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分担研究報告書

エクササイズガイド2006の普及啓発に関する研究

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本研究は，「健康づくりのための運動指針・エクササイズガイド」の普及啓発を最終目的に，人々に身体活動量増強および運動実践を行わせるためにフォーマティブリサーチを実施し，対象者に合わせた内容やメッセージを探った.

A．研究目的

本研究の目的は，ヘルスコミュニケーションの観点から身体活動量増強および運動実施に関して国民への普及啓発をはかる方策を検討し，最終的には「健康づくりのための運動指針・エクササイズガイド」に見合った運動量にまで到達させることである．本研究においては，熟考ステージ者（かんがえているものの実行に移していない人たち）を対象にして，まずは実行できる活動に注目した.

B．研究方法

東京都S区保健所と共同で，身体活動のスモールチェンジ・キャンペーンを実施することを目的に，S区16カ所において区民対象の予備調査を実施した．それらの調査内容としては，日常生活の中で，わずかに取り入れることができ，しかも無理なく実践が継続できるような身体活動内容を聞き出し，同時に対象者の属性（性別・年齢，職種・体型など）との関係を探った.

（倫理面への配慮）

S区保健所の許可を得た上で，S区倫理条例に従って，職員立ち会いの上で調査を実施した.

C．研究結果

回答者数は，男性115名，女性119名であった．性別，ステージ別（初期・後期），年齢層（20-30代，40-50代，60代以上）に分けて，身体活動スモールチェンジの内容を検討した結果，男性初期ステージ者においては，どの年代層においても「歩く」が上位スモールチェンジ内容として抽出され，一方．男性後期ステージ者の若年層では「筋力トレーニング」など強度の高い内容があがった．女性初期ステージ者では，50代までは歩くことがスモールチェンジとして認識されていたが，60代以上では「体操」が，また後期ステージ者の若年者では「階段利用」があげられ，その他の年齢層では「歩く」が上位に位置づけられた.

D．考察

「健康づくりのための運動指針・エクササイズガイド」は，生活習慣病予防を対象とした運動量をエビデンスを基にわかりやすく示している．しかし，人はエビデンスを示されただけで，それを行動に移すものではない，人々に行動を起こさせ，それを継続させるためには，戦略的なアプローチが必要とされている．本研究では，「健康づくりのための運動指針・エクササイズガイド」を実践の最終目的としながらも，まずは行動を生じさせ，継続が容易な「スモールチェンジ」活動に焦点をあて，性別，変容ステージ，および年齢層からその内容を探った．その結果，性別，変容ステージ，および年齢層の組み合わせによって，スモールチェンジとする活動内容に違いがあり，それぞれの組み合わせに応じた推奨内容が必要なことがわかった．

E．結論

行動実践に必要な活動内容を提示することによって，対象者の受け入れ程度を高めることを意図してスモールチェンジ活動を提示する必要がある．

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Comparison of ventilatory threshold and exercise habits between Japanese men with and without metabolic syndrome

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Abstract

Objective: We compared the levels of ventilatory threshold (VT) and exercise habits in subjects with metabolic syndrome with those in age, sex-matched subjects without metabolic syndrome.
Methods: We used data of 155 Japanese men (47.1 ± 9.2 years) with metabolic syndrome; the diagnosis was given by the definition and the diagnostic standard for metabolic syndrome in Japan. The influence of metabolic syndrome on oxygen uptake, work rate and heart rate at VT, and exercise habits were evaluated.
Results: Oxygen uptake and work rate at VT in subjects with metabolic syndrome were significantly lower than those in subjects without metabolic syndrome even after adjusting for body mass index (BMI). The number of subjects with exercise habits was significantly lower in metabolic syndrome. The subjects with exercise habits were significantly older than that in subjects without exercise habits. Furthermore, oxygen uptake and work rate at VT were significantly higher in subjects with exercise habits than those in subjects without exercise habits.
Conclusion: Lower level of VT was characteristic in subjects with metabolic syndrome. Promotion of exercise habits is necessary for preventing and improving metabolic syndrome in Japanese men.

Keywords: Metabolic syndrome; Ventilatory threshold; Exercise habits

1. Introduction

Metabolic syndrome is characterized by abdominal obesity, high blood pressure, dyslipidemia and impaired glucose tolerance [1]. New criterion in Japan has been defined in April 2005 and 30.7% in men and 3.6% in women are diagnosed as having metabolic syndrome using the new criterion in Japan [1,2]. Exercise is considered as a useful method for preventing metabolic syndrome and improving each component of metabolic syndrome. The ventilatory threshold (VT) is defined as the upper limit of the aerobic exercise and is thought to serve as an accurate and reliable standard for exercise prescription [3]. Since the exercise intensity at VT is not harmful to cardiovascular function, it can be safely applied to patients with myocardial infarction as exercise prescription [4]. However, the relationship

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between exercise habits and metabolic syndrome, also between physical fitness such as aerobic exercise level defined by VT and metabolic syndrome using the new criterion in Japan are not fully discussed.

In this study, we evaluated the parameters at VT and exercise habits between Japanese men with and without metabolic syndrome.

2. Subjects and methods

2.1. Subjects

The total number of Japanese men with metabolic syndrome, aged 24–68 years, was 155 and they were enrolled into annual health check-ups at Okayama Southern Institute of Health with written informed consent. They were compared with 115 men who were age and sex matched and without metabolic syndrome.

2.2. Anthropometric measurements

The anthropometric measurements were performed by using the following parameters such as height, body weight, body mass index (BMI) and waist circumference. BMI was calculated by weight/[height]^2 (kg/m^2). The waist circumference was measured at the umbilical level [5].

2.3. Blood pressure measurements

Blood pressure of each participant was measured after resting at least 15 min in the sitting position.

2.4. Blood sampling and assays

We measured overnight fasting serum levels of high density lipoprotein (HDL) cholesterol, triglycerides (L Type Wako Triglyceride H, Wako Chemical, Osaka) and plasma glucose.

2.5. Definition of metabolic syndrome

The syndrome was defined [1], among men with a waist circumference in excess of 85 cm and women with a waist circumference in excess of 90 cm [6], as having 2 or more components from among the following: (1) dyslipidemia: triglyceride $\geqq$150 mg/dl and/or HDL cholesterol $\geqq$40 mg/dl, (2) high blood pressure: blood pressure $\geqq$130/85 mmHg, (3) impaired glucose tolerance: fasting plasma glucose $\geqq$110 mg/dl.

2.6. Exercise testing

A graded ergometer exercise protocol [7] was performed. Two hours after breakfast, a resting ECG was recorded and blood pressure was measured. Then, all participants were given graded exercise after 3 min of pedaling on an unloaded bicycle ergometer (Excalibur V2.0, Lode BV, Groningen, Netherlands). The profile of incremental workloads was automatically defined by the methods of Jones [7], in which the workloads reach the predicted $\dot{V}O_2$ max in 10 min. A pedaling cycle of 60 rpm was maintained. Loading was terminated when the appearance of symptoms forced the subject to stop. During the test, ECG was monitored continuously together with the recording of heart rate (HR). Expired gas was collected and rates of oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were measured breath-by-breath using a cardiopulmonary gas exchange system (Oxycon Alpha, Mijnhrdt b.v., Netherlands). VT was determined by the standard of Wasserman et al. [3], Davis et al. [8], and the V-slope method of Beaver [9] from $\dot{V}O_2$, $\dot{V}CO_2$ and minute ventilation ($\dot{V}E$). At VT, $\dot{V}O_2$ (ml/(kg min)), work rate (W), and heart rate (beats/min) were measured and recorded.

2.7. Exercise habits

The data on exercise habits were obtained at interviews by well-trained staff in a structured way according to the National Nutrition Survey in Japan [10]. The subjects were asked if they currently exercise (over the level of 30 min per session, two times per week and prolonged duration for 3 months). When the answer was "yes", they were classified as subjects with exercise habits. When the answer was "no", they were classified as subjects without exercise habits.

2.8. Statistical analysis

Data are expressed as mean ± standard deviation (S.D.) values. Relationship between metabolic syndrome and exercise habits was tested using χ^2-test and comparison of parameters between two groups was used by unpaired t-test: $P < 0.05$ was considered to be statistically significant.

3. Results

Table 1 shows the comparison of age, body weight, BMI and parameters at VT between subjects with metabolic ($n = 155$) and without metabolic syndrome ($n = 155$). There was no significant difference of age between the subjects with and without metabolic syndrome. Oxygen uptake at VT and work rate at VT in subjects with metabolic syndrome was significantly lower than those in subjects without metabolic syndrome. Heart rate at VT in subjects with metabolic syndrome was similar to that in subjects without metabolic syndrome.

We also compared the levels of parameters at VT between the groups with and without each component of definition of metabolic syndrome in Japan (Table 2). Of 310 subjects, 56 subjects were diagnosed as having type 2 diabetes mellitus (fasting plasma glucose

Table 1
Comparison of parameters at VT between metabolic and non-metabolic subjects in men

	Metabolic syndrome (+)	Metabolic syndrome (−)
Number of subjects	155	155
Age	47.1 ± 9.2	47.1 ± 9.2
Body weight (kg)	80.6 ± 12.4	72.9 ± 11.1[a]
BMI (kg/m^2)	28.0 ± 3.6	25.6 ± 3.4[a]
Oxygen uptake at VT (ml/(kg min))	14.2 ± 2.7	16.1 ± 3.6[a]
Work rate at VT (W)	75.6 ± 17.1	80.7 ± 22.5[b]
Heart rate at VT (beat/min)	105.1 ± 12.3	106.5 ± 11.3

VT: ventilatory threshold, BMI: body mass index.
[a] $P < 0\ 01$ vs. metabolic syndrome (+).
[b] $P < 0.05$ vs. metabolic syndrome (+).

≦126 mg/dl). There was no significant difference of age between subjects with or without abdominal obesity or dyslipidemia and high blood pressure. However, there was a significant difference of age between subgroups with or without impaired glucose tolerance. Oxygen uptake at VT in subjects with abdominal obesity, dyslipidemia, impaired glucose tolerance and high blood pressure were significantly lower than those in subjects without such components of metabolic syndrome. Work rate at VT and heart rate at VT in subjects with impaired glucose tolerance were also significantly lower than those in subjects without impaired glucose tolerance. In addition, we compared the levels of parameters at VT between the groups with and without various combinations of each component (Table 2). Oxygen uptake at VT in subjects with two or

Table 2
Comparison of parameters at VT with and without subcriterion of metabolic syndrome in men

	Waist circum ference (+)	Waist circum ference (−)
Number of subjects	243	67
Age	47.0 ± 8.9	47.5 ± 10.0
Oxygen uptake at VT (ml/(kg min))	14.4 ± 2.7	17.8 ± 3.8[a]
Work rate at VT (W)	78.1 ± 19.3	78.4 ± 23.0
Heart rate at VT (beat/min)	105.2 ± 11.9	108.0 ± 11.3
	Dyslipidemia (+)	Dyslipidemia (−)
Number of subjects	175	135
Age	46.4 ± 8.8	48.0 ± 9.6
Oxygen uptake at VT (ml/(kg min))	14.7 ± 3.1	15.7 ± 3.6 a
Work rate at VT (W)	76.5 ± 18.5	80.3 ± 21.9
Heart rate at VT (beat/min)	106.0 ± 12.0	105.4 ± 11.6
	Impaired glucose tolerance (+)	Impaired glucose tolerance (−)
Number of subjects	112	198
Age	49.5 ± 9.0	45.8 ± 9.0[a]
Oxygen uptake at VT (ml/(kg min))	14.1 ± 2.7	15.7 ± 3.5[a]
Work rate at VT (W)	73.8 ± 16.6	80.7 ± 21.5[a]
Heart rate at VT (beat/min)	104.0 ± 11.4	106.8 ± 12.0[b]
	High blood pressure (+)	High blood pressure (−)
Number of subjects	231	79
Age	47.6 ± 8.9	45.7 ± 9.8
Oxygen uptake at VT (ml/(kg min))	14.8 ± 3.0	16.2 ± 3.9[a]
Work rate at VT (W)	77.8 ± 19.6	79.2 ± 21.5
Heart rate at VT (beat/min)	105.1 ± 11.8	107.7 ± 11.6
	Dyslipidemia (+) and impaired glucose tolerance (+)	Dyslipidemia (−) and/or impaired glucose tolerance (−)
Number of subjects	67	243
Age	47.8 ± 8.8	46.9 ± 9.3
Oxygen uptake at VT (ml/(kg min))	14.0 ± 2.8	15.4 ± 3.4[a]
Work rate at VT (W)	74.9 ± 18.6	79.1 ± 20.4
Heart rate at VT (beat/min)	105.8 ± 11.3	105.8 ± 12.0

Table 2 (*Continued*)

	Dyslipidemia (+) and high blood pressure (+)	Dyslipidemia (−) and/or high blood pressure (−)
Number of subjects	142	168
Age	46.6 ± 8.8	47.5 ± 9.5
Oxygen uptake at VT (ml/(kg min))	14.6 ± 2.9	15.6 ± 3.6[a]
Work rate at VT (W)	75.8 ± 17.8	80.2 ± 21.7
Heart rate at VT (beat/min)	105.6 ± 12.3	105.9 ± 11.5
	High blood pressure (+) and impaired glucose tolerance (+)	High blood pressure (−) and/or impaired glucose tolerance (−)
Number of subjects	89	221
Age	49.4 ± 8.8	46.2 ± 9.1[a]
Oxygen uptake at VT (ml/(kg min))	14.2 ± 2.7	15.5 ± 3.5[a]
Work rate at VT (W)	75.6 ± 16.1	79.2 ± 21.5
Heart rate at VT (beat/min)	104.6 ± 11.1	106.2 ± 12.1
	Dyslipidemia (+) and high blood pressure (+) and impaired glucose tolerance (+)	Dyslipidemia (−) and/or high blood pressure (−) and/or impaired glucose tolerance (−)
Number of subjects	54	256
Age	47.8 ± 8.7	47.0 ± 9.3
Oxygen uptake at VT (ml/(kg min))	14.3 ± 2.7	15.3 ± 3.4[b]
Work rate at VT (W)	76.6 ± 17.6	78.5 ± 20.6
Heart rate at VT (beat/min)	106.0 ± 11.0	105.7 ± 12.0

VT: ventilatory threshold.
[a] $P < 0.01$ vs. (+).
[b] $P < 0.05$ vs. (+).

three components was significantly lower than that the subjects without one of these components.

To avoid the influence the BMI on VT, we compared the parameters at VT in obese (BMI ≧ 25) metabolic syndrome subjects with those in obese non-metabolic syndrome subjects (Table 3). There were no significant differences of age and BMI between the subjects with and without metabolic syndrome. Oxygen uptake and work rate at VT in obese men with metabolic syndrome were significantly lower than those in obese men without metabolic syndrome.

Table 3
Comparison of parameters at VT between metabolic and non-metabolic subjects in obese (|BM| ≧ 25) men

	Metabolic syndrome (+)	Metabolic syndrome (−)
Number of subjects	130	87
Age	46.7 ± 9.3	46.2 ± 8.1
BMI (kg/m^2)	28.7 ± 3.4	27.9 ± 2.3
Oxygen uptake at VT (ml/(kg min))	14.0 ± 2.5	14.8 ± 2.6[b]
Work rate at VT (W)	76.2 ± 15.5	84.3 ± 21.7[a]
Heart rate at VT (beat/min)	105.1 ± 12.1	104.9 ± 10.8

VT: ventilatory threshold, BMI: body mass index.
[a] $P < 0.01$ vs. metabolic syndrome (+).
[b] $P < 0.05$ vs. metabolic syndrome (+).

We evaluated the relationship between metabolic syndrome and exercise habits. Of 310 men, 116 men (37.4%) were classified as having exercise habits. The prevalence of metabolic syndrome in subjects with exercise habits (42.2%) was significantly lower than that in subjects without exercise habits (54.6%) (Table 4).

Finally, we compared the parameters at VT between subjects with and without exercise habits (Table 5). Age in subjects with exercise habits was significantly higher than that in subjects without exercise habits. However, oxygen uptake and work rate at VT were significantly higher in subjects with exercise habits than those in subjects without exercise habits.

Table 4
Relationship between metabolic syndrome and exercise habits in men

	Metabolic syndrome (+)	Metabolic syndrome (−)
Exercise habits (+)	49	67
Exercise habits (−)	106	88

$P < 0.05$ by χ^2-test.

Table 5
Comparison of parameters at VT between subjects with and without exercise habits in men

	Exercise habits (+)	Exercise habits (−)
Number of subjects	116	194
Age	48.5 ± 8.7	46.3 ± 9.3[b]
Oxygen uptake at VT (ml/(kg min))	15.9 ± 3.9	14.7 ± 2.8[a]
Work rate at VT (W)	81.8 ± 23.5	76.0 ± 17.5[b]
Heart rate at VT (beat/min)	105.6 ± 11.4	105.9 ± 12.1

VT: ventilatory threshold.
[a] $P < 0.01$ vs. exercise habits (+).
[b] $P < 0.05$ vs. exercise habits (+).

4. Discussion

Our study is the first report on the relationship between metabolic syndrome, defined by the new criterion of metabolic syndrome in Japan, and exercise habits and the levels of VT. Metabolic syndrome has important clinical and public health implications because it is a common disorder in Japan [1,2]. Previous studies documented that metabolic syndrome is an important risk factor for diabetes, coronary heart disease and stroke [11–13]. Our study shows new and important information about the relationship between metabolic syndrome, and exercise habits and oxygen uptake at VT in Japanese men.

The prevalence of subjects with exercise habits in Japan was reported to be 29.3% in men and 24.1% in women by the National Nutrition Survey in Japan [10] and our results were not similar and the prevalence of subjects with exercise habits was higher than that in the previous study. Definition of prolonged time in our study was shorter and, in addition, enrolled subjects in our study were undertook annual health check-ups and they might therefore be more careful of their own health than subjects in the National Nutrition Survey.

Regular physical activity has been linked to increases in HDL and reductions in resting blood pressure, triglycerides, abdominal fat, fating glucose levels, and insulin responses to oral glucose challenge [14–16]. In several reports in the cross sectional study, metabolic syndrome was significantly correlated with physical fitness [17–19]. However, the hypothesis that metabolic syndrome may be caused by lower oxygen uptake at VT cannot be proven in our current cross-sectional design. The Kuopio Ischemic Heart Disease Risk Factor Study [20] followed several hundred men who did not have metabolic syndrome at baseline. Four years later, subjects in the upper one-third of VO_2max at baseline were 75% less likely than unfit men to develop metabolic syndrome. Katzmarzyk et al. reported that the effects of 20 weeks supervised aerobic training program on the prevalence of the metabolic syndrome in 621 men and women who were enrolled in the Heritage Study. After exercise intervention, 30.5% of the participants with metabolic syndrome at baseline were no longer classified as having metabolic syndrome [21]. Ekelund et al. reported that physical activity energy expenditure predicts progression toward the metabolic syndrome independent of aerobic fitness, obesity, and other confounding factors by observation of 5.6 years [22]. In our study, oxygen uptake at VT in men with metabolic syndrome was significantly lower than that in men without metabolic syndrome, even after adjusting for BMI. Oxygen uptake at VT in subjects with sub criterion of metabolic syndrome was also significantly lower than that in subjects without sub criterion of metabolic syndrome. In addition, the number of subjects with exercise habits was significantly lower in metabolic syndrome and the subjects with exercise habits had higher oxygen uptake at VT. It may be hard to clarify the mechanisms as to why the exercise habits are linked to higher oxygen uptake at VT and beneficial for preventing the metabolic syndrome. Although the mechanism is not well-understood, we previously reported that the education program, in which we instructed overweight Japanese men to increase daily step per day and join a weekly exercise course, resulted in increased oxygen uptake at VT and reduced visceral fat area [5].

Our study has potential limitation. First, our study was a cross-sectional and not a longitudinal training study. Second, we could not accurately prove the mechanism between lower oxygen uptake at VT and metabolic syndrome. However, it seems reasonable to suggest that simply moving from the lower oxygen uptake at VT to higher oxygen uptake at VT might result in the amelioration of the metabolic syndrome in some Japanese men. Therefore, we need promote exercise habits for preventing and improving metabolic syndrome. Further prospective studies are needed in Japanese using the new criterion of Japan.

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ORIGINAL ARTICLE

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 to increased sympathetic tonus, thereby increasing lipolysis

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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 × 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]

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

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]

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

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