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Original article

Exercise training at the maximal fat oxidation intensity improved health-related physical fitness in overweight middle-aged women

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Abstract

Background/Objective: The purpose of this study was to test the hypothesis that exercise training at the maximal fat oxidation (FATmax) intensity would improve the health-related physical fitness in overweight middle-aged women.
Methods: Thirty women (45−59 years old and BMI 28.2 ± 1.8 kg/m^2) were randomly allocated into the Exercise and Control groups. Body composition, FATmax, predicted maximal oxygen uptake, heart function during submaximal exercise, stroke volume, left ventricular ejection fraction, trunk muscle strength, and body flexibility were measured before and after the experimental period.
Results: Following the 10 weeks of supervised exercise training, the Exercise group achieved significant improvements in body composition, cardiovascular function, skeletal muscle strength, and body flexibility; whereas there were no changes in these variables of the Control group. There was also no significant change in daily energy intake for all participants before and after the interventions.
Conclusion: The 10-week FATmax intensity training is an effective treatment to improve health-related physical fitness in overweight middle-aged women.

Keywords: Exercise training; Health-related physical fitness; Maximal fat oxidation rate; Obesity; Women

Introduction

Health-related physical fitness consists of body composition, cardiovascular function, muscular function, and body flexibility; all of these components are important factors contributing to health and wellbeing.[1,2] Obesity or being overweight is currently a serious public health problem, which negatively affects the characteristics of health-related physical fitness.[3−6] Exercise training has been used as a commonly used means for the treatment of obesity. There is evidence that exercise training decreases body fat, improves cardiovascular function, and increases muscle strength in obese or overweight people.[7,8] In the literature, many obesity and aerobic training studies applied the "moderate exercise intensity" in their training programs. The moderate exercise intensities are usually determined by a certain percentage of the participants' maximal oxygen consumption (VO_2max) or maximal heart rate (HR), but there is not enough scientific evidence to demonstrate why the intensity was applied and what energy substrates were utilized during exercise training at the chosen intensity.[9−11]

Searching the optimal exercise training program, in particular, the most effective training intensity to help people treat obesity, as well as improve their physical fitness, has been one of the major tasks of exercise physiologists. From the studies of substrate utilization during exercise, it has been reported that fat oxidation rate increases as the exercise

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intensity increases. This reaches a peak at a certain intensity and then decreases, and the carbohydrate oxidation rate takes the lead.[12,13] The peak of fat oxidation rate has been defined as the maximal fat oxidation rate (FATmax).[14,15] It is reasonable to train obese or overweight individuals at this special intensity because the primary goal of treating obesity is to burn fat more effectively. A few studies have evaluated this possibility in adults.[16–20] Variables of body composition, insulin sensitivity, lipid profile, and cardiovascular function were measured following the training. However, there is still no constant outcome reported of the effect of FATmax training on body composition and cardiovascular function from these previous studies. In addition, there is no report regarding the effect of FATmax training on muscle strength and flexibility so far. Thus, more researches should be carried out to evaluate the clinic value of FATmax training for treating obesity or overweight. The purpose of the present study was to investigate the changes in body composition, cardiovascular function, muscle strength, and flexibility in a group of overweight middle-aged women before and after a 10-week FATmax training program. We tested the hypothesis that the FATmax exercise training would improve important variables of health-related physical fitness of the participants.

Methods

Participants

Thirty women were the participants of this study. The inclusion criteria were females who were 45–59 years, had body mass index (BMI) > 25 kg/m^2 and percentage body fat > 30%, not engaged in regular exercise training over the past 2 years, with normal menstrual cycle if the participant was premenopausal at the time of their enrolment. Those individuals with heart disease, hypertension, pulmonary disease, diabetes, along with those who had neurological limitations to physical exercise were excluded. The experimental details of the study were explained to the participants before the baseline test, and a written informed consent to the study was obtained from each of them. This study was approved by the Ethics Committee of Tianjin University of Sport, Tianjin, China.

Study design

Participants were randomly allocated into the Exercise and Control groups ($n = 15$ each). Following the baseline test, which included body composition, FATmax, predicted VO_2max, heart function during submaximal exercise, stroke volume, left ventricular ejection fraction, trunk muscle strength, and body flexibility, the Exercise group participated in supervised exercise training at the intensity of individualized FATmax. The Control group was required to maintain their personal habit of physical activity and not engage in any prescribed exercise training during the experimental period. All variables of the baseline test were measured again at the end of the experiments; the tests were separated by at least 2 days from the last training session of the Exercise group. All measurements were carried out from the early phase up to the midfollicular phase for the participants who were premenopausal in order to minimize the effect of female hormones on metabolic level. Meanwhile, there was no diet control in this study, but only two 5-weekday dietary diaries were recorded by all participants themselves at the beginning and the end of the experimental period.

Measurements

Body composition

Each participant's body mass and height were measured to calculate BMI through dividing body mass (kg) by height in meters squared (m^2). After overnight fasting, the body composition was measured using a dual-energy X-ray absorptiometry (DXA; Prodigy Advance, GE Healthcare Lunar, Madison, WI, USA). By means of the standard soft tissue analysis provided by the same company, the nonbone fat-free soft tissue, fat tissue, bone mineral content, and abdominal fat mass were measured. The total body fat % was determined as a portion of the total amount of fat in the entire body mass. Fat mass and fat-free mass were also calculated.

Maximal oxygen uptake

VO_2max was estimated through a submaximal exercise test on a bicycle ergometer and oxygen uptake (VO_2) was measured by using an open-circuit indirect gas analyzer (Cortex Metalyzer 3B gas analyzer, CORTEX Biophysik GmbH, Leipzig, Germany), which was calibrated with the standard gas before each test. The HR and the VO_2 at 25 watts and 75 watts were measured and used to develop the best-fit line of HR and VO_2 for each participant. The VO_2max was then estimated from the estimated maximal HR (220-age).[21]

Cardiovascular variables

Blood pressure (BP) was measured using the auscultatory method after the participant had 10 minutes of resting. Resting stroke volume (SV) and left ventricular ejection fraction were measured by the M-mode echocardiography (Aloka SSC-290 echocardiograph, Aloka, Tokyo, Japan) with an oscillator frequency of 3.5MHz. All of these measurements were carried out by the same experienced technician. A 3-minute step test was used to test the HR response to a fixed workload. This test focused on how fast the HR recovers towards the resting condition after the exercise.

$$\text{HR index} = [\text{exercise time(s)}/\text{sum of the 3 30-second post exercise HR} \times 2] \times 100.^{16} \tag{1}$$

Trunk muscle strength measurements

After a 3-minute warm-up of walking and skeletal muscle stretches, the isometric strengths of the trunk flexion, trunk extension, and trunk right or left lateral flexion were measured using the Back-check compact machine (Dr. Wolff Sports & Prevention GmbH, Arnsberg, Germany). Each exercise was tested three times and the average was analyzed and reported.

The strength of hand grip was measured using a hand-grip dynamometer. Each hand was tested three times and the average was reported.

Body flexibility test

Sit-and-reach test was run on a gym mattress in the laboratory. In a sitting position with the knee joint extended, the distance between the middle finger and the feet was measured. The average of three tests was reported as the body flexibility.

FATmax procedure

Participants were asked to refrain from vigorous exercise for 24 hours and fast for at least 10 hours before the FATmax test. All FATmax tests were carried out in the morning between 8:00 AM and 10:00 AM to avoid circadian variance. A graded treadmill walking–running test was used to measure the FATmax. Briefly, there was a warm-up exercise of walking at 3.5 km/h with an incline of 1% for 3 minutes, followed by a 2-minute break. The first stage of exercise was set at a speed of 4 km/h with an incline of 1% for 4 minutes. The speed was increased to 5 km/h for 4 minutes as the second stage, 6 km/h for 4 minutes as the third stage, and 6.5 km/h for 4 minutes as the fourth stage. The test was terminated when the respiratory exchange ratio (RER) reached 1 (RER $\geq$ 1). VO_2 and carbon dioxide production (VCO_2) were measured using the same gas analyzer as in the VO_2max test.

The average gas values of every 15 seconds during the exercise test, before the RER reached 1, were recorded to calculate the fat oxidation rate, using the following stoichiometric equation with the assumption that the urinary nitrogen excretion rate was negligible:

$$\text{Total fat oxidation} = 1.67 \times VO_2(\text{L/min}) - 1.67 \times VCO_2(\text{L/min}) \quad (2)$$

The value 1.67 is derived from the volume of VO_2 and VCO_2 from oxidation of 1 g of fat.[22] The exercise intensity at which the highest rate of fat oxidation occurred was defined as the FATmax.[14] HR was recorded continuously during the test by an electrocardiogram. The corresponding HR at the FATmax intensity (FATmax HR) was recorded and then applied individually to control the intensity of exercise training followed.

Exercise training program

The Exercise group undertook 10 weeks of FATmax exercise training, 1 hour per day, 5 days per week. The training session consisted of a 10-minute warm-up period, which included walking and jogging, as well as skeletal muscle stretches; This was followed by 40 minutes of walking or running with the intensity controlled at the individualized FATmax HR. Short breaks of 1–2 minutes were allowed when it was necessary to drink water; and finally, there was a 10-minute cool-down period by walking slowly and stretching the muscles. All of these training sessions were supervised by the researchers and every participant wore a HR monitor (Polar Electro, Kempele, Finland) during the training so as to maintain the right training intensity. An alarm on the HR monitor was set up at ± 5 beats of the target HR for the participant to judge the moving speed and exercise intensity.

Dietary records

The 5-weekday dietary diary was recorded at the beginning and the end of the experimental period. The weight of food and the percentages of carbohydrate, fat, and protein in the food were estimated from the records. Daily energy intake was then calculated by multiplying the weight of carbohydrate, fat, and protein consumed with their energy values (carbohydrate provides 4 kcal/g of energy, fat 9 kcal/g, and protein 4 kcal/g). After removal of the highest and the lowest data, the average of other 3 days was reported as the daily energy intake.

Statistical analyses

All the values were presented as mean ± standard deviation. Effects of FATmax training on the measured variables were detected using two times (before and after experiment) × two groups (Exercise and Control) factorial design, split plot analysis of variance (SPANOVA). Pearson correlation coefficient was calculated to assess the relationships between the abdominal fat mass and trunk muscle strengths and flexibility. A p value < 0.05 was regarded as statistically significant. All analyses were performed using the SPSS version 21 for Windows (SPSS Inc., Chicago, IL, USA).

Results

All of the 15 participants of the Exercise group completed the 10-week exercise training. Six of them missed two to four training sessions because of personal reasons, but no catch-up sessions were given. There was no physical injury caused by the FATmax training in this study. Four participants of the Control group failed to do the test at the end of the experimental period. Therefore, the data of 15 participants of the Exercise group and 11 participants of the Control group were analyzed and reported. The average FATmax HR of the Exercise group was 106 ± 8 beat/min, which corresponded to ~62% of the maximal HR of the participants (220 − age). Daily energy intake and macronutrient intake percentages were not changed significantly before and after the experimental period. There was no significant difference in these nutritional variables between the two groups.

There was no difference in the variables of body composition between the two groups at baseline. Ten weeks of FATmax training significantly decreased body mass, BMI, fat %, fat mass, abdominal fat, and BP; but increased VO_2max, heart rate index, stroke volume, and left ventricular ejection fraction for the participants of the Exercise group. There was no change in these variables in the Control group (Table 1).

Following the FATmax training, FATmax rate of the Exercise group increased significantly from 0.38 g/min to 0.45 g/min. FATmax occurred at 52 ± 6% VO_2max before training,

Table 1
Body composition and cardiovascular variables of the participants.

Variables	Exercise group ($n = 15$)		Control group ($n = 11$)	
	Before	After	Before	After
Age (y)	50.7 ± 5.5		49.7 ± 7.9	
Body mass (kg)	71.5 ± 7.3	68.5 ± 6.8*	71.7 ± 5.8	72.2 ± 4.3
BMI (kg/m^2)	28.5 ± 2.1	27.3 ± 2.0*	27.8 ± 1.5	28.5 ± 1.6
Fat%	39.4 ± 3.5	37.7 ± 4.2**	38.4 ± 5.9	38.6 ± 4.1
Fat mass (kg)	28.2 ± 3.6	25.8 ± 3.7**	27.7 ± 2.8	28.6 ± 3.4
Abdominal fat (kg)	2.4 ± 0.4	2.2 ± 0.4*	2.4 ± 0.3	2.5 ± 0.3
Fat-free mass (kg)	43.4 ± 5.5	42.8 ± 5.5	44.2 ± 4.6	44.3 ± 4.5
Predicted VO_2max (mL/min/kg)	33.9 ± 4.0	37.4 ± 4.4*	33.5 ± 4.1	32.6 ± 2.9
Systolic BP (mmHg)	129 ± 7	114 ± 12*	130 ± 8	132 ± 60
Diastolic BP (mmHg)	78 ± 8	69 ± 7*	75 ± 13	75 ± 8
Heart rate index	54.3 ± 4.0	64.9 ± 7.4*	54.1 ± 10.0	54.6 ± 15.4
Stroke volume (mL)	67 ± 6	72 ± 10*	66 ± 7	67 ± 6
Ejection fraction (%)	58.3 ± 5.4	62.9 ± 4.5*	57.7 ± 6.3	56.5 ± 7.0

Data are presented as mean ± standard deviation.
*$p < 0.05$.
**$p < 0.01$ before and after FATmax training.
BMI = body mass index; BP = blood pressure; FATmax = maximal fat oxidation.

although this percentage was changed to 48 ± 8% VO_2max after training. This change was not significant. The Control group did not have any changes in the FATmax rate, their preexperiment data were 0.40 g/min at 52 ± 6% VO_2max and the postexperiment data were 0.41 g/min at 57 ± 10% VO_2max. In addition, VO_2, fat oxidation rate, and RER at rest, end of 4-minute exercise at 4 km/h and 5 km/h were presented (Table 2). Exercise group's VO_2 data were decreased significantly at these three points after FATmax training. Fat oxidation rates increased; although RERs decreased at 4 km/h and 5 km/h after training. The fat oxidation rates at higher intensities were not calculated as the RER was higher than 1. There was no change in these variables in the Control group.

Trunk muscle strengths of the Exercise group were improved significantly, but no change was found in hand grip strengths following FATmax training. Muscle strengths of the Control group were not changed. Sit-and-reach test showed increased results from the Exercise group but no change in the Control group (Table 3). Correlation analyses indicated that abdominal fat mass had a significant relationship with sit-and-reach test result, $r = -0.74$ ($p < 0.01$) before training and $r = -0.54$ ($p < 0.05$) after training; but not with the trunk muscle strengths. There was no significant correlation between the change of abdominal fat mass and those of trunk muscle strengths and flexibility following FATmax training.

Table 3
Trunk muscle strength and body flexibility variables of the participants.

Variables	Exercise group ($n = 15$)		Control group ($n = 11$)	
	Before	After	Before	After
Trunk flexion (kg)	27.8 ± 9.4	31.1 ± 8.7**	27.9 ± 10.9	26.6 ± 10.6
Trunk extension (kg)	22.1 ± 8.1	31.1 ± 7.7**	21.2 ± 5.0	21.4 ± 4.8
Trunk right lateral flexion (kg)	25.8 ± 8.5	40.7 ± 12.2**	24.1 ± 1.5	24.6 ± 9.2
Trunk left lateral flexion (kg)	28.6 ± 10.1	44.1 ± 12.1**	25.3 ± 9.1	24.5 ± 8.7
Right hand grip (kg)	28.1 ± 4.8	27.5 ± 4.5	27.2 ± 5.7	26.3 ± 4.9
Left hand grip (kg)	28.4 ± 5.2	28.0 ± 4.8	26.9 ± 5.1	27.3 ± 5.3
Sit and reach test (cm)	5.3 ± 8.0	10.6 ± 6.4**	12.1 ± 9.3	11.6 ± 9.2

Data are presented as mean ± standard deviation.
**$p < 0.01$ before and after FATmax training.
FATmax = maximal fat oxidation.

Discussion

Following 10 weeks of FATmax training, most variables of body composition decreased, cardiovascular function improved, trunk muscle strength increased, and body flexibility improved. There were no changes in these variables in the Control group, as well as no significant change in daily energy intake for all participants before and after the interventions. Therefore, this outcome supports the hypothesis of the present study.

The Exercise group decreased their body mass, BMI, and fat% significantly following 10 weeks of FATmax training.

Table 2
Oxygen uptake, fat oxidation rate, and respiratory exchange ratio at rest and two different workloads before and after the interventions.

Groups	Tests	Variables	Rest	4 km/h	5 km/h
Exercise group ($n = 15$)	Before	VO_2 (mL/min)	340 ± 33	1204 ± 195	1352 ± 165
		Fat oxidation rate (g/min)	0.08 ± 0.09	0.22 ± 0.06	0.14 ± 0.10
		RER	0.87 ± 0.15	0.89 ± 0.03	0.94 ± 0.05
	After	VO_2 (mL/min)	291 ± 42*	987 ± 114**	1164 ± 150**
		Fat oxidation rate (g/min)	0.07 ± 0.03	0.32 ± 0.11*	0.28 ± 0.08**
		RER	0.84 ± 0.08	0.81 ± 0.07**	0.85 ± 0.04**
Control group ($n = 11$)	Before	VO_2 (mL/min)	328 ± 71	1011 ± 115	1291 ± 208
		Fat oxidation rate (g/min)	0.11 ± 0.06	0.28 ± 0.09	0.22 ± 0.10
		RER	0.80 ± 0.08	0.83 ± 0.04	0.89 ± 0.05
	After	VO_2 (mL/min)	308 ± 59	1122 ± 205	1335 ± 201
		Fat oxidation rate (g/min)	0.10 ± 0.04	0.32 ± 0.10	0.18 ± 0.20
		RER	0.79 ± 0.08	0.83 ± 0.05	0.91 ± 0.09

Data are presented as mean ± standard deviation.
*$p < 0.05$.
**$p < 0.01$ before and after FATmax training.
FATmax = maximal fat oxidation; RER = respiratory exchange ratio (=VCO_2/VO_2); VO_2 = oxygen uptake.

Associated with these changes, we found that fat mass decreased but not fat-free mass. This result is agreeable to the previous FATmax training studies.[16,18,19] More importantly, the decreased abdominal fat mass was observed in our study. This decrease is an encouraging outcome as this part of fat deposit has been thought as a strong risk factor of heart disease, type 2 diabetes, and the metabolic syndrome.[23,24] The present result provides evidence that overweight participants trained at the FATmax intensity can burn their body fat, including the abdominal fat effectively.

Middle-aged obese women have shown increased risks of coronary heart disease, heart failure, or stroke compared with women in healthy weight range.[5] One of the reasons for this situation may be that the excessive fat storage accumulates not only in adipose tissue, but also in skeletal muscle, liver, and heart; the cardiac fat accumulation may lead to cardiac dysfunction.[25,26] In the present study, we found that cardiovascular function of the Exercise group was improved following the FATmax training. This improvement can be reflected through the HR response in the 3-minute step test. The significantly higher HR index of the Exercise group means that the trained hearts have an improved function and can manage the fixed workload much easier after the FATmax training. The same result has been found in young overweight women following 8 weeks of FATmax training.[16] Hypertension is a major risk factor of cardiovascular disease, renal disease, and mortality.[27] The decreased BP of our Exercise group implies that the FATmax training is effective in controlling BP for middle-aged overweight women. This result is in accordance with a review in which aerobic exercise was recognized as an effective method for hypertension treatment.[28] In this study, we also observed the increases in stroke volume and left ventricle ejection fraction. This beneficial effect on the left ventricle systolic function following aerobic training is agreeable to the outcome of previous exercise and obesity studies.[10,26]

In the present study, we found that the FATmax rate was significantly increased from 0.38 g/min to 0.45 g/min, although the VO_2 at the FATmax did not change following 10 weeks of FATmax training. This result suggests that at the certain workload, trained participants will use more fat as energy than before training. Analyzing the data of VO_2, fat oxidation rate, and RER at rest, 4 km/h and 5 km/h, it has shown that the Exercise group had a decreased VO_2 at rest, but fat oxidation rate and RER were not changed; although at 4 km/h and 5 km/h exercises, these three variables were changed significantly. The decreased RER at 4 km/h and 5 km/h after FATmax training indicated more fat was used as energy. This result associated with the increased fat oxidation rates at these workloads. VO_2 at 4 km/h and 5 km/h were decreased after FATmax training, which also suggests an improved exercise economy.[29] That, however, may reduce the effectiveness of exercise training on energy expending for participants who are obese or overweight. Thus, the clinical value of changed cardiovascular variables should be evaluated critically when they were achieved after exercise training.

Aerobic exercise training has been reported to improve muscle strength,[30,31] but there is no study regarding the change in skeletal muscle strength following FATmax training. In this study, we monitored the effect of FATmax training on the core muscle strength,[32] the important factor controlling body stability, and may result in lower back pain when impaired.[33] The measured trunk muscle strengths which belonged to the core muscle strength were increased significantly in the Exercise group. Correlation analyses between trunk muscle strengths and abdominal fat mass did not show any significant relationships. This result suggests that the improved trunk muscle strengths might be obtained from whole body movement (i.e., walking and jogging) of FATmax training, but not from the abdominal fat loss. The hand grip strength was measured as a general marker of muscle strength of the body; however, it was not changed after FATmax training. It may be explained due to the major exercise mode of the present study being walking or running, although not much upper limb exercise was done. Body flexibility was also improved in the Exercise group. Though there was a significant correlation between sit-and-reach test result and abdominal fat mass at the baseline and after training, the changes in these two variables are not correlated, other factors, such as whole body movement, and muscle and joint stretching may play roles in this flexibility improvement. Consequently, FATmax training can improve core muscle strength and flexibility, which are important components of health-related physical fitness.

There are limitations in this study. As our hypothesis was to test whether the FATmax training is an effective intensity to improve health-related physical fitness for overweight middle-aged women, we did not set up another intensity group. Therefore, the present result cannot be compared with the outcome from training utilizing other intensities. Comparing the effect of FATmax training to other intensities or programs would provide more evidence regarding the optimal exercise training intensity for obesity treatment. Another limitation is the short duration of training. Even though there were significant decreases in body fat %, fat mass, and abdominal fat mass, our trained participants were still overweight, classified by BMI, at the end of the 10-week experimental period. Longer training duration would yield more benefits for the participants.

We have demonstrated that the 10-week FATmax intensity training provided effective improvements to body composition, cardiovascular function, core muscle strength, and body flexibility in overweight middle-aged women. This result suggests that the FATmax is an optimal exercise training intensity for improvement of health-related physical fitness for the participants.

Conflicts of interest

All authors have no conflicts of interest to declare.

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