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REVIEW

A dose–response relation between aerobic exercise and visceral fat reduction: systematic review of clinical trials

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Objective: It has been suggested that exercise has preferential effects on visceral fat reduction. However, the dose–response effect remains unclear because of limited evidence from individual studies. The purpose of this study was to systematically review the current literature to establish whether reduction of visceral fat by aerobic exercise has a dose–response relationship.
Methods: A database search was performed (PubMed, 1966–2006) with appropriate keywords to identify studies exploring the effects of aerobic exercise as a weight loss intervention on visceral fat reduction. Visceral fat reduction was expressed as the percentage of visceral fat change per week (%ΔVF/w). The energy expenditure by aerobic exercise was expressed as $\sum$(metabolic equivalents × h per week (METs · h/w)).
Results: Nine randomized control trials and seven non-randomized control trials were selected. In most of the studies, the subjects performed aerobic exercise generating 10 METs · h/w or more. Among all the selected groups (582 subjects), visceral fat decreased significantly ($P<0.05$) in 17 groups during the intervention, but not in the other 4 groups. There was no significant relationship between METs · h/w from aerobic exercise and %ΔVF/w in all the selected groups. However, when subjects with metabolic-related disorders were not included (425 subjects), METs · h/w from aerobic exercise had a significant relationship with %ΔVF/w ($r=-0.75$). Moreover, visceral fat reduction was significantly related to weight reduction during aerobic exercise intervention, although a significant visceral fat reduction may occur without significant weight loss.
Conclusion: These results suggest that at least 10 METs · h/w in aerobic exercise, such as brisk walking, light jogging or stationary ergometer usage, is required for visceral fat reduction, and that there is a dose–response relationship between aerobic exercise and visceral fat reduction in obese subjects without metabolic-related disorders.
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Keywords: central obesity; metabolic-related disorder; clinical trial; METs · h/w; aerobic exercise

Introduction

Obesity is a widespread and growing problem around the world, with a population of more than 1 billion overweight adults, of which at least 300 million are clinically obese.[1] Excess adipose tissue, especially visceral adipose tissue, releases inflammatory cytokines that increase insulin resistance in skeletal muscles.[2] Furthermore, central obesity, which is defined as a state of excessive visceral fat accumulation, is associated with a decreased production of adiponectin, an adipose-specific molecule with anti-diabetic, anti-atherosclerotic and anti-inflammatory functions.[3] In recent years, central obesity has been defined as a predominant risk factor for metabolic syndrome,[4,5] a condition for which a collection of cardiovascular biomarkers are correlated with an increased probability of heart disease, stroke and diabetes. These biomarkers include high plasma triacylglycerol, low high-density lipoprotein cholesterol, high plasma blood glucose, and high blood pressure.

Numerous studies have investigated the effects of diet, drugs and exercise on reduction in weight, total fat mass and/or visceral fat mass.[6,7] Generally, diet therapy is the most effective method for decreasing weight and total fat mass rapidly, because it easily results in a negative energy balance, as compared with exercise or drug therapies.[8] However, it has been suggested that aerobic exercise has specific effects on decreasing visceral fat mass as it may lead

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to increased sympathetic tonus, thereby increasing lipolysis especially in abdominal fat.[9] For that reason, exercise therapy is expected to be one of the most effective methods for improving central obesity.

Several investigators have reviewed the effects of physical activity (or aerobic exercise) on the reduction in body weight, total fat mass and/or visceral fat mass.[10–14] Ross and Janssen[13] suggested that physical activity was associated with a reduction of total fat, in a dose-dependent manner, within 16 weeks. However, the effects of physical activity on visceral fat reduction were unclear. Kay and Fiatarone Singh[10] also reviewed the influence of physical activity on abdominal fat. Although they concluded that physical activity had a beneficial influence on visceral fat reduction, a dose–response relationship was not examined. After Ross and Janssen[13] reviewed the dose–response relationship between physical activity and visceral fat reduction, several papers were published.[15–25] In the present study, we systematically reviewed the literature to clarify whether aerobic exercise for weight loss is positively associated with visceral fat reduction, and to determine the minimal amount of aerobic exercise required to achieve visceral fat reduction.

Materials and methods

Data collection

A PubMed (1966–May 2006) database search was performed to identify studies examining the effects of aerobic exercise as a weight loss intervention on visceral fat reduction using the following keywords: (physical activity, exercise, (physical and training), sports, physical education, or physical fitness) and (((abdominal, abdomen, or visceral) and (fat or adipose)) or ((waist, abdominal, or abdomen) and (girth or circumference))). The searches were limited to humans and clinical trials. Several studies were selected from reference lists cited in the selected studies.

Study selection

Studies were selected if they met the following criteria: (1) they involved clinical trials (that is, randomized controlled or non-randomized); (2) they must have included at least one group of aerobic exercise alone; (3) the age of subjects was between 18 and 65; (4) subjects had a mean body mass index (BMI) of $<25\,kg/m^2$, or a mean BMI of $\geqslant 25\,kg/m^2$, but with a small amount of visceral fat (if the mean plus s.d. of the visceral fat area (VFA) in a group was less than $100\,cm^2$ (in which case, only 16% of the subjects are estimated to have over $100\,cm^2$ of visceral fat), that group was considered not to need to reduce visceral fat) were excluded;[15,26–28] (5) the studies used computed tomography (CT) or magnetic resonance imaging (MRI) as a measurement of visceral fat; (6) the subjects were instructed to maintain energy intake before and during the intervention; and (7) the exercise amount and change in visceral fat could be calculated by the procedures described. Only groups that were instructed to practice aerobic exercise without weight loss by additional energy intake, which corresponded to the increased energy expenditure (EE) by prescribed aerobic exercise, were included.[22,29] We excluded data from studies using drug therapy, but included data from their control groups with aerobic exercise therapy alone.[17] Resistance training groups were also excluded, because calculation of their EE is difficult and the mechanism of decreasing visceral fat during resistance training may be different to that for aerobic exercise. Furthermore, if we identified two studies that used approximately the same research subjects, the study containing the least amount of information was excluded. Within these criteria-matched studies, groups that were not instructed to practice exercise during the intervention were employed as the control group for the degree of visceral fat reduction compared to the aerobic exercise groups.[15,19,21–23,29] Eligible studies were reviewed independently by two of the authors to assess inclusion suitability and data extraction accuracy.

Conversion to %ΔVF/w

In the selected studies, several units (for example, cm^2, cm^3, kg) were used for expressing the quantity of visceral fat. VFA was measured at either the 3rd-4th lumbar or 4th-5th lumbar vertebrae. Kvist *et al*.[30] and Shen *et al*.[31] have shown a strong correlation between the 4th-5th lumbar VFA, or the 3rd-4th lumbar VFA, and total visceral fat volume, respectively. However, they have also reported that the actual values do not accurately match between the 4th-5th and 3rd-4th lumbar VFA as well as VFA measured by CT vs MRI in the same region.[32] Therefore, we converted the visceral fat amount reported in each study to a percentage of visceral fat change per week (%ΔVF/w), which enabled us to directly compare the groups.

Conversion to METs·h/w

Aerobic exercise amounts during the intervention were converted to $\sum$(metabolic equivalents $\times$ h per week (METs·h/w)), which adjusted the EE for body size. Weekly EE by aerobic exercise during the intervention was acquired using the following criteria: (1) if an actual value was shown, that value was used;[22,29] (2) if an estimated or instructed value by authors was stated, that value was used;[16,19,24] (3) if values were not expressed,[9,15,17,18,20,21,23,25,27,33,34] EE was calculated using exercise intensity, exercise time, exercise frequency, body weight and VO2max/VO2peak as follows:[35]

$$\begin{aligned} \text{EE (kcal/week)} &= (V \times I)/1000 \times 5 \times F \times T \times W \text{ or} \\ &= (3.5 + (V - 3.5) \times I')/1000 \times 5 \times F \times T \times W, \end{aligned}$$

where 3.5 ml/kg/min is resting metabolic rate, 5 kcal/l is EE for oxygen consumption per liter, V is VO2max or VO2peak (ml/kg/min), I is exercise intensity (for example, if exercise was done by 70%VO2max, the value is 0.7.), I′ is exercise intensity (if exercise was done by 70% heart rate reserve, the value is 0.7.), F is exercise frequency (times/week), T is exercise time (min/session) and W is body weight (kg).

For the exercise intensity and time used in the EE calculation, the values decided by authors in each study were used. For studies that gradually increased exercise intensity and time, final target values were used. In cases where only the number of daily steps was shown,[20] 100 steps was calculated as one minute of exercise,[36] and intensity was assumed to be that for normal walking (3.5 METs).[37] If only the percentage of the heart rate maximum (%HRmax) for exercise intensity was shown, the exercise intensity by %HRmax was converted into exercise intensity by percentage of heart rate reserve. For the EE calculation, we did not include exercise volume during warm-up and cool-down (for example, stretching) periods, since several studies described this information, while others did not. Following these calculations, EE by aerobic exercise/week in each study was converted to METs·h/w using the following equation:[35]

$$\mathrm{METs} \cdot \mathrm{h/w} = \mathrm{EE}/((\mathrm{W} \times 3.5 \times 5/1000) \times 60),$$

where W is body weight (kg).

Data analysis

The amount of visceral fat decrease in each group was considered to be statistically significant if the *P*-value was less than 0.05. Correlations between METs·h/w and %ΔVF/w in selected groups, with or without the metabolic-related disorders, such as type 2 diabetes and dyslipidemia, were assessed by weighted Pearson's correlation coefficients (*r*) for the number of subjects. The Kruskal–Wallis test and the Mann–Whitney's *U*-test for *post hoc* comparisons were applied for comparing the mean %ΔVF/w values between the control and exercise groups that had been divided into tertiles by METs·h/w amount. We also analyzed these correlations in several categorized groups (for example, groups with only women or men, and groups with more or less than 16-week interventions). Furthermore, the relationship between METs·h/w and %ΔWeight/w, and between %ΔVF/w and %ΔWeight/w, were expressed by weighted *r* values for the number of subjects. Because %ΔVF/w and METs·h/w were calculated from mean values in each study, only these variables and the number of subjects were available for analyses. Therefore, specific analytic programs for meta-analysis could not be used, although the number of subjects was weighted for.

Results

Two hundred and fifty-five studies were selected from PubMed (1966–May 2006) with the appropriate keywords. From these papers, plus the added references collected from the cited literature, nine randomized control trials (RCT)[9,15,16,19,22–24,29,33] and seven non-randomized control trials (nRCT)[17,18,20,21,25,27,34] were selected according to our criteria (Table 1). The studies included 13 RCT groups and 8 nRCT groups examining solo aerobic exercise interventions (Table 2). The subjects of six groups in four of the studies were diagnosed as having metabolic-related disorders.[9,16,24,33] In all of the selected studies, the calculated METs·h/w ranged from 5.9 to 47.1, and the %ΔVF/w ranged from −6.062 to 0.078, including four groups that did not show any significant changes in VF during the intervention period.

Correlation coefficients between METs·h/w and %ΔVF/w are shown in Figure 1. METs·h/w had a significant correlation with %ΔVF/w in the groups that did not include subjects with metabolic-related disorders ($r = -0.75$), although there was no significant correlation when all groups were selected ($r = -0.28$). The selected groups without metabolic-related disorders were divided into tertiles by their METs·h/w amount. %ΔVF/w values in the 1st, 2nd and 3rd exercise groups were significantly higher than that of the control group, although these exercise groups were not significantly different from each other (Figure 2). Significant correlations were also observed in the women-only group, while there was no significant correlation in the men-only group (Table 3). Groups were also categorized by their duration of either shorter or longer than the 16-week intervention period (short-term or long-term intervention duration). Only in the short-term intervention groups, without metabolic-related disorder subjects, did METs·h/w exhibit a significant correlation with %ΔVF/w ($r = -0.81$).

For analysis of the relationship between %ΔWeight/w and METs·h/w or %ΔVF/w, the two groups[22,29] that did aerobic exercise without weight loss, were excluded. As a result, METs·h/w had a significant correlation with %ΔWeight/w in all of the selected groups ($r = -0.79$), as well as the groups without metabolic-related disorder subjects ($r = -0.87$) (Figure 3). Furthermore, %ΔVF/w had a strong relationship with %ΔWeight/w in the groups not including metabolic-related disorder subjects ($r = 0.93$), even though there was a significant correlation in all the selected groups ($r = 0.64$) (Figure 4).

Discussion

Dose–response relationship between aerobic exercise and visceral fat reduction

The present study indicates aerobic exercise volume has a dose–response relationship with visceral fat reduction in subjects without metabolic-related disorders. There are several excellent reviews for investigating the relationship between diet and exercise interventions and weight and/or visceral fat reduction.[6,7,10–14] Ross and Janssen[12] suggested that physical activity with or without weight loss was associated with a reduction in visceral adipose tissue, although insufficient evidence limited their reaching a definitive conclusion. Based on this research, Ross and Janssen[13] also reviewed dose–response relationships between

Table 1 Characteristics of selected studies in this paper

Reference	*RCT or nonRCT*	*Intervention*		*Subject*			
		Duration	*Type of group*	*Gender*	n	*Age (year)*	*Specific characteristics*
Despres *et al.*[34]	NonRCT	6 months	A	F	13	38.8±5.3	—
Donnelly *et al.*[15]	RCT	16 months	A	F	25	24±5	—
			C	F	18	21±4	—
			A	M	16	22±4	—
			C	M	15	24±4	—
Green *et al.*[17]	nonRCT	20 weeks	Dr+A	F	30	56.4±5.4	Estrogen replacement therapy (ERP), postmenopausal
			A	F	18	52.3±6.3	Non ERP, postmenopausal
Halverstadt *et al.*[18]	nonRCT	24 weeks	A	M+F	83 (34+49)	57.9±0.6	Combined LIPG (endothelial lipase gene) genotype CC and CT/TT
Irwin *et al.*[19]	RCT	12 months	A	F	87	61.0 (59.6–62.5)	Menopausal
			C	F	86	60.6 (59.1–62.1)	Menopausal
Miyatake *et al.*[20]	nonRCT	1 year	A	M	31	(32–59)	—
Park *et al.*[21]	nonRCT	24 weeks	C	F	10	43.1±1.67	—
			A	F	10	42.2±1.91	—
			A+R	F	10	43.4±1.04	—
Ross *et al.*[22]	RCT	14 weeks	Di	F	15	43.9±4.9	—
			A	F	17	43.2±5.1	—
			A[a]	F	12	41.3±7.2	—
			C	F	10	43.7±6.4	—
Ross *et al.*[29]	RCT	12 weeks	Di	M	14	42.6±9.7	—
			A	M	16	45.0±7.5	—
			A[a]	M	14	44.7±7.6	—
			C	M	8	46.0±10.9	—
Schwartz *et al.*[27]	nonRCT	27 weeks	A	M	13	28.2±2.4	—
			A	M	15	67.5±5.8	—
Short *et al.*[23]	RCT	16 weeks	A	M+F	65	40.5±1.1	—
			C	M+F	37	40.7±1.4	—
Wilund *et al.*[25]	nonRCT	12 weeks	A	M+F	16 (6+10)	56±1	CETP (cholesteryl ester transfer protein) genotype (B1B1)
			A	M+F	14 (8+6)	56±1	CETP (cholesteryl ester transfer protein) genotype (B1B2)
Boudou *et al.*[33]	RCT	8 weeks	A	M	8	42.90±5.20	Type 2 diabetics
Giannopoulou *et al.*[16]	RCT	14 weeks	Di+A	F	11	57.4±1.7	Diabetics, menopausal
			Di	F	11	58.5±1.7	Diabetics, menopausal
			A	F	11	55.5±1.7	Diabetics, menopausal
Mourier *et al.*[9]	RCT	8 weeks	A	M+F	10	45±2	Diabetics
			C	M+F	11	46±3	Diabetics
Slentz *et al.*[24]	RCT	32 weeks	A[b]	M+F	40	54.0±5.5	Dyslipidemia, postmenopausal
			A[b]	M+F	46	53.0±7.0	Dyslipidemia, postmenopausal
			A[b]	M+F	42	51.5±5.3	Dyslipidemia, postmenopausal
			C	M+F	47	52.3±7.65	Dyslipidemia, postmenopausal

Abbreviations: A, aerobic exercise therapy; A[a], aerobic exercise therapy without a weight loss; A[b], three different types of aerobic exercise therapy in the study; C, control; Di, diet therapy; Dr, drug therapy; F, female subjects; M, male subjects; *n*, number of subjects (number of males+number of females); R, resistance training therapy; RCT, randomized control trials. Age expressed by mean±s.d. (range).

Table 2 Summary of aerobic exercise groups in this paper

Reference	Subjects				Aerobic exercise	
	Gender	Age (yr)	BMI (kg/m²)	% fat (%)	Session time and intensity	Mode or used exercise instrument
Despres *et al.*[34]	F	38.8	34.5	47.0	90 min, 55%HRmax	Walking
Donnelly *et al.*[15]	M	22	29.7	28.3	45 min, 70%VO2max	Treadmill
Green *et al.*[17]	F	56.4	29.3	40.8	75%VO2max	Ergometer
Halverstadt *et al.*[18]	M+F	57.9	—	36.0	70%VO2max	—
Irwin *et al.*[19]	F	61	30.5	47.6	Mean 81%HRmax	Treadmill walking and stationary bicycling in Lab, and aerobic exercise (e.g. walking, aerobics, bicycling) at home
Miyatake *et al.*[20]	M	32–59	28.6	29.3	7012→8839 steps/day (plus 1827 steps/days)	Normal walking
Park *et al.*[21]	F	42.2	25.3	42.2	60–70%HRmax	Fast walking
Ross *et al.*[22]	F	43.2	32.8	—	Mean 80%HRmax	Brisk walking or light jogging on treadmill
	F	41.3	32.9	—	Mean 82%HRmax	Brisk walking or light jogging on treadmill
Ross *et al.*[29]	M	45	32.3	—	Mean 77%HRmax	Brisk walking or light jogging on treadmill
	M	44.7	31.3	—	Mean 77%HRmax	Brisk walking or light jogging on treadmill
Schwartz *et al.*[27]	M	67.5	26.2	24.7	45 min, 85%HRreserve	Walking/jogging
Short *et al.*[23]	M+F	40.5	26.6	31.4	80%HRmax	Stationary bicycling
Wilund *et al.*[25]	M+F	56	—	38.0	40 min, 70%VO2max	—
	M+F	56	—	34.0	40 min, 70%VO2max	—
Boudou *et al.*[33]	M	42.9	28.3	—	1) 2 times/week, 45 mi n, 75%VO2peak, 2) 1 time/week, 10 min, 85%VO2peak, and 12 min, 50%VO2peak	Ergometer
Giannopoulou *et al.*[16]	F	55.5	35.9	—	60 min, 65–70%VO2max, energy expenditure: 250.95–298.75 kcal/session	Walking
Mourier *et al.*[9]	M+F	45	30.4	24.4	1) 2 times/week, 45 min, 75%Vo2peak, 2) 1 time/week, 10 min, 75%VO2peak, and 12 min, 50%VO2peak	Ergometer
Slentz *et al.*[24]	M+F	54	29.8	—	40–55%VO2max, 14 kcal/kg/wk (12 miles/week)	Treadmill walking
	M+F	53	29.7	—	65–80%VO2max, 14 kcal/kg/wk (12 miles/week)	Treadmill jogging
	M+F	51.5	29.1	—	65–80%VO2max, 23 kcal/kg/wk (20 miles/week)	Treadmill jogging

Table 2 (Continued)

Aerobic exercise					Weight						Visceral fat							
VO2max (baseline)	*Frequency (times/ week)*	*Time (min/ session)*	*Energy expenditure (kcal/week)*	*METs·h/w*	*Before (kg)*	*After (kg)*	*Δ (kg)*	*%Δ (%)*	*%Δ (%/ week)*	*Sig[1]*	*Before*	*After*	*Δ*	*Unit*	*%Δ (%)*	*%Δ (%/ week)*	*Sig[2]*	*Method*
	4–5	90	1913	20.2	90.0	86.3	−3.7	−4.11	−0.069	*	124.7	121.3	−3.4	cm^2	−2.73	−0.045	NS	CT
	5	45	3300	33.4	94.0	85.2	−8.8	−9.36	−0.136	*	97.9	75.5	−22.4	cm^2	−22.88	−0.334	*	
21.3±4.0	3	50	920	11.4	76.8	76.9	0.1	0.13	0.007	NS	121.6	117.8	−3.8	cm^2	−3.13	−0.156	NS	CT
25.2±0.5	3	40	853	10.1	80.6	79.5	−1.1	−1.36	−0.057	*	127.8	113.4	−14.4	cm^2	−11.27	−0.469	*	CT
20.1 (19.3–20.9)	3.5	176/week	1051	12.3	81.6	—	−1.3	−1.59	−0.031	*	147.6	—	−8.5	cm^2	−5.76	−0.113	*	CT
	7	18.27	507	5.9	82.0	79.0	−3.0	−3.66	−0.091	*	108.7	87.0	−21.7	cm^2	−19.96	−0.499	*	CT
34.2±3.2	6	60	1908	28.5	63.7	59.0	−4.7	−7.38	−0.307	*	195.0	112.4	−82.6	cm^2	−42.36	−1.765	*	CT
	7	64	3668 (524±52/session)	40.2	86.9	80.9	−6.0	−6.90	−0.493	*	2.3	1.6	−0.7	kg	−30.43	−2.174	*	MRI
	7	63	3619 (517±58/session)	39.1	88.1	87.6	−0.5	−0.57	−0.041	NS	2.2	1.8	−0.4	kg	−18.18	−1.299	*	
	7	60.4	4886 (698/session)	45.8	101.5	94.0	−7.5	−7.39	−0.616	*	186.0	134.0	−52.0	cm^2	−27.96	−2.330	*	MRI
	7	63.3	4844 (692/session)	47.1	97.9	97.4	−0.5	−0.51	−0.043	NS	191.0	159.0	−32.0	cm^2	−16.75	−1.396	*	
29.1±4.4	4.44±0.43	45	2009	24.0	79.6	77.1	−2.5	−3.14	−0.131	*	144.5	109.0	−35.5	cm^2	−24.57	−1.024	*	
25.6 (40.5±1.1/ FFM)	4	40	1166	14.0	79.2	78.7	−0.5	−0.63	−0.039	*	133.0	124.0	−9.0	cm^2	−6.77	−0.423	*	CT
25±1	3	40	882	10.0	84.0	83.2	−0.8	−0.95	−0.079	NS	146.0	130.0	−16.0	cm^2	−10.96	−0.913	*	CT
26±1	3	40	863	10.4	79.0	77.8	−1.2	−1.52	−0.127	*	128.0	109.0	−19.0	cm^2	−14.84	−1.237	*	
23.45±3.60	3	1) 45, 2) 22	836	9.2	86.9	85.0	−1.9	−2.19	−0.273	NS	153.3	84.2	−69.1	cm^2	−45.06	−5.632	*	MRI
	3–4	60	962	9.9	92.9	91.2	−1.7	−1.83	−0.131	NS	5204.0	4675.0	−529.0	cm^3	−10.17	−0.726	*	MRI
23.0±1.2	3	1) 45, 2) 22	795	8.9	85.3	83.8	−1.5	−1.76	−0.220	NS	156.1	80.4	−75.7	cm^2	−48.49	−6.062	*	MRI
	3.5	178	1232	6.9	88.0	—	—	−0.70	−0.022	*	173	—	—	—	1.70	0.053	NS	CT
	3.1	120	1190	13.3	85.0	—	—	−0.80	−0.025	*	154	—	—	—	2.50	0.078	NS	
	3.6	173	1971	21.9	85.7	—	—	– 2.60	−0.081	*	168	—	—	—	−6.90	−0.216	*	

Abbreviations: CT; computed tomography; F, female subjects; M, male subjects; METs·h/w, ∑(metabolic equivalents × hour) per week; MRI, magnetic resonance imaging; Sig[1], a significant weight change was observed during the intervention ($P<0.05$); Sig[2], a significant visceral fat change was observed during the intervention ($P<0.05$); Δ, change. Results expressed by mean (range) or mean ± s.d.

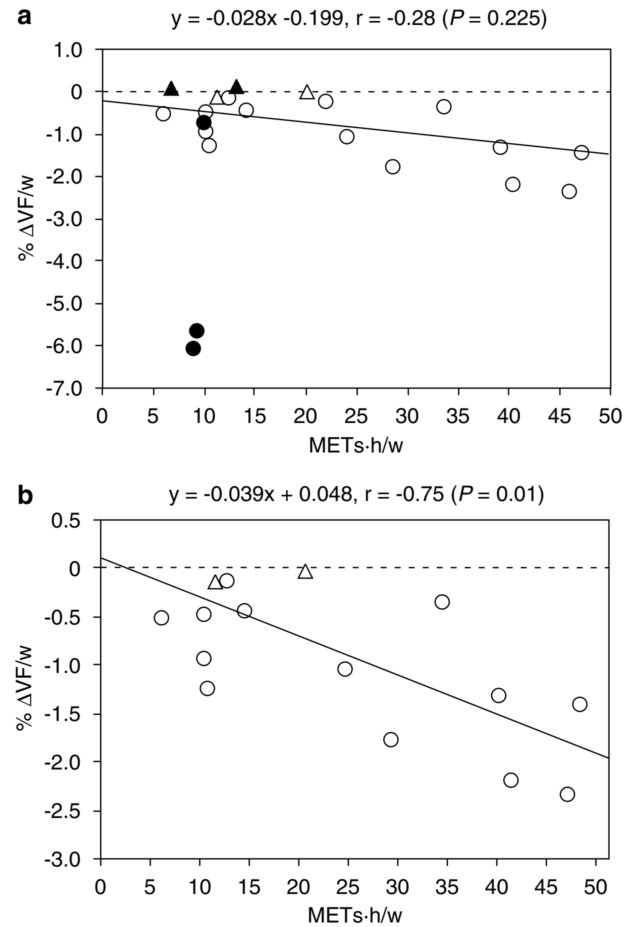

Figure 1 Relations between METs · h/w and %ΔVF/w during interventions in the all selected groups (**a**) and the groups without metabolic-related disorder subjects (**b**). Abbreviations: METs · h/w, ∑(metabolic equivalents × hour) per week; %ΔVF/w, percentage of visceral fat change per week; *r*, Pearson's correlation coefficient weighted for the number of subjects in each group; ○, the no metabolic-related disorder group with a significant visceral fat reduction ($P<0.05$); △, the no metabolic-related disorder group without a significant visceral fat reduction ($P<0.05$); ●, the metabolic-related disorder group with a significant visceral fat reduction ($P<0.05$); ▲, the metabolic-related disorder group without a significant visceral fat reduction ($P<0.05$).

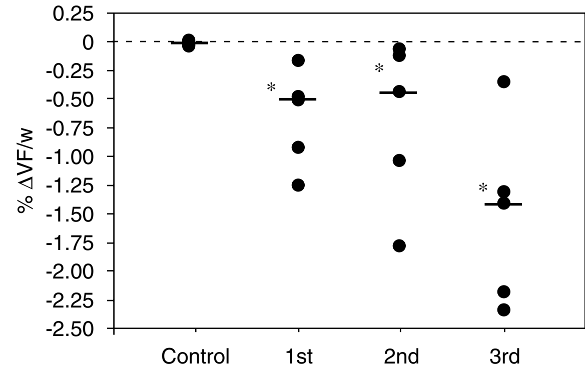

Figure 2 Comparison of mean %ΔVF/w between a control group and exercise groups divided into tertiles by METs · h/w amount in the groups without metabolic-related disorder groups. Ranges of METs · h/w in each categorized group were 5.9–11.4 (1st), 12.3–28.5 (2nd), 33.4–47.1 (3rd). Side bar means median in each group. Statistically significant difference between the groups were observed ($P=0.003$). * A significant difference was found in comparison with the control group using the *post hoc* test ($P<0.05$). Abbreviations: %ΔVF/w, percentage of visceral fat change per week; METs · h/w, ∑(metabolic equivalents × hour) per week.

physical activity and total or regional fat reduction. As a result, even though some literatures were added for the analysis, whether physical activity was associated with reductions in abdominal fat in a dose–response manner was still unclear. Kay and Fiatarone Singh[10] also reviewed the beneficial influence of physical activity on visceral fat reduction, but dose–response data were not examined. These previous reviews did not include studies involving large amounts of exercise. In our analysis, some additional studies, especially three studies with values of 35 METs · h/w or more,[21,22,29] were included in addition to papers used by previously published reviews. Furthermore, the amount of aerobic exercise undertaken during the intervention was expressed as METs · h/w, because METs · h could adjust the EE for each subject's weight. As a result, there was no relationship between METs · h/w and %ΔVF in the 21 groups from 16 studies including the metabolic-related disorder subjects. However, in subjects without metabolic-related disorders, we found a dose–response relationship between aerobic exercise and visceral fat reduction. Indeed, if obese subjects without metabolic-related disorders practiced aerobic exercise, the degree of visceral fat reduction could be directly attributed to the aerobic exercise amount. For example, if an obese person without metabolic-related disorders tries to reduce 10% of his VF amount in 10 weeks, instructors should prescribe about 27 METs · h/w, because 27 METs · h/w corresponds to 1% of ΔVF/w. Thus, our findings could be used to affect decisions on the amount of aerobic exercise recommended for visceral fat reduction in obese people.

In the selected studies, six groups from four studies consisted of metabolic-related disorder subjects. Results from the metabolic-related disorder subjects were contradictory. Two groups with type 2 diabetes[9,38] clearly exhibited a significant visceral fat reduction, although these results may have been exaggerated by the shortest-term intervention (8 weeks) in the selected studies. Two groups with dyslipidemia[24] did not significantly reduce visceral fat, while the group with type 2 diabetes reported by Giannopoulou *et al.*[16] was close to the regression line for identifying a dose–response relationship. Kelly and Simoneau[39] showed that the capacity of fat oxidation during aerobic exercise in individuals with type 2 diabetes was lower than that for healthy individuals. However, several other investigators did not find any significant difference in fat oxidation capacity between subjects with or without type 2 diabetes.[40,41] Furthermore, Raguso *et al.*[42] observed that fat oxidation during aerobic exercise in the group with type 1 diabetes was higher than that of the control group. These studies were conducted

Table 3 Mean METs · h/w and %ΔVF/w, and correlate coefficients between METs · h/w and %ΔVF/w during interventions in the groups categorized by intervention duration or gender

Groups	*Intervention duration*		*Gender*	
	⩽16 week	*>16 week*	*Women only*	*Men only*
From all the selected groups				
Number of groups	10	11	7	6
Number of subjects	183	399	168	98
METs · h/w	23.5±17.1	17.1±9.1	23.1±13.0	27.6±17.7
%ΔVF/week	−2.22±2.00	−0.41±0.55	−0.90±0.86	−1.83±1.98
r (*P* value)	−0.06 (0.877)	−0.34 (0.302)	−0.89 (0.007)	−0.05 (0.931)
From the groups without metabolic-related disordered subjects				
Number of groups	7	8	6	5
Number of subjects	154	271	157	90
METs · h/w	29.5±17.2	18.2±9.8	25.3±12.7	31.3±17.1
%ΔVF/w	−1.40±0.67	−0.55±0.58	−0.93±0.94	−1.07±0.73
r (*P* value)	−0.81 (0.027)	−0.36 (0.378)	−0.93 (0.008)	−0.71 (0.184)

Abbreviations: METs · h/w, ∑(metabolic equivalents × hour) per week; *r*, Pearson's correlate coefficient; %ΔVF/w, percentage of visceral fat change per week. *r* values were weighted for the number of subjects in each group.

under conditions where the subjects with or without diabetes had fasted.[39–42] Thus, visceral fat reduction in the metabolic-related disorder subjects could be due to more complex mechanisms. Therefore, formulation of a dose–response relationship between aerobic exercise and visceral fat reduction has to take into account the separation of subjects with and without metabolic-related disorders.

How much exercise is needed for significant visceral fat reduction?

It is important to suggest a lower limit for the quantity of aerobic exercise required for significant visceral fat reduction. In our selected groups, METs · h/w values ranged from 5.9 to 47.1. Except for the lowest METs · h/w obtained from Miyatake *et al*.[20] in which the subjects were instructed to increase the number of steps walked every day for 1 year, significant visceral fat reduction was observed from about 10 METs · h/w.[16,18,25] Thus, at least 10 METs · h/w is required for significant visceral fat reduction by aerobic exercise, such as brisk walking, light jogging or stationary ergometer usage. For the purpose of weight or body fat loss, the American College of Sports Medicine (ACSM) recommends obese individuals to engage in moderately intense physical activity for minimum 150 min/w, and preferably more than 200–300 min/w.[43] The minimum value in this recommendation nearly equals to 10 METs · h/w when performing moderate physical activities such as brisk walking. In the present study, we divided the aerobic exercise groups into tertiles by their METs · h/w amount to determine the boundary of obvious visceral fat reduction. As a result, each exercise group category had a higher visceral fat reduction than the control group. However, there was no significant difference between %ΔVF/w values in the three exercise categories. This result may be due to an insufficient number of groups. The median of %ΔVF/w in the 3rd tertile exercise group was 40.2, which was much higher than that of the 1st and 2nd tertile exercise groups. That is to say, approximately 40 METs · h/w or more may be required to reduce visceral fat solely by aerobic exercise, such as brisk walking, light jogging or stationary ergometer usage. Forty METs · h/w equates to approximately 3780 kcal/w for a person with 90 kg body weight. Although this value is slightly lower than the ACSM's recommendation corresponding to a minimum 4500 kcal/w for combined exercise and diet with intakes of not lower than 1200 kcal/d, this results in an energy deficiency of approximately 500–1000 kcal/d, which could be hard for obese people with low physical fitness to practice continuously. Therefore, for an individual's prescription for visceral fat reduction, recommendations that balance diet and exercise should be examined in another research.

Influences of intervention duration or gender on the dose–response relationship

Ross and Janssen[13] revealed that an increase in physical activity is positively associated with a reduction in total fat in a dose–response manner in short-term interventions (⩽16 week), but not in long-term interventions (⩽26 week). In the review by Kay and Fiatarone Singh,[10] there was no relation between change in abdominal fat and intervention duration. In the present study, EE by aerobic exercise was positively correlated with visceral fat reduction in the short-term (⩽16 wk) studies when the metabolic-related disorder groups were discounted. Ross and Janssen[13] suggested that in long-term exercise studies, it is difficult to complete a weight loss of an expected volume from expended energy consumption, although it is not clear which factors, such as the adherence to interventions, or over-reporting of exercise amount, influenced the results. Our results support this trend with

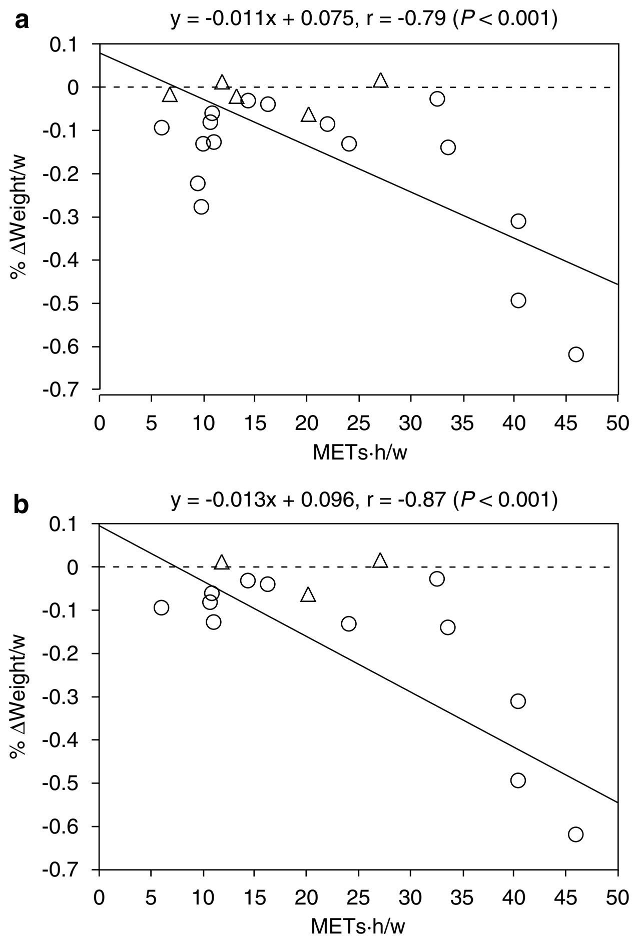

Figure 3 Relations between METs · h/w and %ΔWeight/w during interventions in the all selected groups (**a**) and after excluding the groups with metabolic-related disorder subjects (**b**). Abbreviations: METs · h/w, ∑(metabolic equivalents × hour) per week; %ΔWeight/w, percentage of weight change per week; *r*, Pearson's correlate coefficient; ○, the group with a significant visceral fat reduction ($P<0.05$); △, the group without a significant visceral fat reduction ($P<0.05$). The groups without a weight loss intentionally were excluded for these analysis.

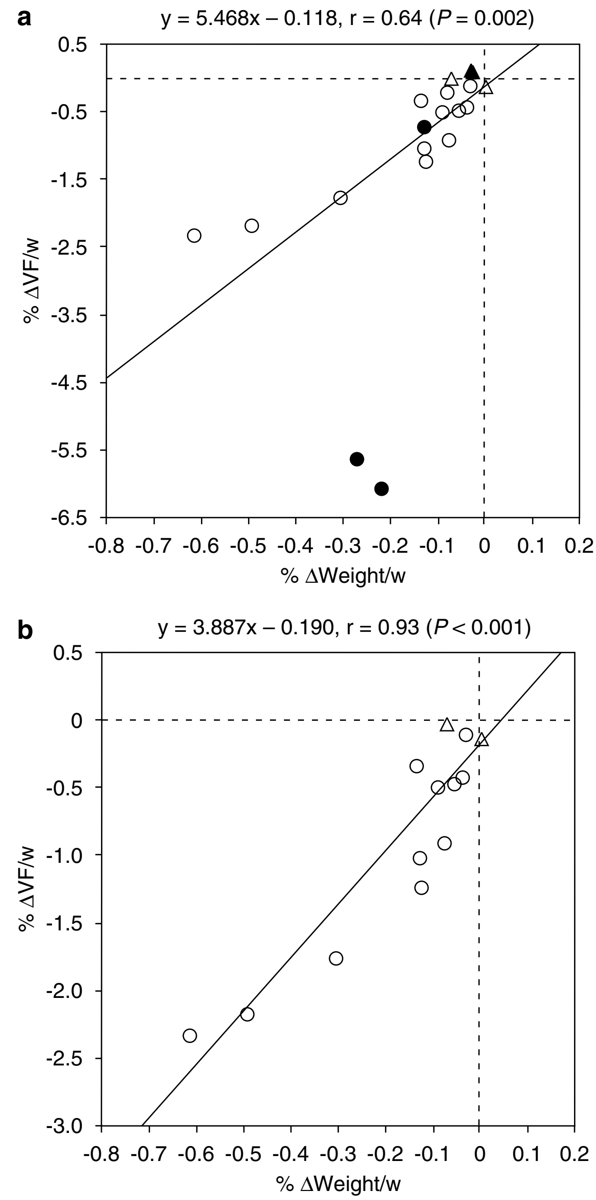

Figure 4 Relations between %ΔVF/w and %ΔWeight/w during interventions in the all selected groups (**a**) and after excluding the groups with metabolic-related disorder subjects (**b**). Abbreviations: %ΔVF/w, percentage of visceral fat change per week; %ΔWeight/w, percentage of weight change per week; *r*, Pearson's correlation coefficient weighted for the number of subjects in each group; ○, the no metabolic-related disorder group with a significant visceral fat reduction ($P<0.05$); △, the no metabolic-related disorder group without a significant visceral fat reduction ($P<0.05$); ●, the metabolic-related disorder group with a significant visceral fat reduction ($P<0.05$); ▲, the metabolic-related disorder group without a significant visceral fat reduction ($P<0.05$).

respect to visceral fat reduction. That is, if subjects can complete the instructed exercise volume, short-term interventions could be more efficient than long-term interventions for weekly visceral fat reduction. Generally, if participants do not quickly observe the benefits of a weight-loss program, their motivation for continuing the regimen is reduced.[44,45] Accordingly, for significant visceral fat reduction, obese people should initially practice a relatively high volume of aerobic exercise, which can then be reduced to a manageable amount that they can practice for the long term.

In the present study, a significant relationship between METs · h/w and %ΔVF was observed in women-only groups, with and without the metabolic-related disorder subjects, while there was no significant relationship in the men-only groups. The limited number of studies was insufficient to determine the influence of gender on the dose–response relationship. However, it is difficult to compare differences of the amount of visceral fat reduction by aerobic exercise between men and women, as women generally store a greater total fat mass relative to body weight than men.[46] Also, body fat distribution is different between men and women as men tend to have more central obesity than women.[47] Initial values of visceral fat could contribute to the amount of visceral fat lost during intervention. If these biases between men and women were excluded, that is, if the absolute amount of total and visceral fat were matched between men and women, then the relative obesity levels for each gender would be much different. It is likely that gender, as well as intervention duration, could be factors in the differences in rate of visceral fat reduction per week.

Relationship between visceral fat reduction and weight reduction

Weight reduction during interventions could be seen solely as the result of fat mass reduction, because fat-free mass reduction accounts for only a small part of weight reduction.[38] Visceral fat volume is about 10–20% of total fat volume[48,49] and reduction of the subcutaneous fat volume largely reflects weight reduction. In a limited number of selected studies, METs · h/w and %ΔWeight/w had a significant correlation in both the groups with and without metabolic-related disorders. Therefore, metabolic-related disorders, especially type 2 diabetes, may have a small impact on a dose-relation between weight loss and aerobic exercise during intervention compared to the amount of visceral fat reduction.

On the other hand, our results indicate a significant relationship between %ΔWeight/w and %ΔVF/w, especially in the subjects without metabolic-related disorders. We can say that %ΔVF/w corresponds to four to five times %ΔWeight/w when obese people practice aerobic exercise. However, previous studies suggest that visceral fat is used more quickly as an energy resource than subcutaneous fat during aerobic exercise-induced weight loss.[50] In our analysis, the intercept of the regression line between %ΔWeight/w and %ΔVF/w in the subjects without metabolic-related disorders was significantly different from zero. Although the trend showed that the more weight was lost, the more visceral fat was reduced, a significant reduction of visceral fat, which occupies less than 5% of body weight,[48,49] may also occur without a significant weight reduction with aerobic exercise. In fact, this phenomenon was reported by studies that examined whether or not visceral fat was reduced by aerobic exercise, if energy intake corresponding to the EE value by prescribed aerobic exercise was added to the baseline. Such an adjustment in the calculation did not lead to a significant weight reduction.[22,29] Generally, it is difficult for obese people to reduce weight largely by practicing exercise alone, compared to diet.[8] Therefore, exercise is inclined to be optional with a diet therapy for weight loss. However, even if insufficient weight loss does occurs, visceral fat could be reduced by doing aerobic exercise, a prescription supported by recent studies.[16,22] These results provide evidence of the usefulness of aerobic exercise for visceral fat reduction.

There are a number of limitations in the present study. The number of selected studies, especially those which measured EE for the prescribed exercises, were still insufficient for defining a clear aerobic exercise amount that resulted in significant visceral fat reduction. Additionally, the influence of several factors, such as metabolic-related disorders, gender and intervention duration, on visceral fat reduction remains unclear. Most of trials in the selected studies had applied brisk walking, light jogging and stationary ergometer, so whether or not other types of activities could lead to a similar result cannot be clarified from this study. Furthermore, while the present study investigated visceral fat reduction, studies with visceral fat gain should also be included in the analyses.

In conclusion, data collected from selected studies suggested that aerobic exercise as a weight loss intervention has a dose–response relationship with visceral fat reduction in obese subjects, excluding groups with metabolic-related disorders. Additionally, visceral fat reduction is significantly related to weight reduction during aerobic exercise intervention, although a significant visceral fat reduction may also occur without significant weight loss. Furthermore, for significant visceral fat reduction, at least 10 METs · h/w of aerobic exercise is required. However, since the number of selected studies was still insufficient, further studies are required.

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CORRIGENDUM

A dose–response relation between aerobic exercise and visceral fat reduction: systematic review of clinical trials

K Ohkawara, S Tanaka, M Miyachi, K Ishikawa-Takata and I Tabata

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After the publication of the above paper, the authors have noticed an error in Figure 3, as the position of one plot should be changed and two plots should be erased, while statistical results remain unchanged. The correct figure is shown below.

The authors apologize for the errors.

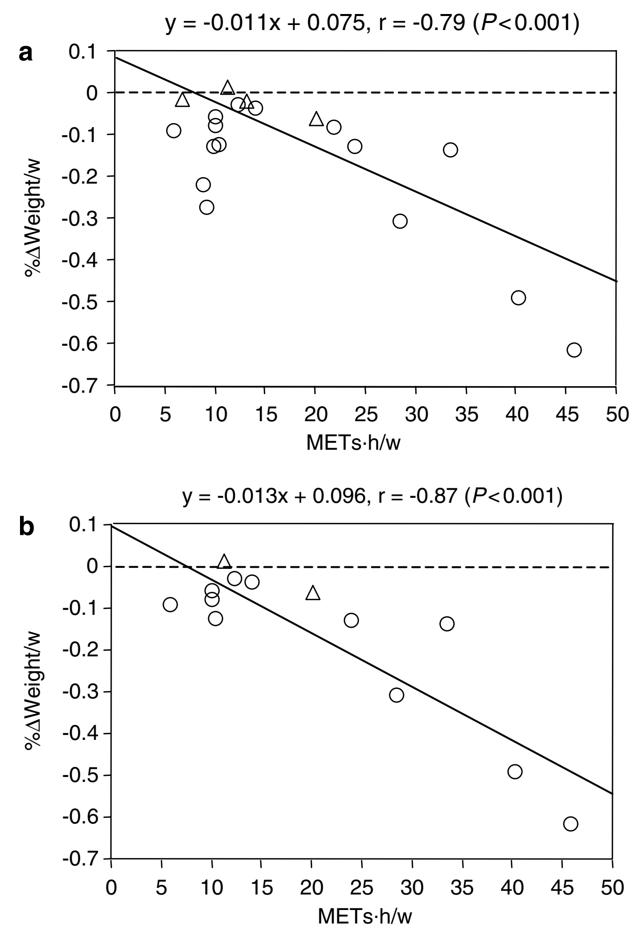

Figure 3 Relations between METs · h/w and %ΔWeight/w during interventions in the all selected groups (**a**) and after excluding the groups with metabolic-related disorder subjects (**b**). Abbreviations: METs · h/w, Σ(metabolic equivalents × hour) per week; %ΔWeight/w, percentage of weight change per week; *r*, Pearson's correlate coefficient; ○, the group with a significant visceral fat reduction ($P<0.05$); △, the group without a significant visceral fat reduction ($P<0.05$). The groups without a weight loss intentionally were excluded for these analysis.