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EFFECTS OF MODERATE EXERCISE ON METABOLIC RESPONSES AND RESPIRATORY EXCHANGE RATIO (RER)

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ABSTRACT

To counteract insulin resistance, it is necessary to increase the utilization rate of fatty acids in blood and adipose tissue. The aim of the present study was to determine the relation between metabolic responses and exercise duration from changes in the respiratory exchange ratio (RER). The mean RER during 30 minutes of moderate exercise (mean pulse 115 beats/min) was 0.89±0.02, indicating no major change. Significant changes were observed in the levels of plasma glucose (PG), plasma free fatty acid (FFA), and plasma immunoreactive insulin (IRI) before and after exercise, demonstrating a decrease in PG and IRI, and an increase in FFA levels. However, the RER value indicated that carbohydrate was the dominant metabolic substrate; therefore, prolonged or repetitive brief and mild to moderate exercise is necessary to increase the utilization of fatty acids.

Key Words: metabolic responses, moderate exercise, respiratory exchange ratio (RER)

INTRODUCTION

There are numerous studies on the effectiveness of exercise therapy for lifestyle-related diseases associated with insulin resistance such as diabetes, hypertension, hyperlipidemia, and obesity. To diminish insulin resistance, it is necessary to increase the utilization rate of fatty acids in blood and adipose tissue[1)]. Long-term moderately intense exercise at 50% of maximal oxygen consumption has been recommended for both obese and non-obese subjects[2,3)], because it has been known that fatty acids cannot be used for muscle energy following an exercise of short duration[4)]. However, a positive correlation has been reported between the improvement of insulin resistance and the number of steps walked per day[5)], which suggests that increasing the amount of cumulative exercise is more important than the duration of exercise in improving insulin resistance[6)]. Therefore, it might be speculated that fatty acids are available for energy following a short-term exercise.

To verify this point, we investigated changes in the respiratory exchange ratio (RER) during moderate exercise based on the relation between exercise duration and metabolic responses.

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SUBJECTS AND METHODS

Nine untrained healthy subjects (7 males, 2 females) with a mean age of 23±5 (mean±SD) years and a body mass index (BMI) of 20.6±2.3 kg/m^2 participated in this study after giving informed consent. The study was approved by the Ethical Committee of the Research Center of Health, Physical Fitness and Sports, Nagoya University.

The subjects were studied in the postabsorptive state after an overnight fast. A bicycle ergometer (active 10 II, Takei Equipment, Niigata, Japan) was used, and the exercise load was continued for 30 minutes with a heart rate of 120 beats/min. An expired gas analysis was conducted during the exercise using the breath-by-breath method (2900 SensorMedics, California, USA), and RER was measured. The exercise intensity was confirmed from the percentage of the actual oxygen consumption ($\dot{V}O_2$) level against the estimated maximal oxygen consumption ($\dot{V}O_2max$), and was checked after the exercise with the rating of perceived exertion (Borg's score) of subjective intensity[7]. Blood samples were collected before and after the exercise for analyses of plasma glucose (PG), immunoreactive insulin (IRI), total cholesterol (TC), triglycerides (TG), free fatty acids (FFA), and lactic acid (LA). PG was measured by the glucose oxidase method, and IRI by radioimmunoassay (Phadeseph Insulin RIA, Pharmacia AB, Sweden). TC, TG and FFA were analyzed enzymatically. LA was determined using a Lactate Pro (LT-1710 Arkray, Kyoto, Japan). Data were presented as means±SD. Student *t*-test was used for the statistical analysis, and $p<0.05$ was considered statistically significant.

RESULTS

RER (Figure 1)

RER in the resting state was 0.75. RER decreased slightly after 3.5 minutes and increased slightly to 0.78±0.05, but then gradually rose to a maximum level of 0.94±0.07 9 minutes after the start of exercise. Subsequently there was a slight downward trend, but no major fluctuations were found. The mean levels were 0.89±0.02.

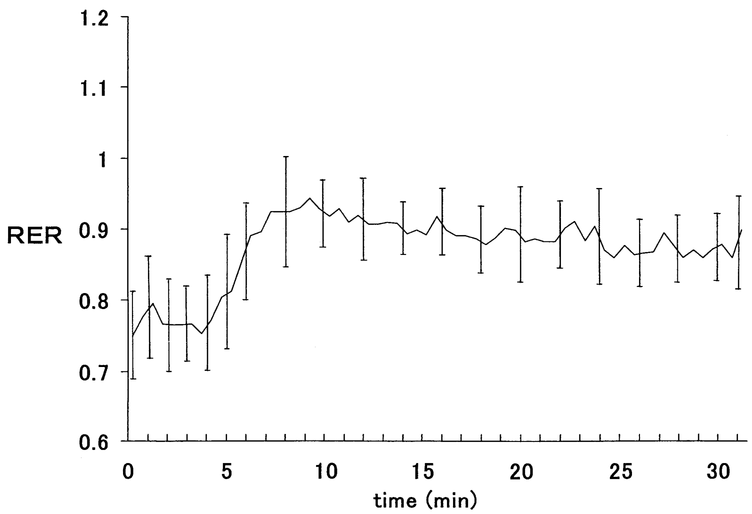

Figure 1: The responses of RER during exercise.
Values are means±SD for nine subjects.

Exercise intensity

The mean heart rate of subjects during exercise was 115±3 beats/min (Figure 2), which was 62.2±1.3% of the estimated mean maximum heart rate for those subjects. $\dot{V}O_2$/kg increased gradually and reached a plateau (17.2±4.15 ml/kg/min) 9 minutes after the initiation of exercise (Figure 3). At this point the percentage of the mean of $\dot{V}O_2$ against the mean of estimated $\dot{V}O_2$ max was 47.4±10.8%. The Borg's score was 13 (12-14).

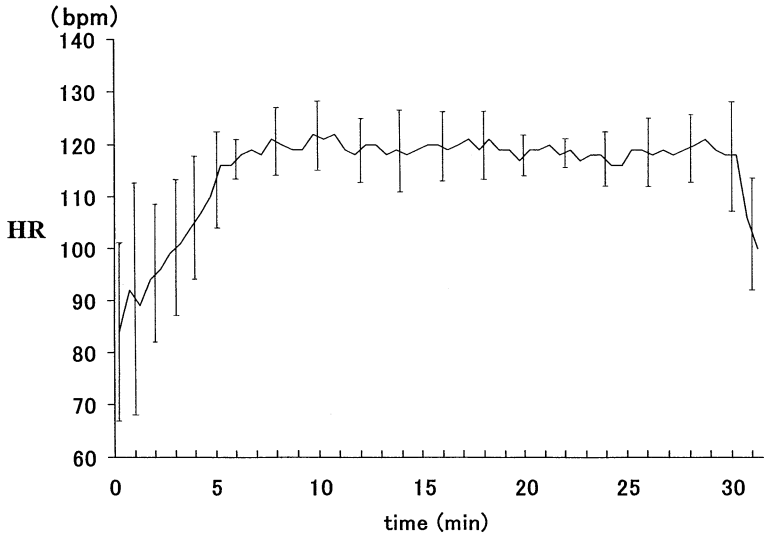

Figure 2: The responses of HR during exercise.
Values are means±SD for nine subjects.

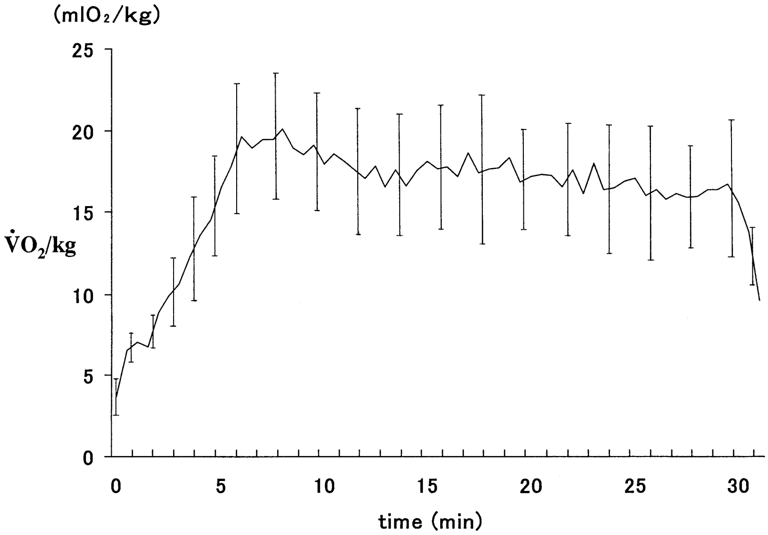

Figure 3: The responses of $\dot{V}O_2$/kg during exercise.
Values are means±SD for nine subjects.

Blood chemical data (Table 1)

A one-sided test revealed significant changes in PG, IRI, and FFA before and after exercise. PG ($p<0.05$) and IRI ($p<0.05$) decreased, whereas FFA ($p<0.05$) increased.

DISCUSSION

Carbohydrate and lipids are used as energy sources during endurance exercise, and the proportion of carbohydrate and fatty acids used depends on the intensity and the duration of the exercise[8]. Fatty acid utilization is known to increase in endurance exercise, continuing for more than 90 minutes[9], whereas during exercise below the level of 50% $\dot{V}O_2max$ the utilization of carbohydrate and fatty acids is roughly the same. To prevent and/or reduce insulin resistance, it is necessary to increase the utilization of fatty acids in adipose tissue and blood. Exercise intensity should be moderate or lower. The mean heart rate of 115 beats/min in the present study corresponded to 40~50% of $\dot{V}O_2max$[10], and the percentage of mean $\dot{V}O_2$ to the mean of estimated $\dot{V}O_2max$ was 32~47%.

The ratio of carbohydrate to lipid utilization can be estimated from the respiratory quotient (RQ). Because there are large fluctuations in the CO_2 concentration during strenuous exercise, CO_2/O_2 during that time is taken to be RER, which is distinct from RQ but is thought to correspond to RQ during aerobic exercise below the maximum level[11]. The initial decrease in RER after the start of exercise is thought to be due to the difference in the response of carbon dioxide elimination ($\dot{V}CO_2$) compared to that of $\dot{V}O_2$[12]. The RER in the resting state was 0.75 ±0.06, which corresponded to a metabolic substrate ratio of 14.7% for carbohydrates and 85.3% for fatty acids[13]. If exercise is continued for a long duration, RQ is known to gradually decrease with exercise time due to a decrease in the amount of stored carbohydrates. This same trend was also observed in the present study. The RER 9 minutes after the start of exercise was thought to be in a state of near equilibrium below the maximum aerobic exercise, and a mean RER of 0.89±0.02 corresponded to a metabolic substrate ratio of 64.2% for carbohydrates and 35.8% for fatty acids[13].

In the blood chemical data, significant changes were found before and after exercise in PG, FFA, and IRI. There is considerable uptake of PG by the muscles during exercise, but since there is also an increase in the release of glucose from the liver, there is little decrease except when the exercise continues for a long time[12]. In the present study a slight decrease in PG was observed following 30 minutes of exercise. However, the above changes were within physi-

Table 1 Blood chemical data

	before exercise	after exercise	
PG (mg/dl)	87±8	84±7	*
IRI(μU/ml)	9.2±5.3	8.4±5.4	*
TC (mg/dl)	166.4±33.2	168.0±33.4	
TG (mg/dl)	58.7±14.2	58.0±15.9	
FFA(mEq/l)	0.56±0.19	0.70±0.27	*
LA (mmol/1)	1.04±0.25	1.26±0.66	

Values are means±SD. PG: plasma glucose level; IRI: immnoreactive insulin; TC: total cholesterol; TG: triglyceride; FFA: free fatty acid; LA: lactic acid;
*: $p<0.05$; statistically significant from before exercise.

ological ranges. As exercise intensity and duration increase, the catecholamine and glucagon levels increase and insulin levels decrease. This is accompanied by an increase in plasma FFA levels, which is related to higher lipid utilization in muscle and lipolysis in adipose tissues[12]. In the present study a significant decrease in IRI and an equally significant increase in FFA levels were observed.

In the present study, during moderate exercise for 30 minutes the RER value indicated that carbohydrate was the dominant metabolic substrate. However, the half-life of FFA in subjects at rest was 2~3 minutes, and might have become even shorter during exercise. Therefore, even repetition of a short-term exercise could increase the rate of fatty acid metabolism. Kelley et al. reported that under fasting conditions, obese subjects with insulin resistance had an elevated leg respiratory quotient (RQ, 0.09±0.01 vs. 0.83±0.02; $p<0.01$) and reduced fat oxidation[14]. Therefore, it becomes necessary for obese subjects to perform mild physical exercise for a long time. However, recently people seem to be always very busy and have few chances to engage in prolonged physical exercise. In these cases, repetition of short-term physical exercise should be carried out on a regular basis. As already shown in this study, fatty acids can be utilized even during mild short-term physical exercise.

In conclusion, the present study suggests that an increase in the cumulative amount of brief and mild to moderate exercise is important for both the prevention and treatment of lifestyle-related diseases involving insulin resistance.

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