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Original Research Article

Relationship between regular aerobic physical exercise and glucose and lipid oxidation in obese subjects – A preliminary report

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ABSTRACT

Introduction: The worldwide epidemic of obesity is due to the imbalance between physical activity and dietary energy intake. This is a major contributor to various diseases including type 2 diabetes, dyslipidemia, coronary heart disease, hypertension, sleep apnea, and some kinds of cancer. In obese individuals disturbances in glucose and lipid oxidation are observed, which probably could be improved upon after exercise training. However, the influence of exercise performed by obese individuals on their glucose and lipid metabolism is not clearly understood.

Aim: This study examined whether the intervention of aerobic exercise influences the rates of lipid and glucose oxidation at rest and after an insulin-stimulated state in obese women.

Materials and methods: We examined five obese (BMI > 30 kg/m^2) females without diabetes, aged 31–62, who participated in a 12-week program of aerobic exercise (5 days/week, 30 min/day). Insulin sensitivity was evaluated by the euglycemic hyperinsulinemic clamp (EHC) technique and whole-body lipid and glucose oxidation rates were measured by indirect calorimetry (IC) using the ventilated hood technique. EHC and IC were performed before and after the 12-week exercise program.

Results and discussion: During our investigation, the measurements of body weight, BMI, waist and hip circumferences, body fat (%), fat-free mass (kg), insulin sensitivity, rates of lipid and glucose oxidation, non-oxidative glucose metabolism and increase in the respiratory exchange ratio were taken before and after the exercise intervention. However, the statistical evaluation did not show any significant differences between corresponding results taken before and after the training program. We observed that fat mass decreased and insulin sensitivity increased in three subjects; whereas, in two cases we did not observe any changes after the aerobic training program.

Conclusions: The results obtained indicated that a 12-week aerobic training program was not sufficient to improve insulin sensitivity and substrate metabolism in each obese

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woman. Perhaps some individuals need training of a longer duration to improve their insulin sensitivity and metabolic flexibility.

1. Introduction

The worldwide epidemic of obesity is due to the imbalance between physical activity and dietary energy intake. Obesity concerns an excess of adipose tissue that results from a mixture of genetic predisposition, environmental influences and behavioral components.[18] This is a major contributor to various diseases including type 2 diabetes, hyperuricemia, dyslipidemia (elevated triglycerides and lowered high-density lipoprotein cholesterol), coronary heart disease, hypertension, sleep apnea, some kinds of cancer and a reduced quality of life.[5] The influence of exercise on the glucose and lipid metabolism of obese individuals is not clearly understood. In obese individuals a loss of metabolic flexibility is observed.[21] In this condition, in the skeletal muscle, glucose oxidation (GOx) increases under basal conditions and decreases under insulin-stimulated circumstances, whereas lipid oxidation (LOx) behaves in an opposite manner.[12]

Due to the high prevalence of obesity, interventions such as exercise to promote weight loss have become increasingly important to reduce morbidity in the general population. The current physical activity guideline for adults recommending 30 min of moderate intensity activity daily is of importance for limiting risk factors for a number of chronic diseases.[1,16]

2. Aim

This study examined whether the intervention of physical activity influences the rates of LOx and GOx at rest and after an insulin-stimulated state in obese women.

3. Materials and methods

3.1. General study protocol

We examined five, previously untrained, obese (BMI > 30 kg/m^2) weight-stable females, aged 31–62, who participated in a 12-week program of aerobic exercise. We performed an euglycemic hyperinsulinemic clamp (EHC) to evaluate insulin sensitivity and indirect calorimetry (IC) to assess substrate oxidation before and after a 12-week exercise program. None of the volunteers had type 2 diabetes, morbid obesity, cardiovascular disease, hypertension, infections or any other serious medical problems. None reported taking anti-inflammatory drugs (within the previous 3 months) or any drugs known to affect glucose and lipid metabolism. Before the onset of the study, physical examinations were performed. All subjects underwent an oral glucose tolerance test (OGTT) and did not have diabetes according to the World Health Organization (WHO) criteria. All subjects provided written informed consent before their inclusion in the study. The study protocol was approved by the Ethics Committee in the Medical University of Białystok, Poland.

3.2. Anthropometric measurements

BMI was calculated as body weight in kilograms divided by height in meters squared (kg/m^2). The waist circumference was measured at the smallest circumference between the rib cage and the iliac crest, with the subject in the standing position. Percent of body fat was estimated by bioelectric impedance analysis using the Tanita TBF-511 Body Fat Analyzer (Tanita Corp., Tokyo, Japan).

3.3. Insulin sensitivity

Insulin sensitivity was evaluated by the EHC technique as described by DeFronzo et al.[4] Insulin (Actrapid HM, Novo Nordisk, Copenhagen, Denmark) was given as a primed, continuous intravenous infusion for 2 h at 40 mU $\times$ m^{-2} $\times$ min^{-1}, resulting in a constant hyperinsulinemia of approximately 75 mU/L. Arterialized blood glucose was obtained every 5 min and a 20% dextrose (1.11 mol/L) infusion was adjusted to maintain plasma glucose levels at 5.00 mmol/L. The glucose infusion rate approached stable values during the final 40 min of the study and the rate of whole-body glucose uptake (M value) was calculated as the mean glucose infusion rate from 80 to 120 min, corrected for glucose space and normalized per kilogram of fat-free mass (M_{fffm}).

3.4. Lipid and glucose oxidation

Whole-body LOx and GOx rates were measured by IC using the ventilated hood technique (Oxycon Pro, Viasys Healthcare GmbH–Erich Jaeger, Hochberg, Germany) in order to calculate LOx and GOx from respiratory gas exchange (oxygen consumption and carbon dioxide production). The device was calibrated before each test using reference gases. Measurements were performed while the subjects were lying in a supine position at baseline (in the fasting state) and during the last 30 min of the clamp study. Each study was performed in a thermoneutral environment, after relaxing for 15 min. Non-oxidative glucose metabolism (NOGM) was calculated by subtracting the GOx rate during hyperinsulinemia from the whole-body glucose disposal rate. An increase in the respiratory exchange ratio (delta RER) in response to insulin was used as the measure for metabolic flexibility.

3.5. Exercise training protocol

The exercise program was performed utilizing a stationary bicycle. Subjects were asked to participate in exercise sessions 5 days a week, lasting 30 min per session for 12 weeks.

Training intensity was gradually increased. A physiotherapist supervised each session. Each session included some gentle stretching exercises lasting 5 min. For the first 4 weeks, subjects had a load of 20 W, during the following 4 weeks loading was 40 W, and during weeks 9–12 volunteers achieved 60 W of load, intensity eliciting 70% of maximal heart rate. Compliance with the target workloads and number of sessions was more than 90%.

3.6. *Biochemical analyses*

Plasma glucose was measured immediately employing the enzymatic method using a glucose analyzer (YSI 2300 Stat Plus, YSI Inc., Yellow Springs, USA).[7]

3.7. *Statistical analysis*

Statistical analysis was performed employing the Statistica 8.0 program (StatSoft, Kraków, Poland). The differences between the groups were evaluated with an unpaired Student's *t*-test. The level of significance was accepted at *P*-value less than 0.05.

4. Results

The clinical characteristics of the study group are shown in Table 1. During our investigation the measurements of body weight, BMI, waist and hip circumferences, body fat (%), fat-free mass (kg), insulin sensitivity, rates of LOx, GOx, NOGM and delta RER were taken before and after the exercise (Table 2). However, the statistical evaluation did not present any significant differences between corresponding results taken before and after the training program. We observed that fat mass decreased and insulin sensitivity increased in three females, whereas in two cases, we did not observe any changes following the aerobic training program.

5. Discussion

It is evident that exercise can significantly reduce the incidence of many diseases, although available studies have not established any specific mechanisms for these beneficial effects. Currently, the American Diabetes Association recommends at least 150 min of moderate activity per week to prevent or delay type 2 diabetes.[1] We performed a 12-week course of aerobic exercises (5 days/week, 30 min/days) and examined whether physical activity influences rates of LOx and GOx and NOGM and changes insulin sensitivity in obese females. In our investigation we did not obtain statistically significant differences before and after the training program. In recent years, researchers have shown that an exercise training program can elicit changes in the rate of substrate oxidation.[8,9,15,19,25] Zarins et al. noticed decreased GOx and increased LOx, without changes in body weight, during submaximal exercise.[24] Similarly, Sial et al. found that endurance training can increase LOx and decrease GOx in elderly individuals.[19] Solomon et al. showed that exercise training improves resting substrate oxidation along with promoting lipid utilization in skeletal muscle.[20] Despite results derived from other studies,[19,24,25] we did not find significant changes in GOx, LOx and NOGM in response to a 12-week aerobic training for obese females. This could mean that before and after the training, GOx and LOx were working at their maximal capacities. Gaine et al. obtained the same result.[6] Obesity is characterized by an impaired ability to oxidize fat during exercise,[8,11,23] but this result was not achieved in all studies.[10] We know that substrate oxidation during exercise can be influenced by exercise intensity, duration and type of exercise or gender. Scharhag-Rosenberger et al., who trained 17 non-obese sedentary participants for 1 year, observed that endurance training did not influence resting metabolic rate (RMR) and substrate oxidation at rest. In contrast, they showed that training improved maximal exercise LOx rate.[17] However, this data was obtained from non-obese subjects so

Table 1 – Clinical characteristics of the study group.

	Before training	After training
BMI (kg/m^2)	33.5±3.2	33.4±2.7
Body weight (kg)	85.9±11.9	85.5±9.5
Waist circumference (cm)	99.0±10.0	96.0±6.0
Hip circumference (cm)	115.0±10.0	109.0±8.0
Body fat (%)	41.8±5.1	39.6±7.2
Fat-free mass	49.5±3.5	51.2±3.7
Fat mass	36.4±9.4	34.2±9.4
Systolic blood pressure	125.0±5.0	125.0±5.0
Diastolic blood pressure	75.0±5.0	75.0±5.0

Comments: data are presented as mean±SD.

Table 2 – Respiratory exchange ratio, nutrient oxidation rate, NOGM, metabolic flexibility, insulin sensitivity index before and after a 12-week aerobic training program.

	Before training	After training
RER_1	0.82±0.06	0.77±0.05
RER_2	0.80±0.05	0.79±0.05
REE_1	1480±223	1456±124
REE_2	1559±94	1518±148
GOx_1 [mg × kg_{ffm}^{-1} × min^{-1}]	1.90±1.04	0.68±1.07
LOx_1 [mg × kg_{ffm}^{-1} × min^{-1}]	1.45±0.93	1.89±0.85
GOx_2 [mg × kg_{ffm}^{-1} × min^{-1}]	1.81±1.17	1.48±1.03
LOx_2 [mg × kg_{ffm}^{-1} × min^{-1}]	1.66±0.66	1.64±0.71
NOGM [mg × kg_{ffm}^{-1} × min^{-1}]	3.07±1.94	4.34±2.50
delta RER	−0.01±0.02	0.02±0.07
M [mg × kg_{ffm}^{-1} × min^{-1}]	6.7±3.4	8.1±3.3

Comments: data are presented as mean±SD. Abbreviations: RER_1 – respiratory exchange ratio before clamp; RER_2 – respiratory exchange ratio during clamp, REE_1 – resting energy expenditure before clamp; REE_2 – resting energy expenditure during clamp; GOx_1 – rate of glucose oxidation in the basal state; LOx_1 – rate of lipid oxidation in the basal state; GOx_2 – rate of glucose oxidation during hyperinsulinemia; LOx_2 – rate of lipid oxidation during hyperinsulinemia; NOGM – non-oxidative glucose metabolism; delta RER – change in respiratory exchange ratio in response to hyperinsulinemia; *M* – whole-body glucose uptake normalized per kg of fat-free mass.

we could not compare these results with ours. Interestingly, Crisp et al. demonstrated that there were no significant differences between overweight and normal weight boys with respect to substrate oxidation at rest and during exercise, but that the early recovery RER transiently increased in the overweight boys.[3] Other researchers achieved similar results concerning exercises for obese children.[2] Lazzer et al. observed no significant changes in the substrate oxidation rate during exercise and post-exercise recovery, but they showed that low intensity physical activity (40% of VO_{2max}) favored LOx.[14] We did not estimate substrate metabolism during exercise. We measured GOx and LOx at rest and after insulin stimulation before and after a 12-week aerobic training program. It is possible that we did not observe changes in the substrates metabolism after the aerobic training program because of differences occurring only during exercise. On the other hand, the sample size of our study was too small and the exercise intervention was not sufficiently long enough. We did not obtain, in each subject, an increase in fat-free mass after the training program, i.e., a major determinant of substrate utilization, and that could be the main reason for the absence of change in substrate metabolism. There are also large interindividual differences with respect to substrate metabolism.

In the present study we also investigated the influence of aerobic exercise on changes concerning insulin sensitivity in obese volunteers. The HEC technique was performed to reflect muscle insulin sensitivity.[4] Available data indicate clearly that aerobic exercise training improves oxidative capacity and insulin sensitivity in obese subjects.[8,13,15,22] We demonstrated a tendency to an increase in insulin sensitivity in three subjects; whereas in two females insulin sensitivity remained unchanged after a 12-week aerobic training program.

6. Conclusions

Obesity is an important health problem that increases the risk for many diseases of civilization. Despite many studies that have appeared in recent years, we need more knowledge about the impact of exercise on obesity. The results obtained by us showed that a 12-week aerobic training program is not sufficient to improve insulin sensitivity and substrate metabolism in each obese female subject. Perhaps some individuals require training of a longer duration to improve their insulin sensitivity and metabolic flexibility.

Conflict of interest

None declared.

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