

Exercise in the Management of Obesity

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Abstract

Obesity is associated with significant cardiovascular morbidity and mortality. A weight loss strategy including diet and exercise is routinely recommended to achieve weight loss and cardiovascular risk reduction. Although the benefits of exercise for cardiovascular risk reduction are well accepted, exercise is generally thought to be less effective than caloric restriction in achieving and maintaining weight loss and to be most useful when coupled with diet and especially to maintain weight loss achieved by diet. However, similar weight loss to that achieved with diet can occur providing energy deficits are comparable. This however may necessitate efforts to curb a compensatory increase in caloric intake associated with exercise. Even in the absence of weight loss, exercise has many beneficial effects, including a decrease in both abdominal and visceral fat, an increase in lean body mass, and improvements in insulin sensitivity, lipid profile, and cardiovascular fitness.

Keywords: Aerobic exercise; Diet; Energy expenditure; Energy Intake; Exercise; Obesity; Review; Strength training; Weight loss; Weight maintenance

Introduction

The epidemic of obesity remains the most pressing public health problem facing the U.S. and most other developed countries. Within the past two decades, the prevalence of obesity among U.S. adults has doubled. During the years 2007-2008, 32.2% of adult men and 35.5% of adult women were obese [1]. Obesity is associated with many adverse common clinical outcomes, including coronary artery disease, stroke, diabetes, hypertension, and lipid disorders. Studies demonstrate that intentional weight loss results in many cardiovascular health benefits, including improved glucose control, decreased blood pressure, and improved dyslipidemia [2]. Weight loss may also decrease inflammation [3] and may have a beneficial effect on kidney disease [4].

Obesity is a consequence of energy imbalance with caloric intake exceeding energy expenditure. A lack of physical activity is thought to be a major contributor to the obesity epidemic, and U.S. adults are recommended to achieve at least 150 minutes per week of moderate intensity exercise [5]. Some clinical guidelines include an even greater increase in physical activity (300 minutes per week of moderate intensity exercise or 150 minutes per week of vigorous exercise) to achieve more extensive health benefits [6]. However, this may not be an attainable goal for many adults due to time conflicts or associated conditions which limit physical activity. In addition, the efficacy of physical activity for weight management has been recently questioned [7].

In this narrative review, we summarize the evidence for a beneficial effect of exercise in obesity management based on a review of the literature published over approximately the past decade (January 2000-November 2010). A summary of the review is given in Table 1. We focused on randomized controlled trials of at least 8 weeks duration that specifically address weight management strategies which focus on exercise alone (aerobic exercise, strength training, or both) and exercise combined with diet. Overall, the available data suggest that exercise alone is generally less effective than caloric restriction in achieving and maintaining weight loss. However, substantial weight loss similar to that achievable by diet is seen if efforts are made to assure an equal energy deficit. Moreover, even in the absence of weight loss,

exercise has many beneficial effects on body composition, metabolism, and cardiovascular fitness.

Aerobic Exercise Alone

Evidence supports the notion that aerobic exercise can be an effective method of weight loss in the absence of diet. In studies from the Midwest Exercise Trial (MET), walking on a treadmill (without diet) for 16 months has been shown to produce substantial (~6 kg) weight loss as compared to control [8]. Most studies show a lesser effect on weight though. Weight loss was modest but greater with walking versus stretching; aerobics also increased exercise capacity (maximum walk time) [9]. Aerobic exercise (walking, running, treadmill, cycling, and calisthenics) caused weight loss, decreased insulin resistance, increased aerobic capacity, decreased lipids, decreased systolic blood pressure, and decreased inflammation (C-reactive protein) [10]. Treadmill walking or stationary bicycling (with strength training recommended but not enforced) was superior to control in achieving weight loss but lean mass and bone mineral density were not affected [11]. A one year aerobic exercise program resulted in more weight loss and increased ghrelin levels versus control [12].

Weight loss does not always occur with exercise alone. Brun et al. [13] reported that eight two-hour sessions of cycling over four weeks followed by a one year follow up with home exercise (walking, jogging, gymnastics) did not result in weight loss though a decrease in insulin resistance and decrease in health care costs noted. Boudou et al. [14] also did not find a difference in weight loss with exercise, although exercise did decrease abdominal fat and improved insulin sensitivity.

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Received January 28, 2012; **Accepted** March 03, 2012; **Published** March 09, 2012

Citation: Moinuddin IK, Collins EG, Kramer HJ, Leehey DJ (2012) Exercise in the Management of Obesity. J Obes Weig los Ther 2:117. doi:10.4172/2165-7904.1000117

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Table 1: Effect of exercise on body weight.

MODALITY	Weight change	Study duration Exercise type	N	P value	Ref
AEROBIC EXERCISE ALONE					
Exercise Control	-5.6 kg +0.9	16 mo Walking Treadmill	66	< 0.05	8
Exercise Control (Stretching)	-2.1 kg -1.1	6 mo Walking	174	< 0.05	9
Exercise Control	-1.32 kg +0.61	6mo Walking Running Treadmill Cycling Calisthenics	60	< 0.05	10
Exercise Control	-1.3 kg +0.1	12mo Treadmill Walking Bicycling	173	< 0.05	11
Exercise Control	-1.4 kg -0.1	12 months Aerobics	168	< 0.01	12
Exercise Control	+0.26 kg -4.83	4 wks supervised cycling/ 1 yr home exercise	25	> 0.05	13
Exercise Control	-1.9 kg -1.6	8 wks Aerobics	16	>0.05	14
Exercise (men) Control (men) Exercise (women) Control (women)	-5.2 kg -0.5 +0.6 +2.9	16 mo Aerobics	131	0.01 0.03	15
AEROBIC + RESISTANCE EXERCISE ALONE					
Exercise Control	-2.3 kg -0.5	6 mo Resistance Treadmill Cycle Stair stepper	115	< 0.05	16
Exercise Control	-0.9 kg -0.45	48 wks Aerobics Resistance	189	> 0.05	17
AEROBIC EXERCISE ALONE VARIOUS INTENSITY					
3000-3500 kcal/wk 700-800 kcal/wk	-8.2 kg -3.7	5 mo /1-year follow-up Walking Treadmill Ergometers	74	< 0.05	18
Continuous Intermittent	-2.1% No change	18 mo Walking	22	< 0.05	19
(Amount/Intensity) High/vigorous Low/vigorous Low/mod Control	-2.9kg -0.6 -0.9 +1.0	8 mo Cycle ergometers Treadmill Elliptical trainers	120	< 0.05	20
2500kcal/wk 1000 kcal/wk	6, 12, 18 mo -9, -8.5, -6.7 kg -8.1, -6.1, -4	18 mo Walking	202	< 0.05 at 12 and 18 mo	21
High intensity Low intensity Control	-3.5 kg -2.1 -0.9	16 wks Aerobics	27	> 0.05 high vs. low	22
Land treadmill Underwater treadmill	-1.5 kg -0.7	12 wks Treadmill	57	> 0.05	23
(Intensity/Duration) Vigorous/high Moderate/mod Vigorous/mod Moderate/high	-8.9 kg -6.3 -7.0 -8.2	12 mo Treadmill	201	> 0.05 between groups	24
Low volume/moderate intensity High volume/low intensity	-4.27% -4.17	Aerobics	30	> 0.05	25

Continuous Long bout Short bout	Non-significant	18 mo Treadmill	148	> 0.05	26
4 kcal/kg/wk Exercise 8 kcal/kg/wk Exercise 12 kcal/kg/wk Exercise Control	-1.4 kg -2.1 -1.5 0	6 mo Aerobics	411	> 0.05 between groups	27
AEROBIC EXERCISE VS. DIET					
Diet Exercise	-10.2% -8	12 mo Aerobics	34	> 0.05	28
Diet Exercise Control	-8.3 kg -6.8 -1.3	12 mo Aerobics	44	0.004 overall NR D vs. E	29
Diet Exercise	-10.7% -9.5	12 mo Aerobics	34	> 0.05	30
Diet Exercise	-1.74kg -0.85	2 months Jogging Swimming Bicycling	13	< 0.05	31
AEROBIC EXERCISE + DIET VS. DIET					
Control Diet Diet + Exercise Very Low Calorie Diet	-1 kg -8 -8 -11	24 wks Aerobics	48	> 0.05 D + E vs. D group	32,33
Diet Diet + Exercise	-14.7kg -15.2	40wks Cycling Walking Aquajogging	40	> 0.05	34
Control Diet Diet + Exercise	0% -8 -8	6mo Walking Running Cycling	36	< 0.05 both vs. C > 0.05 D + E vs. D	35
Control Diet (CR 25%) Diet (CR 12.5%) + Exercise (12.5%)	0% -10 -10	6 mo Endurance	36	< 0.05 both vs. C > 0.05 D + E vs. D	36
Diet + Exercise Diet	-10.8% -9.2	16 wks Aerobics	16	> 0.05	37
Control Diet Diet + Exercise	-0.1 kg -3.2 -4.8	12 wks Aerobics	34	<0.05 both vs. C NR D + E vs. D	38
Diet Diet plus aerobics	-7.1kg -8.4	12 wks Aerobics	60	0.20	39
Diet Diet + Exercise	-9.7% -12.1	12 wks	49	0.036	40
Step 2 diet + Exercise Step 1 diet + Control (stretching)	-3.9 kg +1.3	24 mo Walking Jogging	62	< 0.05	41
Control Intraabdominal fat obesity: Diet Diet + Aerobics Subcutaneous fat obesity: Diet Diet + Aerobics	0 kg -7 -9.6 -7.9 -7.9	14 wks Aerobics	209	< 0.001 in IA group; >0.05 in SF group	42
Diet Diet and Exercise Control	Men Women -5kg -4.1 -8.7 -5.1 +1.7 +1.3	1 year Walking Jogging	264	< 0.05 vs. C	43
DASH DASH + Exercise Control	-0.3 kg -8.7 +0.9	4 mo Biking Walking Jogging	144	< 0.05	44
DASH DASH + Exercise Control	-0.8 kg -8.9 0	16 wks Aerobics	124	< 0.05	45
Control Diet + Aerobics Hi Protein Hi Protein + Aerobics	-2.1 kg -4 -4.6 -7	12 wks Aerobics	44	< 0.05 between groups	46

AEROBIC EXERCISE VARIOUS INTENSITY + DIET VS. DIET					
Diet + Low intensity Exercise Diet + High intensity Exercise Diet alone	-14.8 kg -11.9 -14	20 wks Treadmill Walking	34	> 0.05	47
Diet Diet + mod exercise Diet + intense exercise	All had approx 12.1 kg wt loss	20 wks Treadmill	112	> 0.05	48
Diet Diet + mod ex Diet + intense exercise	-10.4 kg -10.9 -8.8	20 wks Treadmill	45	> 0.05	49
Diet Diet + walking (low) Diet + walking (high)	-4.2 kg -5.8 -5.8	12 wk Walking	56	> 0.05	50
Very low cal diet Diet + walking Diet + dance	-7.7 kg -9.1 -10.2	14 wks	90	< 0.01 dance vs. other groups	51
RESISTANCE EXERCISE + DIET VS. DIET					
Diet Diet + casein + resistance Diet + whey + resistance	-2.5 kg -2.5 -2.5	12 wks Resistance	38	> 0.05	52
Diet Diet plus resistance Control	-6.3% -7.7 0	16 wks Resistance	34	> 0.05 D + R vs. D	53
Diet Diet plus resistance	-12.5 kg -11.5	25 wks Resistance	67	0.13	54
Diet Diet plus resistance	-6.2 kg -8.6	14 wks Resistance	42	0.05	55
Diet Diet + Resistance	-5.1kg -5.8	6 mo Resistance	107	> 0.05	56
Diet (DASH) Diet (DASH) + Resistance	-1.7 kg -3.3	10 wks Resistance	27	0.137	57
Control Control + high protein Control + resistance High protein + resistance	-8.6 kg -9 -10.5 -13.8	16 wks Resistance	83	< 0.04 group effect	58
AEROBIC AND/OR RESISTANCE EXERCISE + DIET VS. DIET					
Diet Diet + Aerobic Exercise Diet + Resistance Exercise	-10 kg -11.1 -10	16 wks	38	>0.05	59
Diet (800 kcal/d) Diet + Endurance Exercise Diet + Resistance Exercise	-12.1 kg -12.1 -12.1	160d	141	>0.05	60
Resistance + Diet Aerobics + Diet No Training + Diet	AA EA -10.9 -12.4 kg -13.4 -12.6 -12.1 -13.6	21 wks Walking Jogging Treadmill	94	> 0.05	61
Diet Diet plus Aerobics Diet plus Aerobics plus resistance training	-8.9 kg -11 -8.7	20 wks Aerobics Resistance	104	0.5	62
High protein/lo carb diet Hi pro, lo carb + Exercise Lo pro, high carb Lo pro, hi carb + Exercise	-9.8 kg -9.8 -7.8 -6.7	16 wks Walking Strength Training	48	< 0.05 hi prot vs. hi carb >0.05 D + E vs. D	63
AEROBIC EXERCISE + DIET VS. EXERCISE					
Diet + Exercise Exercise	-8.0 kg -3.2	12 wks Aerobics	21	<0.001	64
Diet + Exercise Exercise	-8.3% -2.8	12 wks Aerobics	19	0.002	65
Diet + Exercise Exercise	-7.7% -3.3	12 wks Aerobics	16	<0.001	66
Diet + Exercise Exercise	-18.8lb -4	24 wks Weight training Walking	24	< 0.05	67

12 wks: Aerobics Diet + aerobics	+0.2 kg -6.9	24 wks Aerobics	90	< 0.05	68
24 wks: Aerobics Diet + aerobics	-0.4 -7.1				
Aerobics Diet + aerobics	-3.7 kg -6.8	12 wks Aerobics	24	0.02	69
AEROBIC EXERCISE VARIOUS INTENSITY + DIET VS. EXERCISE (3 groups)					
Diet + low intensity Diet + high intensity Control + low intensity Control + high intensity	-10.88 kg -11.66 -0.44 -1.55	16 wks	60	< 0.001 vs. C >0.05 high vs. low	70
AEROBIC EXERCISE + DIET VS. AEROBIC EXERCISE VS. DIET (3 groups)					
Exercise Diet Diet + Exercise	-3.5kg -12.3 -12.3	12 wks Bicycling Jogging Treadmill Stair stepping	79	< 0.05 D and D + E vs. E > 0.05 D + E vs. D	71
Exercise Diet Diet + Exercise	-1.3kg -9.3 -8.6	16 wks Aerobics	64	< 0.05 D and D + E vs. E > 0.05 D + E vs. D	72
Exercise Diet Diet + Aerobics Control	-1 kg -7.8 -8.1 -0.8	12 wks Aerobics	121	<0.001 D and D + E vs. E > 0.05 E vs. C	73
Exercise Diet Diet +Exercise Control	-0.3 kg/m ² -1.3 -1.8 +0.3	1 year Endurance Circuitry training Walking Jogging	186	< 0.05 from baseline only in D and D + E	74
COMBINED AEROBIC/RESISTANCE EXERCISE PLUS DIET VS. EXERCISE VS. DIET					
Exercise Diet Diet + Exercise Lifestyle	-3.7% -4.9 -5.7 -1.2	18 mo Walking Strength training	316	Both diet groups < 0.05 vs. lifestyle	75
RESISTANCE EXERCISE + DIET VS. RESISTANCE EXERCISE VS. DIET (3 groups)					
Resistance Diet Diet + Resistance Control	-1.7 kg -4 -3.6 0	12 wks Resistance	48	Both diet groups <0.05 vs. control	76
STUDIES EXAMINING EFFECTS OF EXERCISE WITH AND WITHOUT WEIGHT LOSS					
Diet wt loss Exercise wt loss Exercise wt stable Control	-7.4 kg -7.6 0 0	3 mo Walking Jogging Treadmill	52	> 0.05 D wt loss vs. E wt loss	77,78
WEIGHT MAINTENANCE					
0-6 months Diet Diet + resistance 6-12 mo follow-up Diet Diet + resistance	-3.3 kg -2.7 +1.6 +1.7	48 wks Resistance	36	Similar wt regain in D+R and D groups	81
Wt maintenance w/ Walking Resistance Control	-14.2 kg during VLED; -4.8 kg at end.	VLED for 2 mo followed by 6 mo wt maintenance and follow-up at 31 mo	90	Similar wt regain in all groups	82

Wt maintenance w/ Diet Diet + Exercise	-15 kg during CR; -6.7 kg at end	10 wk diet Followed by 43 wks weight maintenance Cycle ergometer Walking Aqua jogging	40	Similar wt regain in D+E and D groups	83
Wt maintenance after diet-induced wt loss Control Walking Resistance	-14 kg during VLED; ~ 8kg of wt regained	2 mo VLED 6 mo supervised followed by 23 mo unsupervised wt maint	68	Similar wt regain in all groups	84
Wt maintenance Maintenance 4.2 MJ/wk Maintenance 8.4 MJ/wk Follow-up 4.2 MJ/wk Follow-up 8.4 MJ/wk	Difference vs. control -2.7 kg -2.6 -3.5 -0.2	12 wk diet 40 wk walk 2 year follow up	82	Trend toward less wt regain with walking (0.07)	85
LEARN LEARN + self control	-7 kg -5.4 63% of wt regained at 1 year	1 year Aerobic physical activity		Wt regain significant (< 0.05)	86
Intensive lifestyle Metformin Placebo	Max End -7kg -2 -2.5 -2 < -1 <-1	5-7 yr Aerobics	2766	< 0.05	87
Caloric restriction on weekdays Caloric restriction on weekends	-0.02 kg/d +0.06 kg/d	1y Daily exercise	48	Weight gain on weekends (0.02)	88
Twice weekly strength training Control	+1.7% +2.4	2y	164	> 0.05	89

ACRONYMS: N = number of subjects; Ref = reference number; carb = carbohydrate; pro = protein; KKW = kcal/kg/wk; NR = not reported; D = diet; E = exercise; R = resistance; C = control; VLED = very low energy diet; IA = intraabdominal; SC = subcutaneous; DASH = Dietary Approaches to Stop Hypertension; LEARN = Lifestyle, Exercise, Attitudes, Relationships, and Nutrition; ADAPT = Arthritis, Diet, and Activity Promotion Trial; AA = African American; EA = European American

With the exception of the MET study [13], the amount of weight loss achieved with exercise alone was modest (< 2 kg). However, the effect of exercise on weight loss may be different in men and women. In the MET trial, in which subjects underwent moderate-intensity (~ 400 kcal/d, 5d/wk) aerobic exercise for 16 months, significant weight loss (~ 5 kg) only occurred in men [15].

Aerobic Plus Resistance Exercise Alone

Stewart et al. [16] studied aerobic exercise (treadmill, cycling, and stair stepper) plus resistance training versus control. Aerobics combined with resistance training not only caused significant weight loss but improved fitness, preserved lean mass, decreased high density lipoprotein (HDL) cholesterol, and decreased total and abdominal fat (independent of weight loss). However, in another study, aerobic exercise plus resistance training decreased body fat and increased lean mass but did not cause weight loss [17].

Intensity of Aerobic Exercise

There is some evidence that intensive exercise is more effective in achieving weight loss than less intensive exercise. For instance, achieving 3000-3500 kcal/wk of energy expenditure was significantly more effective than achieving only 700-800 kcal/wk [18]. In a study by Donnelly et al. [19] continuous brisk walking (3 days/week, 30 minutes, 60-75% maximum heart rate) not only increased aerobic capacity more than intermittent brisk walking (two 15 minute sessions separated by 2 hours, 5 days/week, 50-65% maximum heart rate) but also caused a statistically significant 2.1% weight loss not seen in the other group. These data suggest that the intensity and duration of exercise may be important variables when weight loss is desired. The STRRIDE study randomized subjects to exercise (cycle ergometers, treadmills, and elliptical trainers) of high amount/vigorous intensity, low amount/vigorous intensity, low amount/moderate intensity, and

control. High amount/vigorous intensity was significantly superior to the other groups in the achievement of weight loss and loss of fat mass [20]. Energy expenditure via walking (2500 kcal/week) resulted in greater weight loss at 6 months and better maintenance of weight loss at 12 and 18 months as compared to energy expenditure of 1000 kcal/week via standard obesity behavior therapy. It should be noted that the 2500 kcal/wk group was encouraged by social support, coaching, and monetary compensation [21].

On the contrary, there is also evidence that high intensity exercise is not superior to moderate exercise in terms of weight loss [22]. Both land treadmill and underwater treadmill exercise improved aerobic capacity and caused equivalent weight loss; only underwater treadmill increased lean body mass [23]. In a dose response study of treadmill walking, there was no difference in weight loss between vigorous intensity/high duration, moderate intensity/moderate duration, vigorous intensity/moderate duration, and moderate intensity/high duration exercise [24]. Another study found that low volume/moderate intensity was equivalent to high volume/low intensity exercise [25]. As opposed to the previously cited study [19], Macera et al. [26] found that continuous exercise (20 to 40 min, 5 days/week) was no different than short bout exercise (10 min at a time, 5 days a week) in terms of weight loss. A study of the dose-response relationship in exercise randomized subjects to energy expenditure of 4 kcal/kg/wk, 8 kcal/kg/wk and 12 kcal/kg/wk. The 4 kcal/kg/wk and 8 kcal/kg/wk groups lost weight as expected; however, the 12 kcal/kg/wk fell short of expectation [27].

Aerobic Exercise vs. Diet

There are several studies which directly compare aerobic exercise to diet. In two studies by the CALERIE team, 12 months of aerobic exercise was shown to be equally effective as diet in effecting weight loss [28,29]. In the study of Hofer et al. [28] the goal of the exercise intervention was to induce an energy deficit identical to that achieved

by diet; this was done by increasing daily energy expenditure through physical activity without changing caloric intake in the exercise group. Both exercise and diet decreased oxidative stress. In the study of Weiss et al. [29], participants were given exercise energy expenditure prescriptions on a weekly basis again to match the energy deficit achieved by diet. In another 12-month study from this group, not only was exercise as effective as calorie restriction, but lower extremity muscle size and strength and aerobic capacity were better preserved with exercise [30]. In a shorter-term study (2 months in duration), by Tsai et al. [31] although diet was more effective in inducing weight loss than exercise (walking, jogging, swimming, bicycling), it was less effective in reducing body fat and maintaining lean body mass. Putting these data together, it appears that long-term exercise may be as beneficial as diet in effecting weight loss providing that energy deficit is the same, and although short-term exercise may not be as effective in reducing weight, it may be superior in maintaining lean body mass.

Aerobic Exercise Plus Diet vs. Diet Alone

As mentioned in the previous sections, it appears that, contrary to some common perceptions, exercise alone, if carried out for a sufficient length of time and prescribed to assure comparable energy deficit, can be as effective as diet in reducing weight. A different question is whether there is an additional benefit of combining exercise and diet as compared to diet alone.

In the CALERIE study, 48 overweight volunteers were randomly assigned to four groups: control (100% of energy requirements), 25% calorie restriction, 12.5% calorie restriction +12.5% energy expenditure through structured exercise, or 15% weight loss by a low-calorie diet followed by weight maintenance for 6 months (LCD) [32]. The diet plus exercise group did not lose more weight than the diet group alone. However, addition of exercise improved insulin sensitivity. It should also be noted that the dietary intervention was less stringent in the combined exercise/diet group. In a follow-up report, similar data with respect to weight loss were reported, but it was noted that calorie restriction decreased physical activity, suggesting a potential mechanism by which calorie restriction can cause large inter-individual variability in the rates of weight loss [33]. In a 40-week study, there was a substantial (~ 15 kg) weight loss with both diet alone and diet with cycling, walking, and aqua jogging but only diet and exercise prevented the post-diet decline in fat oxidation [34]. In two studies in which exercise was carried out for 6 months, calorie restriction with and without exercise were shown to be equivalent in terms of weight loss but only exercise decreased diastolic blood pressure and increased insulin sensitivity [35]; similarly, calorie restriction alone was equivalent to calorie restriction plus exercise in terms of weight loss but exercise had added benefits of decreased LDL and decreased diastolic blood pressure [36]. Other studies, albeit of shorter duration, also reported no difference in weight loss between the diet plus exercise and diet groups [37-39]. However, exercise increased aerobic capacity and mitochondrial function [37].

However, some studies have shown that diet plus aerobic exercise can result in greater weight loss than diet alone [40]. The American Heart Association (AHA) step 2 diets plus walking or jogging on a treadmill produced greater weight loss and better insulin sensitivity than the AHA step 1 diet plus stretching [41]. Interestingly, in one study of diet and aerobic exercise vs. diet alone, subjects with intra abdominal fat obesity lost more weight with combined therapy whereas subjects

with subcutaneous fat obesity did not [42]. Thus, the type of obesity may affect the response to the addition of exercise. Another factor may be gender, as men lost more weight with addition of exercise to diet than did women [43].

Addition of exercise has increased weight loss when added to certain diets. In the ENCORE study, DASH alone produced only modest weight loss (-0.3 kg) whereas DASH plus exercise (biking, walking, jogging) produced significantly greater weight loss (-8.7 kg); both DASH alone and DASH plus exercise lowered blood pressure [44]. This finding was duplicated in another study, in which it was also reported that exercise improved cognition [45]. Finally, high protein plus aerobic exercise was superior to caloric restriction and aerobic exercise in inducing weight loss [46]. In this study, the high protein groups experienced reduced total and LDL cholesterol and triglycerides.

Various Intensity of Aerobic Exercise Plus Diet vs. Diet Alone

Most studies find that, when combined with diet, intensity of aerobic exercise is not an important determinant of weight loss. In one study, dietary restriction alone, diet with low intensity exercise, or diet with high intensity exercise demonstrated identical weight loss [47]. In a larger study, caloric restriction, caloric restriction plus moderate intensity treadmill exercise, and caloric restriction plus vigorous intensity treadmill exercise all produced equivalent weight loss with varying increases in aerobic capacity [48]. Weight loss, decreased fat mass, decrease in percent fat, waist and hip girths were all achieved equally well with diet alone, diet plus low intensity exercise (walking on a treadmill, 20-55 min at 45-50% maximum heart rate), and diet plus high intensity exercise (walking on a treadmill, 30 min at 70-75% of maximum heart rate) [49]. Bond Brill reported that addition of walking exercise to diet did not significantly increase weight loss, and 300 minutes of weekly exercise was not better than 150 minutes [50].

However, in one study, diet plus aerobic dance (350 kcal/session, 70-80% of maximal heart rate) caused greater weight loss, greater decrease in LDL, and greater increase in aerobic capacity than diet alone or diet plus walking (150 kcal/session, 40-50% of maximal heart rate) [51]. Since the type of exercise was different in the high intensity group, it is difficult to compare these findings to those cited above.

Resistance Exercise Plus Diet vs. Diet Alone

A number of studies show that the combination of resistance training plus caloric restriction does not increase weight loss compared to diet alone [52-56]. Resistance training did have some benefits, including an increase in insulin sensitivity and decreased LDL cholesterol [53] and decreased oxygen uptake [54]. Unlike the situation with aerobic exercise, DASH plus resistance training did not result in greater weight loss compared to DASH alone, but there was an increase in lean mass and strength [57]. Finally, a high protein diet plus resistance exercise caused somewhat greater weight loss than resistance exercise alone or high protein diet alone [58].

Aerobic and/or Resistance Exercise Plus Diet vs. Diet Alone

Janssen et al. [59] showed that diet (-1000 kcal/day), diet plus aerobic exercise, and diet plus resistance exercise produced equivalent weight loss, decreases in abdominal and visceral fat, and improvement in metabolic parameters. Similar results were obtained by other investigators utilizing an 800 kcal/day diet [60]. Hunter et al. [61] showed

that diet plus strength training, diet plus aerobic training (walking, jogging, treadmill), and diet without exercise all produced similar weight loss; however, only strength training maintained fat free mass, maintained strength, and did not decrease resting energy expenditure. Another study confirmed that neither aerobics alone nor aerobics plus resistance training when added to diet improved weight loss; however exercise did improve depression [62]. Finally, a comparison of four diet/exercise regimens (high protein/low carbohydrate, high protein/low carbohydrate plus exercise, low protein/high carbohydrate, low protein/high carbohydrate plus exercise) demonstrated that a high protein diet with or without exercise produced greater weight loss; although there was no increase in weight loss with the addition of exercise, exercise did decrease body fat and preserve lean body mass. In this study, exercise included five days a week of walking and two days a week of strength training [63].

Aerobic Exercise Plus Diet vs. Exercise Alone

Some studies have been designed to compare the combination of exercise and diet to exercise alone rather than to diet alone [64-69]. Not surprisingly, all of these studies have demonstrated superiority of the combination vs. exercise alone in achieving weight loss. Improvements in insulin sensitivity and metabolic syndrome occurred in both groups [64,66,69]. In one study, diet plus walking plus weight training caused an 18.8 lb weight loss whereas walking and weight training alone only reduced weight by 4 lbs [67]. In the largest of these studies, although weight loss was significantly greater in the diet plus aerobics group, fat mass decreased in both groups and lean mass increased only with exercise alone [68].

Aerobic Exercise of Various Intensity Plus Diet vs. Exercise Alone

In a single study designed in this fashion, there was no difference between high and low intensity exercise when combined with diet. As expected, there was a marked increase in weight loss (by ~ 10 kg) when diet was added to exercise [70]

Aerobic Exercise Plus Diet vs. Aerobic Exercise vs. Diet

The relative benefits of exercise, diet, and the combination on weight loss are probably best studied in 3-arm randomized trials. In a recent study directly comparing these three modalities, in which aerobic exercise consisted of 12 weeks of bicycling, jogging, treadmill, and stair stepping, weight loss was only effected if dietary intervention was included [71]. Similarly, diet alone or diet plus aerobics were equivalent and superior to exercise alone in causing weight loss, although exercise improved fitness and fat metabolism [72]. Some studies included a control arm as well. In one such study, both diet and the combination of diet and aerobics decreased weight, but exercise alone was similar to control [73]. In a larger, long-term study (one year), diet alone was as good as diet plus endurance exercise, circuit training, fast walking, or jogging in weight reduction as well as in reducing leptins [74].

Combined Aerobic/Resistance Exercise Plus Diet vs. Exercise vs. Diet

In the ADAPT study, which compared diet and exercise vs. either alone to non-specific lifestyle changes, the combined exercise plus diet and the diet alone groups lost a significant amount of weight; however, the exercise alone group was similar to the lifestyle control group [75].

Resistance Exercise Plus Diet vs. Resistance Exercise vs. Diet

In the single study performed, which included a control group, both the combination of diet plus resistance training and diet alone resulted in weight loss [76]. However, diet alone resulted in a decrease in lean body mass and global physical capacity score significantly improved in the resistance group vs. the control group.

Effects of Exercise With and Without Weight Loss

Ross et al. [77] compared the effects of exercise when weight was kept constant (by increasing calorie intake) and exercise in which weight loss was achieved. All participants followed a weight maintenance diet for a 4 to 5 week baseline period, with energy requirement adjusted to maintain body weight. The diet-induced weight loss group reduced the isocaloric diet by 700 kcal/d during the treatment period to achieve a weekly weight loss of approximately 0.6 kg. To lose the same amount of weight, participants in the exercise-induced weight loss group were asked to maintain the isocaloric diet for the duration of the treatment period and to perform exercise that expended 700 kcal/d. Participants assigned to exercise without weight loss consumed enough calories to compensate for the energy expended during the daily exercise sessions. Both of the weight loss groups lost an equivalent amount of weight (~ 7.5 kg). Exercise-induced weight loss reduced total fat and improved cardiovascular fitness more than diet-induced weight loss. In addition, exercise without weight loss also reduced both abdominal and visceral fat. In a follow-up report, this group reported that weight loss results in a decrease in circulating leptin, and exercise, independent of its effects on weight loss, did not affect leptin secretion [78].

Exercise has many cardiovascular benefits even without weight loss, such as decreases in lipids, inflammation, and blood pressure, incidence of insulin resistance/diabetes, health care costs, hospitalization, and psychiatric diseases such as depression. Differences in known risk factors explained a large proportion (59.0%) of the observed benefits of exercise. Body mass index (BMI) changes were only responsible for 10% of the reduced risk [79]. Even moderate levels of physical activity (600 kcal/wk) lower the risk of clinically important cardiovascular events. In a cohort of men with diabetes, low fitness level was associated with increased risk of cardiovascular mortality independent of weight category (normal weight, overweight, and class 1 obese weight categories) [80]. Calorie restriction with and without exercise were shown to be equivalent in terms of weight loss but only exercise decreased diastolic blood pressure and increased insulin sensitivity [35]. Similarly, caloric restriction alone was equivalent to calorie restriction plus exercise in terms of weight loss but exercise had added benefits of decreased LDL and decreased diastolic blood pressure [36]. A decrease in health care costs has also been noted [13]. Thus, exercise, even in the absence of weight loss, has many metabolic and cardiovascular benefits, including a decrease in insulin resistance, decrease in lipids, decrease in blood pressure, and decrease in inflammation.

Weight Maintenance After Weight Loss

The difficulty of maintaining weight reduction after initial weight loss has been well documented [81]. After induction of weight loss by a very low energy diet (VLED), exercise in the form of walking, resistance training and control were equally incapable of weight maintenance [82]. Lejeune et al. [83] studied VLED with or without exercise (cycling on ergometer, walking, aquajogging) and found equivalent weight loss

Table 2: Our recommendations for achieving and maintaining weight loss based on the literature and existing guidelines.

1	A daily dietary caloric deficit of 500-1000 kcal (30% of the calories should come from fat, 20% from protein, and 50% from carbohydrates) will result in weight loss
2	Moderate intensity exercise (50-80% of maximal heart rate) for 30-60 minutes 5 days/week (total of 150-300 minutes of exercise per week) will result in an energy expenditure of ~ 1500-3000 kcal/wk and may result in weight loss. A combination of endurance and resistance exercise is preferred.
3	Greater energy expenditure by either increasing intensity of duration exercise will result in weight loss providing dietary caloric intake is kept constant. However, weight loss is best achieved by a combination of diet and exercise.
4	Moderate aerobic exercise for > 150 minutes per week can allow for successful weight maintenance after weight loss is achieved providing caloric intake is kept constant.
5	Supervised interventions are generally more effective at achieving weight loss. Most studies of aerobic exercise have used modalities of walking or jogging on a treadmill, stationary bike, stair stepping, aquatic exercises, and swimming. Addition of resistance training bestows the added benefits of maintenance of lean body mass and increasing strength. Squats, leg extension, leg curl, elbow flexion, triceps extension, lateral pull-down, bench press, military press, lower back extension, and bent leg sit-ups are some common strength training exercises. Exercise improves metabolic and cardiovascular fitness even in the absence of weight loss.

which was mostly regained in the weight maintenance phase. In these studies, VLEDs were used to induce weight loss; caloric intake was subsequently increased.

Borg et al. [84] induced weight loss through dietary restriction for 2 months and maintained it for 6 months through supervised walking or resistance training. After 23 months of unsupervised follow-up, lost weight had been regained. Weight maintenance by walking (40 weeks of supervised walking followed by two years of unsupervised follow up) after weight loss via 12 weeks of diet was unsuccessful [85].

The LEARN intervention (Lifestyle, Exercise, Attitudes, Relationships, and Nutrition; low in fat, high in carbohydrate, based on national guidelines), which encouraged treadmill time and increases in leisurely physical activity, resulted in significant weight loss with 63% regain at one year. However, there was persistence in decreases in fat mass, body fat, blood pressure, and cholesterol [86]. This study underscores the importance of increased activity on health even if weight is regained.

Intensive lifestyle changes, which included > 150 min/wk of moderate aerobic exercise, in the Diabetes Prevention Program allowed for successful weight maintenance over five to seven years after initial weight loss and also resulted in a decreased incidence of diabetes [87]. Finally, it has been shown that lower physical activity and higher calorie intake on weekends hinders overall attempts at weight loss [88].

Most studies on weight regain have focused on aerobic exercise. However, a recent randomized study suggests that resistance exercise, although it does not prevent weight regain, effectively decreases adiposity in premenopausal women [89].

Existing Guidelines

The National Heart, Lung, and Blood Institute (NHLBI) published dietary and physical activity guidelines in 1998. In order to effect and maintain weight loss, the NHLBI recommends 30-45 minutes of moderate intensity physical activity 3-5 days/week [90]. The American College of Sports Medicine recommends moderate intensity physical activity between 150-250 minutes/week (~1200-2000 kcal/week) to prevent weight regain, but concede that this will likely produce only modest initial weight loss unless combined with moderate diet restriction. Greater exercise (>250 minutes/week) can result in clinically significant weight loss [91]. Finally, The US Dept of Health and Human Services and The US Dept of Agriculture have published physical activity guidelines which include: 1) 30 minutes of moderately intense daily physical activity may be effective in cardiovascular risk reduction, 2) 60 minutes of moderate to vigorous daily physical activity

may be effective in the prevention of weight gain, and 3) 60-90 minutes of moderate daily physical activity may be effective in sustaining weight loss [92] (Table 2).

Summary

It is clear that weight loss can occur through either a reduction in caloric intake (diet) or an increase in energy expenditure (exercise). In this review, we have focused on the role of exercise per se in reducing and maintaining weight. Most studies suggest that aerobic exercise alone can achieve only a modest (< 3%) weight loss. However, a few studies have reported that aerobic exercise alone can result in up to ~10% weight loss, similar to diet alone. In these studies, care was taken to match the energy deficit in the two groups, suggesting that it is energy deficit that leads to weight loss, no matter how it is achieved. Combining diet with aerobic exercise usually does not increase weight loss over that achieved by diet alone. However, the outcome of this approach probably depends on the degree of caloric restriction imposed, with greater efficacy of combined therapy seen when only modest rather than severe dietary restriction is employed. The combination of diet plus aerobic exercise is clearly more effective than exercise alone. Aerobic exercise can help prevent weight regain. Resistance exercise has not been shown to either cause weight loss or prevent regain of weight.

Since it has been demonstrated that substantial weight reduction can indeed occur with exercise in the absence of diet, why is this approach generally not considered very effective? It is likely that a major factor is the type and intensity of exercise prescription and possibly compliance with the prescription. Another important consideration is the tendency of some individuals to compensate for increased energy expenditure by increasing calorie intake. Studies have documented that a subset of the population respond to exercise with increased energy intake; these people have been called “compensators” [93,94]. Indeed, exercise seems to produce less weight loss than predicted due to a compensatory increase in energy intake [95]. For effective weight loss to occur with exercise alone, this phenomenon of compensation should be curbed by behavioral or other strategies.

Finally, both aerobic and resistance exercise have been shown to decrease abdominal and visceral fat, increase lean body mass, and improve metabolic and cardiovascular fitness even in the absence of weight loss.

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