic or resistance exercise improved glycaemic control, but the best results in terms of blood sugar were obtained with the combined regimen.

Sweeney et al. (1993) paired either severe dieting (40% of normal energy intake) or moderate dietary restriction (70%) with no exercise, aerobic walking, or aerobic plus resistance exercise. With a total of only 30 obese women, group sizes were very small, but no significant additional effects were found from adding either walking alone or walking plus circuit training to the dietary intervention.

Villareal et al. (2017) randomized 160 older obese men on a diet (a 2.0-2.5 MJ/d energy deficit) between aerobic exercise (40 minute sessions, three times a week at 65% rising to 70-85% of peak heart rate), resistance exercise (40 minute sessions, 3 times per week, rising in volume to 2-3 sets at 85% of the 1-repetition maximum force), a combined programme (30-40 min each of aerobic and resistance exercise) and a control group (which did not diet). Over a 6-month period, all 3 interventions caused decreases in body mass (9.0, 8.5, and 8.5 kg, respectively) and fat mass (6.3, 7.3, and 7.0 kg). However, the loss of lean mass was larger with aerobic exercise (2.7 kg) than with resistance or combined exercise programmes (losses of 1.0 and 1.7 kg, respectively). Moreover, bone mineral density was better conserved with resistance or combined exercise than with the aerobic programme.

Wadden et al. (1997) compared diet (3.6-5.0 MJ/d), diet + aerobics (3 sessions/week), diet + resistance exercise and diet + both types of exercise in a sample of 128 obese women. The decrease in body mass averaged 16.5 kg at week 24, and 15.1 kg at week 48, with no difference of body mass or body composition between the 4 types of intervention.

Weinstock et al. (1998) divided 45 obese women between dieting alone (an intake of 3.9-6.3 MJ/d), dieting plus aerobic exercise (3 decreasing to 2 sessions/week with up to 40 min of stepping at an RPE of 11-15 per session) and dieting plus strength training (3 decreasing to 2 sessions/week with durations rising to 40 min per session). All 3 interventions yielded a weight loss of ~13.8 kg at 16 weeks, and this loss was well maintained at 44 weeks, but in the 22 subjects who returned at 96 weeks, 5.3 kg of the lost weight had been regained, and the improved insulin levels seen at week 44 were no longer apparent.

Willis et al. (2012) compared aerobic training (the equivalent of running 19 km per week at 65-80% of peak oxygen intake) with resistance training (3 d/wk, 3 sets of 8-12 repetitions) and a combination of these two programmes in a group of 119 sedentary or overweight obese adults. At 8 months the respective losses of body mass (1.8, 0.8 and 1.6 kg) favoured the aerobic group. Fat losses were 1.0, 0.7 and 2.0%, and changes in lean mass were -0.1, +1.1 and +0.8 kg, with this last finding favouring resistance training.

In summary, the only direct benefit of the resistance exercise in most of these trials has been a conservation of lean tissue. However, the strengthening of the main muscle groups is likely to have benefitted the overall health of the individual, and particularly in older individuals it may have reduced the risk of injuries and osteo-arthritic problems.

Is lifestyle activity preferable to a formal exercise programme in weight reduction?

Given that the factor limiting immediate fat loss with an exercise-based regimen commonly seems to be inadequate energy expenditure, an optimal short-term response might be anticipated from vigorous supervised exercise, rather than from the encouragement of unsupervised lifestyle activities. On the other hand, the formal exercise classes offered to the obese often lack sufficient physical demand, and travel to and participation in a supervised exercise programme tends to lose its appeal after a few months. Thus, particularly in a long-term perspective, a greater fat loss and a better maintenance of a normal body weight may be realized from a form of physical activity that the individual has chosen him- or her-self and enjoys practicing in normal daily life.

Many everyday lifestyle activities tend to be accumulated in 10-15 minute bouts, rather than in the 30-60 minute sessions that are typical of an organized exercise programme. It is often difficult to ascertain the extent of such lifestyle activity by collecting self-reports, but objective data can be obtained by either the wearing of an accelerometer or by examining the metabolism of doubly-labeled water. Given adequate internal and external motivation, the volume of energy expenditure accumulated through routine daily physical activities can be substantial. A systematic review of 18 observational and 8 randomized trials of lifestyle programmes was completed by Bravata et al. (2007). Accelerometer data showed average increases in step count of >2000 steps/day, with associated decreases of BMI averaging 0.38 kg/m^2.

Several authors have made empirical comparisons of the response to formal classes and to the encouragement of lifestyle activities (Table 12). Andersen et al. (1999) compared structured aerobic exercise (3 aerobic classes per week, demanding an energy expenditure of 1.8-2 MJ/class) with an increase of moderate lifestyle activities (the incorporation of deliberate walking and stair-climbing into the daily routine for at least 30 min/d). Both interventions were combined with a daily food intake of only 4.8 MJ/d. At the end of 16 weeks, the reduction in body mass was similar for the 2 groups (8.3 versus 7.9 kg), although the loss of fat-free mass was smaller for the aerobic exercise (0.5 kg) than for the lifestyle programme (1.4 kg). Over the following year, the body mass of the aerobic group regained an average of 1.6 kg, whereas the lifestyle group regained only 0.1 kg of the original weight loss.

Chan et al. (2004) encouraged 106 sedentary workers to engage in greater lifestyle activities by fitting them with pedometers. Over a 12-week intervention, step counts increased substantially, from 7029 to 10,480 steps/day; further, there were significant associated decreases in both BMI and waist girth, correlated with the individual's increase in step count (for example, a person with an initial waist girth of 100 cm lost 2 cm of girth with a 4000 steps/day increase in lifestyle activity).

Donnelly et al. (2000) compared the impact of three 30-min sessions per week of aerobic exercise, conducted at 60-75% of maximum aerobic capacity with the effects of deliberate brisk walking (2 15-min sessions/day, 5 d/wk) in 22 overweight adults. The aerobic group decreased their body mass by an average of 2.1% over 18 months, but no significant change was seen in the intermittent activity walking group.

Dunn et al. (1999) compared a formal aerobic programme (20-60 min of physical activity at 50-85% of maximal aerobic power, undertaken at least 3 d/wk) with lifestyle activities (deliberately accumulating 30 min of moderate physical activity on most days of the week). Over a 24-month intervention, neither group achieved major changes in body composition. However, the small decreases in body mass (0.05 vs. 0.69 kg) and body fat content (-2.4 vs.-1.9%) were similar for the lifestyle and structured exercise interventions.

Table 12: Studies comparing changes of body composition resulting from an increase of lifestyle activities versus the response to formal exercise classes.

Author	Sample	Intervention	Findings	Comments
Andersen et al. (1999)	40 obese women	4.8 MJ/d diet + 3 aerobic classes/ wk (1.8-2.0 MJ/class) vs. 30 min/d lifestyle activity	At 16 wks, wt loss aerobic 8.3 kg, lifestyle 7.9 kg, loss of fat-free mass 0.5 vs. 1.4 kg,	At 1 yr, aerobic group regained 1.6 kg body mass, lifestyle group only 0.1 kg.
Chan et al. (2004)	106 sedentary workers	Lifestyle activity encouraged by wearing pedometers	Over 12 weeks, step count increased 7028 to 10,480 steps/d	Decreases in BMI and waist girth related to increased step count (4000 steps/d = 2 cm decrease of waist girth)
Donnelly et al. (2000)	22 overweight adults	30 min moderate aerobic activity 3 d/wk vs. walking (15 x 2 min/d)	Over 18 months, aerobic group decreased body mass by 2.1%; no change in lifestyle group	
Dunn et al. (1999)	116 men, 119 women	20-60 min aerobic activity >3 d/wk vs. 30 min lifestyle activities/day	Over 24 months small decreases in body mass (0.05 vs. 0.69 kg) and fat (2.4% vs 1.9%)	
Jakicic et al. (1995)	56 obese women aged 41 yr	5.0-6.3 MJ diet + multiple 10-min bouts/d vs. single 40-min bout/d	Multiple bouts give greater weekly activity (224 vs. 189 min) and trend to greater weight loss (8.9 vs. 6.4 kg)	Greater adherence with multiple bouts 87% vs. 69%)
Jakicic et al. [1999]	148 sedentary & overweight women aged ~ 37 yr	Long bout vs. short bout vs. short bout + home aerobic programme	18 months. Short bout + home exercise achieved greatest volume of activity; wt. loss 5.8 vs. 3.7 vs. 7.4 kg	
Schmidt et al. (2001)	Overweight university students	Restricted diet + 30 min/d, 15 x2 min/d or 10 x 3 min/d at 75% of heart rate reserve	Changes of body composition & aerobic fitness similar for 3 programmes	Adherence similar for 3 interventions

Jakicic et al. (1995) tested the effects on 56 obese women aged ~ 41 yr; of multiple 10 min bouts of exercise versus one 40-min bout, both performed 5 d/wk. Over 20 wk, both groups followed a low fat diet providing 5.0-6.3 MJ of energy per day. Greater adherence (87 vs. 69 d attendance) was seen with the multiple brief bouts of exercise, and this form of intervention also resulted in a greater total duration of physical activity (224 vs. 188 min/wk) than that seen with the single longer exercise sessions, with a trend to a greater weight loss (8.9 vs. 6.4 kg). A further study by the same research group (Jakicic et al., 1999) examined the responses of 148 sedentary and overweight women aged ~ 36.7 yr to long-bout, short bout and short-bout plus home treadmill programmes. Over an 18-month trial, the average weight loss of 5.8 kg was no greater for those in the long-bout programme than that seen with the shorter bouts of exercise (3.7 kg), and the group that combined short-bouts with the use of home exercise equipment achieved both the greatest total volume of physical activity and the greatest decrease in body mass (7.4 kg). Jakicic et al. (2011) further noted that home-based physical activity without any prescribed reduction of food intake yielded a 2% weight loss at 6 months, and 1% at 18 months.

Schmidt et al. (2001) compared 30 min of daily exercise at 75% of heart rate reserve with the effects of 15 min x 2 and 10 min x 3 bouts/d in overweight female university students who were following a diet that met only 80% of their resting energy expenditures. Changes of aerobic fitness and of body weight were similar for the three types of intervention.

In summary, substantial increases of energy expenditure have been achieved in some studies by encouraging an increase in lifestyle activities. Typically, these have been of shorter duration but have been repeated more frequently than the organized classes. Thus, they have sometimes achieved a greater total energy expenditure, and a greater fat loss. Moreover, this approach has been better accepted by many participants, with a better long-term programme adherence.

Long-term maintenance of therapeutic weight loss

A current perception is that most obese people regain all of any fat that they have lost within 5 yr of completing a therapeutic weight reduction programme, and such "weight cycling" is regarded as particularly bad for health. Before evaluating the long-term impact of weight maintenance programmes, and the need for continuing exercise as a component of such long-term initiatives, it is necessary to consider the normal variability of body weight and to decide what are appropriate criteria for judging the success of weight maintenance in the light of this variability

Normal variability and definition of weight maintenance

Most people show small spontaneous fluctuations in their body mass from time to time, but repeated larger variations have an adverse effect upon health (Hamm, Shekelle, & Stamler, 1989; Lissner et al., 1991). Bangalore et al. (2017) showed that in a sample of 9509 people with clinically evident coronary artery disease, quintiles of body weight variability between successive clinic visits ranged from 0.93 to 3.86 kg, with each 1 SD increase in the variability of an individual's body mass leading to a 4% increase in the risk of a coronary event. They noted a 64% increase in risk from the lowest to the highest quintile of variability in body mass. Likewise, French et al. (1997) found that in a population-based sample of 33,834 Iowa women aged 55-69 yr, an increase of weight variability (defined as the root mean square of variation around the slope of body weight on age) increased the risk of myocardial infarction, stroke, diabetes and hip fracture. Quartiles of root mean square error in this study ranged from 0.9 kg to 7 kg.

Thus, variations in body mass of less than 5 pounds (2.3 kg) (Sherwood, Jeffery, & French, 2000; St. Jeor, Brunner, & Harrington, 1997) or less than 3% (Stevens, Truesdale, & McClain, 2006) are commonly regarded as evidence that body mass is remaining stable, with a change of more than 5% having an adverse clinical significance (Stevens et al., 2006). Despite the setting of such thresholds, the risks associated with an increase in body mass probably lie on a continuum, with any change having a small adverse effect. Moreover, since severe dieting causes a substantial loss of lean tissue mass, whereas exercise tends to conserve and even enhance lean tissue, it is important to note (although not usually considered) that any criterion of continuing success in weight control should differ between participants in diet- and exercise-based programmes.

Long-term success of weight control programmes

There are a number of reasons why exercise, either alone or in combination with continued dieting might help in long-term weight maintenance, including its impact in terms of sustaining lean tissue mass and thus resting metabolic rate, and the potential for a personally chosen exercise routine to become both an enjoyable part of daily life and a significant component of daily energy expenditures

Reviews and meta-analyses.

The expectation of benefit from continuing exercise is borne out in several reviews and meta-analyses. However, much of the empirical data on weight maintenance has been limited by its observational and/or retrospective nature.

Anderson, Konz, Frederich, and Wood (2001) looked at the long-term impact of weight loss programmes through a meta-analysis of 29 U.S. reports where individuals recruited to structured weight-loss programmes had been followed for a minimum of 2 yr. Very low energy diets yielding a large initial decrease in body mass seemed to bring about a better long-term weight maintenance than hypo-energetic balanced diets (sustained losses of 7 kg and 2 kg, respectively, with no differences of response between men and women). In 6 studies, a continuation of exercise was also associated with better maintenance of the weight loss (a sustained decrease of 15.0 kg versus 7.5 kg). Averaging across investigations provided data for 5 yr or longer, the continuing weight loss was only 3 kg.

A review by Catenacci and Wyatt (2007) concluded that *"Epidemiologic, cross-sectional and prospective correlation studies suggest an essential role for physical activity and weight loss maintenance, and post-hoc analysis of prospective trials shows a clear dose-response relationship between physical activity and weight maintenance."* However, not all reports support this view; looking at four randomized studies after a weight-maintenance phase of 6 months to 40 wk, they noted that In 2 of the four trials the weight regain did not differ significantly between continuing exercisers and those who were simply given dietary advice.

Curioni and Lourenco (2005) reviewed six randomized controlled trials published through 2003 that had compared diet alone with diet plus exercise during the maintenance phase. Over a one-year follow-up, as much as a half of the initial weight loss was regained. However, dieting plus exercise produced a 20% greater continuing weight loss than dieting alone (6.7 versus 4.5 kg).

Dombrowski, Knittle, Avenell, Araűjo-Soares, and Sniehotta (2014) examined 45 trials conducted prior to January 2014; 7788 individual subjects were involved. A combination of continued dietary restriction and physical activity only limited weight regain by an average of 1.56 kg relative to controls over a 12-month follow-up. Walking was the most common form of exercise undertaken; the volumes of physical activity prescribed and achieved were often not clearly described, and possibly larger volumes of physical activity might have been of greater benefit.

A systematic review by Fogelhom and Kukkonen-Harjula (2000) also found that observational studies published between 1980 and 2000 pointed towards exercise as a factor contributing to successful weight maintenance, although often poor programme adherence limited the effectiveness of continuing exercise programmes (Wing, 1999). Thus, in randomized controlled trials, there was only a marginal average difference in the extent of weight regain between those who continued exercise training (an increase in body mass of 0.28 kg/ month) and those that did not (an increase of 0.33 kg/month). Nevertheless, they concluded that the limited additional protection seen among exercisers in these studies was largely because the prescribed exercise did not meet the volume threshold (6.3-8.4 MJ/wk) adopted in observational studies where a clear benefit from exercise would be anticipated.

Franz et al. (2007) made a meta-analysis of 59 reports showing the long-term response to various types of intervention, including both exercise and dietary programmes. At 6 months, weight loss typically began to plateau, at 5 to 8 kg. Over the following 36 months, some regain of weight was observed, but around 3 kg of loss was maintained in the 70% of subjects who persisted with the trial. Sufficient data were obtained to compare responses of dieting and dieting plus exercise versus advice alone (Table 13), with both active options yielding rather similar long-term benefits.

McTigue et al. (2003) found that in a U.S. NIH review, counseling for physical activity in 24 randomized controlled trials had led to a sustained weight loss of 2-3%, with a reduction in abdominal fat content; a greater response was seen with a combination of dieting and physical activity. Further, in a U.K. NHS review of 24 studies, diet and/or exercise yielded a sustained weight loss averaging 3 kg over periods of 1-5 yr.

Miller et al. (1997) evaluated 152 studies of various types (but mostly uncontrolled) that had compared dieting, exercise, or a combination of the two approaches for at least one year following completion of a formal weight-loss programme. The initial weight loss was 11% of the person's weight, and the continued weight loss at one year was 6.6 kg for dieting, 6.1 kg for exercising, and 8.5 kg for combined treatment.

Pronk and Wing (1994) looked at both correlational studies and randomized trials that compared diet with exercise in the maintenance of weight loss. They were impressed with the contribution of exercise as seen in both types of literature. In most correlational studies, the individual's self-reported exercise level was the strongest predictor of weight maintenance, although this finding merits confirmation by objective measurements of habitual physical activity..

Ramage, Farmer, Apps Eccles, and McCargar (2014) reviewed 67 papers where an initial weight loss of 25% had been achieved, and subjects had then been followed for at least an additional year. They concluded that an energy deficit was needed for a safe and continued weight loss,, with physical activity programmes (commonly walking up to 150 min/wk) being a part of 88% of successful long-term interventions.

Middleton, Patidar, and Perri (2012) carried out a meta-analysis of 11 reports on extended care following weight loss.

Table 13: Meta-analysis showing long-term weight loss with dieting alone and dieting plus exercise, relative to minimal advice. Based on data of Franz et al. (2007).

Intervention	6 months	12 months	24 months	36 months
Diet	3.7 kg	4.5 kg	3.3 kg	2.2 kg
Diet + exercise	7.8 kg	3.8 kg	3.3 kg	2.6 kg

This added 3.2 kg of sustained weight loss relative to control or educational groups over a 17.6-month follow-up. Attendance at extended care groups appeared to increase the attention participants paid to both continued physical activity and dietary monitoring.

Empirical studies of long-term weight loss

Assessment of long-term empirical studies (Table 14) is limited by the fact that a number of reports did not include a control group. There is a strong likelihood that in the absence of a programme, obese individuals would have regained a substantial amount of weight (1-6 kg) over 5 yr, relative to their initial loss (Anderson, Vichitbandra, Qian, & Krysiko, 1999). Further, randomized controlled studies tend to lose a substantial proportion of participants over a 5-year follow-up, and there is a probable bias for more successful respondents to treatment to continue attending evaluation sessions, so that the true weight regain may be even larger than suggested by the available data.

Borg, Kukkonen-Harjula, Fogelholm, and Pasanen (2002) followed 2 months of intensive weight loss by a 6-month weight-maintenance programme and a further 23-month follow-up. The initial weight of 106 kg was reduced to 91.7 kg by the immediate two months of treatment. However, subsequent exercise training [45 min, 3 times/week, with energy expenditures of 1.6 MJ/session (an aerobics programme) or 1.2 MJ/session (a resistance training programme)] did not improve weight maintenance relative to controls, with final weights in the range 99.9 to 102.2 kg. Problems during the maintenance phase included poor exercise adherence, an increase of food intake, and an exercise dose that may have been inadequate. Individuals who were successful in maintaining their weight loss had a much higher average weekly exercise energy expenditure of 10.1 MJ. Exercise adherence seemed better with home-based walking than with the resistance exercise, which required travel to an exercise centre; very few subjects were persisting with resistance training by the end of the 23-month period.

de Roon, van Gemert, Peeters, Schuit, and Monninkhof (2017) examined the long-term impact of exercise and dietary programmes in a sample of 195 women. Data were collected one year after completion of two 16-week programmes that had achieved respective weight losses of 4.3 kg/5.4% (mainly exercising, with modest dietary restriction) and 3.4 kg/4.3% (dieting alone). Although the exercisers remained more active than the dieters, the follow-up data showed small self-reported increases of weight in both groups (1.6% and 2.0% respectively).

Ewbank, Darga, and Lucas (1995) and Fogelholm et al (2000) compared body weights for participants in two walking programmes with that of controls after 74 premenopausal women had all completed a 12-week very low energy intake diet inducing an average initial 13.2 kg dec

Table 14: Empirical data on successes in long-term weight maintenance.

Author	Subjects	Intervention	Findings	Comments
Borg et al. (2002)	90 obese men aged 35-50 yr	Aerobics (1.6 MJ/wk) or resistance training (1.2 MJ/wk) vs. controls	14.3 kg loss over 2 months, 29 months follow-up, sustained loss 3.8-5.9 kg	Successful individuals spent 10.1 MJ/wk, home-based walking. more effective than resistance ex.
de Roon et al. (2017)	195 post-menopausal women aged 50-69 yr able to exercise	Aerobics + modest dieting vs. dieting alone for 16 wk	Initial wt. loss 4.3, 3.4 kg, 1.6% to 2.0% regain of wt. over 1 yr	
Ewbank et al. (1995), Fogelholm et al. 2000)	74 premenopausal women	Walking 4.,2 or 8.4 MJ/wk after 13.2 kg wt. loss by dieting	Over 40 wk, further wt loss 2.4, 2.0 kg, fat loss 1.9, 1.9 kg	Lower dose group had higher daily step count
Jakicic et al. (2008)	201 overweight and obese women aged 27-40 yr	4 programmes (4 or 8 MJ/wk, moderate or vig. intensity)	At 6 months (8-10%0 and 24 months (5%) weight loss similar for 4 groups	Those sustaining 10% wt. loss spent 7.6 MJ/wk (275 min ex.)
Klem et al. (1997)	629 women, 155 men wt. loss >15.6 kg for 5 yr	Expenditure 11.8 MJ/wk		50% not associated with formal wt. reduction prog.
Kruger et al. (2006)	6175 adults aged >18 yr, successful wt. maintainers		Deliberate ex. >30 min/day, plus successful adoption of lifestyle activity	Weighed themselves frequently, planned food intake
Leemakers et al. (1999)	67 adults, initially lost 8.7 kg	Exercise-focused vs. weight-focused groups	Weight regain over 1 yr 4.4 vs. 0.8 kg.	Weight-focused group exercised more than nominal exercisers
Pavlou et al. (1989)	Men aged 26-52 yr, >22% overweight	Initial 10-12 kg wt. loss	Weight regain avoided with >3 exercise sessions of 2 MJ/wk	
Perri et al. (1986)	90 moderately obese adults, aged 22-60 yr	80 min aerobic exercise added to behav. therapy vs. behav. therapy	Wt. regain over 18 months 7.2 vs. 6.8 kg	42% of exercisers not exercising at 18 months, remainder only active 45 min/wk
Skender et al. (1996)	127 adults initially 14 kg overweight	Home-based ex. 5/wk vs. diet vs. combination	At 1 yr, wt loss 2.9, 6.9, 8.9 kg, At 2 yr, exercisers retained wt loss of 2.7 kg, combined 2,2 kg, but dieters 0.9 kg above initial wt.	
Wadden and Frey (1997)	621 middle-aged men and women	Initial wt. loss of 25.5% (men), 22.6% (women)	At 2 yr, 77.5% men, 59.8% women had loss >5%	At 5 yr, 58% men, 48% women had 5% loss

rease in body mass, some 70% of which was fat. Over the next 40 weeks, the intervention groups followed programmes designed to expend 4.2 and 8.4 MJ of energy per week. Somewhat surprisingly, during the maintenance period, the lower volume group of walkers tended to fare better than those undertaking a larger volume of walking, with a further weight loss of 2.4 kg and a fat loss of 2.0 kg relative to general counseling controls (as compared with 1.9 and 1.9 kg in those following the more vigorous programme). The problem with the more intensive regimen seems to have been poor adherence, and step counts suggest that during the second year of follow-up the lighter prescription actually resulted in a higher daily step count. Further, weight regain was negatively correlated with the daily step count (Fogelholm, Kukkonen-Harjula, & Oja, 1999). Fogelholm et al (2000) found that 3 yr after the intervention, the walkers had regained 6.2 kg of the lost weight, compared with a regain of 9.7 kg in the general counseling controls.

Jakicic, Marcus, Lang, and Janney (2008) looked at the success of weight maintenance in 201 overweight and obese women aged 27-40 yr. All were asked to reduce their food intake to 4.8-6.0 MJ/d, and individuals were assigned to one of four exercise programmes differing in the volume of physical activity (4 or 8 MJ/wk) and its intensity (moderate or vigorous). At 6 months (8-10% of initial body mass) and 24 months (5%), weight losses showed no inter-group differences. However, post-hoc analyses showed that those sustaining a weight loss amounting to more than 10% of their initial weight at 24 months had a higher weekly energy expenditure (7.6 MJ, 275 min/wk) than the rest of the study participants, suggesting the need for a large continuing volume of physical activity to maintain weight loss.

Klem et al. (1997) analyzed the characteristics of 629 women and 155 men who succeeded in maintaining a weight loss of at least 15.6 kg for 5 yr. Surprisingly, almost a half o this group had lost weight on their own, rather than through formal programmes. A critical life event had triggered the initial weight loss of these individuals. Their average reported food consumption was 5.8 MJ/d, and their reported weekly energy expenditure reached a very high average of 11.8 MJ.

Kruger, Blanck, and Gillespie (2006) also studied adults aged >18 yr who had been successful at weight maintenance. They comprised 31% of those who initially had tried to lose weight. Exercising more than 30 min/d and incorporating additional physical activity into daily life were characteristic features of these individuals. They also weighed themselves more frequently than average, and planned their meals more carefully. The odds of success were substantially reduced in those who perceived barriers to either exercising or a better planning of their food intake.

Leemakers, Perri, and Fuller (1999) compared exercise-focused with weight-focused maintenance programmes in 67 individuals who had initially reduced their body mass by an average of 8.8 kg. Over the following year, there was a larger weight regain with the exercise-focused (4.4 kg) than with the weight-focused group (0.8 kg); however, the latter group also sustained a somewhat greater volume of exercise than the nominal exercisers (165 versus 136 min/wk of walking).

Passman and associates (1999) used a multiple regression technique to explore the correlates of weight maintenance in a sample of 67 women aged ~38 yr. Some 50% of the regain of weight could be explained by physiological and behavioural factors, including the frequency of previous dieting, the hunger score and the change in resting metabolic rate. Unfortunately, differences in exercise patterns do not seem to have been included in this analysis.

Pavlou, Krey, and Steffee (1989) reported that those who were successful in maintaining weight loss continued to exercise to expenditures of 6.3 MJ/wk. Those who followed only dietary programmes regained most of their weight loss over the following 18 months, but exercisers conserved almost all of their initial losses. The supervision of exercise sessions was important during the initial phase of weight loss was important, but if procedures were well taught at this stage, extensive supervision during the maintenance phase was not required.

Perri et al. (1986) examined the effects of adding exercise (80 min/wk of walking or cycle ergometry) to behavioural therapy in the 18 months following a substantial weight loss. The subsequent regain of body weight was similar for the two groups (7.2 versus 6.8 kg), but at this stage 42% of the nominal exercisers were no longer exercising, and in the remaining 58% of the supposedly active group the average volume of exercise was only 46 min/wk.

Skender et al. (1996) studied 127 men and women who were initially at least 14 kg over weight, comparing their response to exercise (5 home-based sessions per week), dieting or a combination of the two treatments. The dietary programme was designed to produce 1 kg of body mass per week. At 1 year, weight losses were 6.8 kg from dieting, 2.9 kg from exercise, and 8.9 kg from the combined treatment. However, at 2 yr, the dieters weighed 0.9 kg above their initial value, whereas the exercise group had retained a weight loss of 2.7 kg, and the combined group a loss of 2.2 kg.

Teixeira et al. (2010) noted that intrinsic motivation to exercise was one of several factors that made a significant contribution to successful weight maintenance.

Wadden and Frey (1997) followed subjects who had initially reduced their weight by 25.5% (men) or 22.6% (women). After 2 yr, both sexes had regained a substantial fraction of the lost weight, but 77.5% of men and 59.9% of women had maintained a reduction in body weight of 5% or more. The number of subjects remaining in the trial at 5 yr was smaller, but among continuing participants 58% of men and 48% of women had maintained a 5% decrease of body mass. Unfortunately, the contribution of exercise to this outcome does not seem to have been analyzed.

The issue of exercise dosage in weight maintenance. The limited benefit from continued exercising seen in many empirical studies of weight maintenance could simply reflect the prescription of too small a volume of physical activity. Several observational studies have pointed to improved weight maintenance among individuals who sustain an exercise energy expenditure in the range of 6.3-8.4 MJ/wk (Fogelholm & Kukkonen-Harjula, 2000), and the U.S. National Registry of successful dieters pointed to an even higher average exercise volume (an estimated expenditure of 11.8 MJ/ per week). Such figures are substantially larger than what has commonly been prescribed, and certainly more than what most obese people actually achieve during the phase of weight maintenance. Even with smaller weekly volumes of exercise, the amount of activity that is undertaken seems to influence success. Thus Kayman, Bruvold, and Stern (1990) found that 90% of successful weight maintainers engaged in at least 30 min of physical activity, 3 times per week, whereas only 34% of those relapsing had even attempted to maintain an exercise programme. Pavlou et al. (1989) also commented that weight maintainers were people who exercised regularly.

Unfortunately, these studies lacked controls, and it could also be argued that the benefit associated with regular exercise participation could reflect a healthier overall lifestyle and a greater capacity for self-regulation, rather than a direct benefit from greater exercise participation.

The minimum weekly energy expenditure needed for weight maintenance seems to be substantial, but in most studies it has not proven impossibly large for middle-aged adults to achieve. In the U.S. National Weight Control Registry report, the exercise energy expenditure of successful weight maintainers averaged 11.8 MJ/wk, but the standard deviation of this total was very large (9.4 MJ/wk)(Klem et al., 1997) The American College of Sports Medicine recommended that obese individuals undertake a minimum of 200 min of moderate to vigorous activity per week, and a number of papers support an exercise prescription of this order (Donnelly et al., 2009). Jakicic et al. (1999) found the success of weight maintenance at 18 months was dependent on the dose of exercise undertaken; sustained weight losses from an exercise-centred programme were 13.1 kg if clients performed more than 200 min of exercise per week, and 8.5 kg with 150-199 min of exercise per week, but only 3.5 kg with less than 150 min of exercise per week. Jakicic, Rogers, Davis, and Collins (2018) further underlined that from the viewpoint of weight maintenance, repeated short bursts of lifestyle activity were just as effective as longer bouts of deliberate exercise, and that availability of a home treadmill appreciably improved outcomes. In a second study where weight loss was achieved by a combination of exercise and dieting, Jakicic, Marcus, and Gallagher (2003) found that the sustained weight loss at 12 months was greater for those undertaking >200 min of exercise per week (11.6 kg) than for those taking 150-199 (8.5 kg) or <150 min/wk (3.8 kg). The most active group in this study maintained an added energy expenditure of >8 MJ/wk, a level that many obese individuals would take some time to attain.

Andersen et al. (1999) found that after completing a 16-week programme that reduced body mass by 8 kg, the body mass of the most active individuals had decreased by a further 1.9 kg at 1 year, whereas the least active group had regained 4.9 kg of their original weight loss. In this study, lifestyle activity was at least as effective as formal aerobic exercise in preventing weight regain.

Schoeller et al. (1997) followed a group of women who had recently reduced their body mass by an average of 23 kg. They found that the largest factor discriminating between those maintaining weight loss and weight regainers was associated with an expenditure of 35 min of vigorous or 80 min of moderate physical activity per day,

Many of the physical activity recommendations for weight maintenance seem within the ability of the average middle-aged individual.

However, the U.S. National Weight Control Registry (Klem et al., 1997) found that 629 women and 155 men who had decreased their body mass by an average of 30 kg, and had maintained a loss of at least 13.6 kg for 5 yr were expending an average of 11.8 MJ/wk.

Motivation to long-term exercise.

Adequate and sustained motivation of the individual is essential to achieving and sustaining weight loss, whether this has been attempted by exercise, by dieting or by a combination of the two approaches. Long-term contact with a health professional is important to success (Perri, McAdoo, & McAllister, 1987). Treatment should be based on a sound theoretical model of health intentions and health behaviours (Godin, Valois, & Shephard, 1987). Clients should be given detailed instruction in techniques of exercising and in healthy eating behaviours, together with information on methods of self-monitoring and goal setting, stimulus control, problem solving and sources of social support (Baker & Kirschenbaum, 1993; Boutelle & Kirschenbaum, 1998). Some clients find pre-packaged meals with a known energy content a useful tool in maintaining the desired limitation of energy intake (Ditschenuneit & Johnson, 1999).

Several authors have suggested that the wearing of a simple pedometer can provide helpful motivation in maintaining the required volumes of daily physical activity (Shephard & Tudor-Locke, 2016). Meta-analyses of this approach have been completed by Bravata et al. (2007) and by Richardson, Newton, and Abraham (2008). Unfortunately, diet was not controlled in many of the trials that were cited, and neither of the meta-analyses examined the influence of the pedometers on the loss of body fat as opposed to decreases in body mass. In many of the trials, the fitting of a pedometer increased the immediate daily walking distance by as much as 3000 steps, equivalent to around 24 min of walking, at a pace of 5 km/h, or an added energy expenditure of ~0.4 MJ/d. However, this is a relatively small figure in terms of daily energy balance, and the impact upon fat loss was correspondingly small.

Bravata et al. (2007) found data on BMI in 18 of 26 reports. The wearing of a pedometer increased daily physical activity by some 27%, or about 2500 paces/day, with an average decrease in BMI of 0.38 kg/m^2 over a period of 18 weeks of treatment. The motivational effectiveness of the pedometer was increased if participants were set a daily stepping target.

Richardson et al. (2008) analyzed 9 interventions, involving 307 participants, with a mean duration of 16 weeks (but ranging from 4 weeks to 1 year). Many of the programmes considered included behavioural counseling, and/or step-count logging and reporting, but diet was not controlled in any of these studies. The average decrease of body mass in this series was only 1.3 kg, although losses were greater with the more sustained interventions. Dropout rates ranged from 0-32% in different studies.

Ancillary health advantages from participation in exercise programmes

Involvement in a regular physical activity programme carries many important health advantages other than decreases in body mass and body fat content (Bouchard, Shephard, & Stephens, 1994), and quite a number of these advantages are not realized with participation in a simple dietary programme (Table 15). Further, as noted above, the ancillary health benefits be realized, even if the impact of an exercise programme upon body mass or body fat content seems to be quite small.

Dieting can be a depressing experience, leading to a deterioration of mood state as blood glucose levels fall. In contrast, physical activity tends to have an arousing effect (Lambourne & Tomprowski, 2010), and is associated with a reduction of anxiety (Anderson & Shivakumar, 2013) and depression (Mata, Thompson, & Jaeggi, 2012). Furthermore, prolonged bouts of vigorous physical activity cause an increased secretion of pleasure-inducing endorphins (Howlett, Tomlin, & Ngahfoong, 1984), although it is unlikely that most obese individuals will sustain a sufficient intensity of physical activity to induce such a response.

The greater physical fitness that results from aerobic conditioning improves overall physical function, with an improvement in the health-related quality of life (Imayama, Alafano, Kong, Foster-Schubert, Bain, Xiao et al., 2011). Gains of cardio-respiratory fitness are likely to be induced by even the modest increases of physical activity achieved by obese individuals (Shephard, 1977), and these gains of fitness facilitate an active lifestyle that is helpful in maintaining subsequent weight loss over long periods.

The issue of conservation of lean tissue mass has been underlined throughout this article. During dieting without exercise, substantial amounts of muscle protein are mobilized in an attempt to maintain blood glucose, but regular exercise (particularly if it includes a resistance component) tends to avert this problem.

An enhanced regulation of blood glucose and blood lipids, as well as a decreased risk of various cancers are other important ancillary dividends of a sustained exercise regimen, although some of these benefits may also be obtained through participation in effective dietary programmes.

Finally, dieting is hardly likely to become an enjoyable regular pastime, but on the other hand a one-hour daily walk can add much to the quality of life for an older person.

Table 15: Ancillary advantages associated with participation in a regular physical activity programme.

- Elevation of mood state
- Increase of cardio-respiratory fitness
- Conservation of lean tissue mass
- Enhanced regulation of blood glucose levels
- Enhanced blood lipid profile
- Decreased risk of many forms of cancer
- Potential for adoption of pleasant lifetime activities

Discussion and conclusions

Despite repeated trials on overweight and obese individuals, the extent of benefit from exercise programmes remains unclear. This reflects several issues of methodology. Reliance on changes in body mass rather than on more direct measurements of body fat content has exaggerated the effectiveness of dieting, while under-estimating the response to exercise interventions. At the same time, the change in daily energy balance created by physical activity programmes has typically been small relative to that achieved by rigorous dieting.

The volume of exercise prescribed in fitness classes has usually been well documented, although sometimes poor adherence has limited the energy expenditures actually achieved. Weight-loss programmes based upon lifestyle exercise have commonly had less rigorous quantitation, and energy expenditures have tended to be over-estimated in studies where observers have upon self-reports of the activities undertaken..

Randomized controlled trials have suggested that exercise programmes induce consistent but sometimes disappointingly small decreases of body mass and body fat content (typically, a 2-3 kg change over a period of several months). Comparisons with dieting have generally shown the latter to yield substantially larger decreases of body weight over a similar period, although it has not always been clear how much of this apparent advantage was due to a loss of lean tissue rather than fat. Weight and fat losses of around 10 kg have commonly been achieved with a combination of dieting and exercise over periods of around 3 months. However, in a few instances, much greater fat losses have been realized (Klem et al., 1997), and there is a need to review why some individuals have been so much more successful in decreasing their body fat content. It is particularly intriguing that as many as a half of the people concerned have not participated in any formal exercise or dietary programme, suggesting the importance of personal commitment and the need to reconsider the content of current formal weight-loss initiatives. Almost all meta-analyses conducted to date have shown only a small additional (1-2 kg) decrease of body mass when dietary programmes have been complemented by regular exercise sessions; however, the inclusion of exercise has sometimes boosted the extent of fat loss. Moreover, when making comparisons between dieting and exercise programmes, it is important to include in the analysis other benefits of increased physical activity, including conservation of lean tissue, an increase of maximal aerobic power and muscular strength, improved eating behaviour (Jakicic, 2002), better psychological health, and improvements in lipid profile, all benefits that do not occur with simple dieting. Further, there have been suggestions that that exercisers are more likely to continue undertaking useful amounts of physical activity once the formal intervention has been completed, with a lesser tendency to regain of weight (Jakicic, 2012); this question merits confirmation.

One important factor limiting the efficacy of exercise interventions seems to have been the adoption of quite a limited dosage of exercise. In support of this criticism, some non-randomized trials with energy expenditures of 2-4 MJ/d have demonstrated much larger and clinically relevant effects (fat losses of >10 kg). In contrast, the exercise prescribed in many otherwise well-designed randomized trials has required only a limited weekly energy expenditure; there remains a need for studies where exercise programmes match dietary restrictions in terms of their impact upon daily energy balance. Several consensus meetings and individual reports have underlined that the minimal dose of physical activity recommended by public health authorities, while appropriate for dealing with issues such as the prevention of hypertension, is insufficient to correct established obesity; indeed, such a dosage adds relatively little to the effects of dieting alone. There is certainly a need for further research on minimum effective doses of physical activity, but the current consensus recommendation is that in order to reduce body fat content, adults should engage in a minimum of 150-250 min of moderate to vigorous aerobic activity per week, incurring an additional weekly energy expenditure of 4.8-8.0 MJ. Moreover, it has been suggested that even larger weekly doses of physical activity may be required for benefit in children. This poses a need to examine how far older individuals with various initial levels of obesity can tolerate exercise programmes with sufficient rigour to metabolize excess fat, and to ensure that physically demanding programmes do not compromise long-term adherence to weight-maintenance programmes.

Reasons for a limited response to an exercise-based weight-loss programme are quite varied, and there remains scope to explore and to rank each of these factors. Potentially adverse influences include not only an insufficient added volume of daily physical activity and a poor adherence to the prescribed regimen, but also a compensatory increase of food intake, probably compounded by some reduction in resting metabolic rate, a decrease of spontaneous leisure activity and a reduction in NEAT.

Fat loss seems to occur a little more easily in men than in women, and there is scope to look further at the mechanisms underlying this difference in response. Possibly, women have humoral fat-conserving mechanisms designed to meet the energy needs of pregnancy and lactation. Further, it seems easier to mobilize abdominal than subcutaneous fat, and abdominal fat deposition is more typical of men than of women.

Given a combination of dietary restraint and intensive exercise, an 8.5 kg loss of fat has been reported over as little as 8 weeks, and there is a need to explore the merits of high intensity effort versus more prolonged moderate aerobic sessions (Boutcher, 2011). High intensity intermittent exercise sometimes seems to cause a greater metabolism of subcutaneous fat (Trapp, Chisholm, & Freund, 2008; Tremblay, Simoneau, & Bouchard, 1994). Possible advantages of intensive physical activity include a catecholamine-induced mobilization of fat, a continuing post-exercise fat oxidation, and a post-exercise inhibition of appetite (Boutcher, 2011). High intensity exercise is also likely to increase the post-exercise stimulation of oxygen consumption, thus prolonging the metabolism of fat (Warren, Howden, Willaims, Fell, & Johnson, 2009). Further, it may have a greater immediate appetite suppressant effect than more moderate physical activity. Finally, the relative proportions of fat and carbohydrate that are metabolized by the working muscles depend upon the intensity of effort that is undertaken (Gonzalez & Stevenson, 2012), with a maximal utilzation of fat when the intensity of exercise is ~70% of maximal oxygen intake.

There has as yet been little research on the cumulative response to several short bouts of vigorous exercise, undertaken at various points during the course of a day, but for those who are severely obese, programme compliance might be facilitated if a single daily 30-minute session of aerobic activity could be replaced by two or three shorter bouts of activity at the same intensity.

Public health recommendations for healthy but sedentary individuals have stressed the need to supplement aerobic exercise programmes by regular, bi-weekly bouts of resistance training. Resistance exercise alone demands only a limited increase in energy expenditure, and it has a correspondingly limited effect in metabolizing body fat, but there remains scope to look at other benefits that can be anticipated if one adds an element of strength training to a combined dieting and aerobic programme. One important likely effect is a greater conservation of lean tissue, and this may in turn help to sustain the resting metabolic rate. The introduction of an n element of resistance training may also increase fat oxidation in the period following a bout of exercise, and a strengthening of key muscles may enhance overall health, reducing an individual's risk of injuries, osteo-arthritic problems, and dependency.

Some people have responded to better to an encouragement of lifestyle activities than to enrolment in formal exercise classes. Lifestyle activities have been seen as more convenient, and some clients have achieved substantial increases of energy expenditure and a substantial fat loss by augmenting such activities. Probably because of greater convenience, long-term adherence has also been better than that seen with formal exercise classes.

Much of the weight initially lost through a combined exercise and dietary programme loss is typically regained within a year of completing the formal intervention, but a continued exercise and dieting programme commonly conserves around 3 kg of the initial weight loss during the maintenance phase. A few investigators have succeeded in sustaining weight loss for as long as 5 yr, and there is a need for further study of programme characteristics in these initiatives.

There remain a number of areas where further research would be helpful. In particular, trials are needed where food intake is carefully monitored and changes in body fat rather than body mass are recorded. At present, the literature contains some puzzling enigmas. For instance, Donelly et al. (2003) planned an exercise intervention to increase the energy expenditure of a group of women by 9.2 MJ/wk, and doubly labeled water data suggested that they actually achieved an increased expenditure of 6.1 MJ/wk. However, their subjects showed no decrease in either body mass or fat mass. What was the cause of this apparent resistance to treatment? Better research design would probably clarify such enigmas. Specifically, there is a need for randomized-controlled trials where data analysis is based upon initial subject allocation rather than the response of adherent subjects, thus eliminating the possibility that data has been drawn from those who persist with an exercise programme, a better disciplined sub-group who are more likely to have a favourable overall lifestyle, and who adhere more closely to prescribed dietary limitations (Jakicic, 2002 ; Kempen et al., 1995).

The optimal intensity and volume of exercise programmes still needs to be clarified. Does one prescription fit all weight-loss candidates, or do some individuals require a more demanding programme than others? Obvious potential determinants of differing programme needs are the individual's age and sex, their initial degree of obesity, and the dietary restrictions that have been imposed, and future studies need to be stratified in terms of these variables. Women plainly develop a smaller increase of energy usage than men for any given task, because they have a lower average body mass.

Substantial evidence points to the favourable contribution of continued physical activity to weight maintenance, but there remains scope to clarify the underlying mechanisms. Is there a specific effect of exercise upon metabolism, or does exercise simply make it easier to maintain the necessary daily energy balance?. Possibly, exercise helps weight maintenance by sustaining lean tissue mass and reducing the tendency to a decrease of resting metabolism. To date, the volume of exercise prescribed in many maintenance programmes has probably been insufficient; there is a need to clarify the optimize dosage and to develop methods of maintaining enthusiasm for an appropriately vigorous physical activity regimen over the remainder of a client's life-course.

Currently, we may conclude that moderate exercise alone generally does less than rigorous dieting in terms of correcting obesity. However, larger benefits may be anticipated if the exercise dose can be increased. Furthermore, even moderate levels of exercise conserve lean tissue, and physical activity an important component of weight maintenance programmes. The challenge faced by health professionals is to develop methods whereby clients can safely reach an effective daily dose of exercise, and to sustain enthusiasm for this regimen in the years after initial weight goals have been attained.

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Author's qualifications

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