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Original article

Acute changes in glycemic homeostasis in response to brief high-intensity intermittent exercise in obese adults

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Abstract

This study investigated the acute changes in glycemic homeostasis in response to brief, high-intensity, intermittent exercise in obese adults. Ten obese adults (age: 25.3 ± 5.1 years; body mass index: 32.0 ± 4.0) volunteered to participate in the study. The time-course changes in blood glucose in response to a 75-g oral glucose tolerance test were examined following: high-intensity intermittent exercise (HIE) of four 30-second all-out cycling efforts interspersed with 4-minute active recovery periods; 24 hours of recovery post-HIE (REC); and no treatment (control, CON). Blood glucose in each trial was measured before, and 30, 60, 90, and 120 minutes after glucose intake (GI). Blood glucose (mmol/L) at 30 minutes post-GI in the HIE (6.9 ± 0.4) trial was significantly lower ($p < 0.05$) than the corresponding values of the CON (9.0 ± 0.4) and REC (8.8 ± 0.4) trials. Blood glucose concentration at 120 minutes post-GI in the REC (5.7 ± 0.3) trial was also significantly lower ($p < 0.05$) than the corresponding value of the CON (6.9 ± 0.4) trial. When blood glucose values were plotted against corresponding time points, the area under the curve (mmol/L/minute) of the CON (890 ± 43) trial was significantly greater ($p < 0.05$) than that of the HIE (834 ± 40) and REC (846 ± 32) trials. The HIE and REC conditions were not significantly different ($p > 0.05$). This study demonstrated the improvement in glycemic homeostasis in obese adults immediately after brief, high-intensity, intermittent exercise. These effects were maintained for at least 24 hours postexercise. The findings may be useful in the development of time-efficient lifestyle intervention strategies for improving obesity-related risk factors for diabetes.

Keywords: High-intensity interval exercise; Obesity; Oral glucose tolerance test

Introduction

Insulin resistance, a key contributor to the development of type 2 diabetes, is associated with obesity and a sedentary lifestyle.[1] Involvement in regular physical activity therefore serves as the first line of defense in preventing diabetes.[2,3] Public health guidelines generally recommend that adults perform physical activity at a moderate intensity for at least 150 minutes/week, or at vigorous-intensity for 75 minutes/week.[4] These recommendations are based on robust evidence that long-term exercise can enhance the capacity of muscle oxidation and glucose transport, which are linked to improved insulin sensitivity and glycemic control.[5] Despite this information, individuals generally choose not to participate in physical activity. Lack of time has been cited as a major barrier to exercise.[6,7]

In an attempt to overcome this obstacle to participation in exercise, low-volume, high-intensity interval training regimes, which could induce similar favorable metabolic adaptations associated with traditional high-volume endurance training, have been developed. Babraj et al[8] reported that a 2-week intense interval training program, comprising of a total of 15 minutes of exercise (three sessions per week; 4–6 × 30-

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second cycle sprints per session), could improve post-training glucose tolerance in young men. Recent studies further demonstrated marked increases in insulin sensitivity after a period of 2 weeks of intense interval training in healthy,[9] as well as overweight, adults.[10] Previous studies have not, however, examined the acute changes in these variables mediated by a single session of interval training. It is unclear whether the observed alterations in glycemic homeostasis following intense interval training were the results of permanent adaptations to training, or simply the acute effects of the last training session in the subsequent recovery period.[5,11] In an attempt to advance the existing knowledge on time-efficient lifestyle intervention strategies for the prevention of diabetes, further understanding of the alterations in glycemic control immediately and 24 hours (a typical duration of recovery following a regular exercise program usually exercise at 24- to 48-hour intervals) after a single session of the intense interval training program were analyzed.

The purpose of this study was to examine the immediate (within 2 hours postexercise) and sustained (24 hours post-exercise) effects of brief, intense, intermittent exercise (4×30-seconds maximal cycling efforts interspersed with 4-minute periods of active recovery) on glucose tolerance in obese adults following a 75-g oral glucose tolerance test (OGTT).

Methods

Design

Following an experimental familiarization trial with experimental procedures, the participants undertook to meet three experimental conditions on different days at the same time of day (09:00h): (1) high-intensity intermittent exercise (HIE); (2) 24-hour recovery post-HIE (REC); and (3) no treatment (control, CON). The HIE and CON interventions were assigned in a random, balanced order, and were separated by 1 week. One day prior to each trial, the individuals were provided with the same meals (approximately 60% carbohydrate, 25% fat, and 15% protein) at the same time, and were instructed not to eat after 23:00 PM.

Participants

Ten Chinese males (age: 25.3 ± 5.1 years; height: 173.7 ± 5.3 cm; and weight: 96.7 ± 13.1 kg) volunteered to participate in this study. All of their recorded body mass indexes were >28 (28.7–42.2; 32.0 ± 4.0), which is the cutoff for obesity in Chinese populations.[12] All of the men had a weight variation within 2 kg recorded in the previous 6 months, were free from hypertension, diabetes, and eating disorders and were non-smokers. They did not engage in regular exercise; had no previous history of coronary heart disease or family history of early cardiac death (<40 years); and required no chronic medication. Following an explanation of the purpose and constraints of the study and the potential benefits and risks involved in the exercise tests, the men gave written informed consent to participate. The College Ethical Committee for the Use of Human and Animal Subjects in Research provided ethical approval of the study.

Intervention

The HIE trial consisted of 14-minute high-intensity intermittent exercise. The protocol comprised of four 30-second maximal exercise bouts interspersed with 4-minute active recovery periods. The participants cycled maximally against a load equivalent to 5% body weight on a stationary cycle ergometer (Monark Ergomedic 839E, Monark, Sweden) during the 30-second exercise, and cycled against a minimum load during the 4-minute recovery period. A REC trial was conducted 24 hours after the HIE trial. This trial had identical conditions to the HIE trial, but in place of cycling the participants sat quietly for an equivalent period of time. The control (CON) trial was held 7 days apart from the HIE trial. The conditions were identical to that of the REC trial.

Outcome measures

Following the 14-minute exercise (HIE) or non-exercise period (REC and CON), subjects underwent an OGTT by ingestion of 75 g anhydrous glucose dissolved in 300 mL of water at around 09:20 AM. Arterialized venous blood samples from capillary finger-prick samples were collected before, and 30, 60, 90 and 120 minutes after glucose intake (GI) for the examination of glycemic responses. Blood glucose concentrations were measured immediately upon collection using an Ascensia Elite Blood Glucose Meter with Ascensia Elite Blood Glucose Test Strips (Bayer Corp., Mishawaka, USA). The reported detection range and the relative standard variation were 1.1–33.3 mmol/L and <3.1%, respectively.

Data analysis

Blood glucose values were plotted against corresponding time points. The glucose area under the curve (AUC) for each trial was calculated, based on the conventional trapezoid rule, by applying GraphPad Prism 5.01 software (San Diego, CA, USA). The difference in glucose AUC between the three trials was examined using one-way within-participant analysis of variance. Two-way repeated measure analysis of variance was used to examine the difference in glucose response in relation to the five time points and across the three trials. *Post-hoc* analyses using the Newman-Keuls method were performed when the main effect was significant. A level of $p < 0.05$ was considered statistically significant in this study. All of the results are expressed as mean ± standard error of the mean.

Results

All of the participants were able to complete the four 30-second exercise bouts with maximum effort in the HIE trial. The mean power output for the first to fourth exercise bouts were 425.6 ± 59.6 W, 370.9 ± 36.3 W, 300.7 ± 53.4 W, and 286.3 ± 54.3 W, respectively.

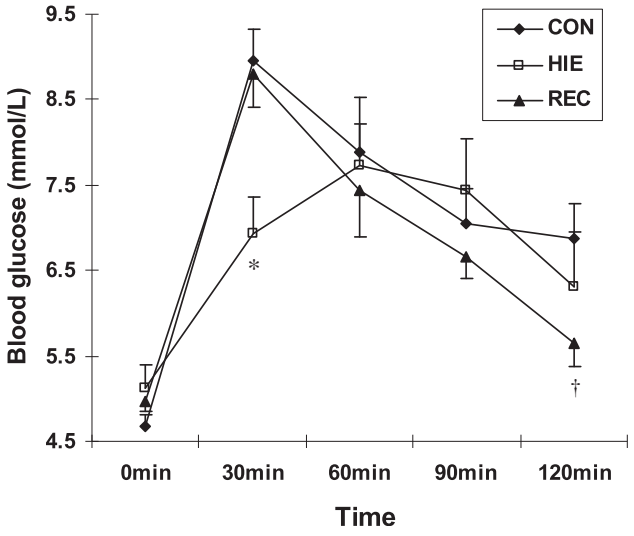

Fig. 1. Mean and standard error of the mean for blood glucose in response to a 75-g oral glucose tolerance test (OGTT) preceded by a high-intensity intermittent exercise trial (HIE), a non-exercise recovery trial (REC), and a control trial (CON) over time [Pre-OGTT (0 min), 30 min, 60 min, 90 min, and 120 min post-OGTT]. *Significantly different from CON and REC, $p < 0.05$. †Significantly different from CON, $p < 0.05$.

The glycemic responses to OGTT in the HIE, REC and CON trials are shown in Fig. 1. Blood glucose levels at 30 minutes post-GI in the HIE trial (6.9 ± 0.4 mol/L) were significantly lower ($p < 0.05$) than the corresponding values of the CON (9.0 ± 0.4 mol/L) and REC (8.8 ± 0.4 mol/L) trials. Blood glucose concentrations at 120 minutes post-GI in the REC (5.7 ± 0.3 mol/L) trial was also significantly lower ($p < 0.05$) than the corresponding value of the CON trial (6.9 ± 0.4 mol/L).

The glucose AUC of the CON (890 ± 43 mmol/L/minute) trial was significantly greater ($p < 0.05$) than that of the HIE (834 ± 40 mmol/L/minute) and REC (846 ± 32 mmol/L/minute) trials. No significant difference ($p > 0.05$) was found between the HIE and REC trials.

Discussion

To our knowledge, this is the first study to demonstrate the acute effect of a brief, high-intensity, intermittent exercise (an exercise period of 2 minutes) on glucose tolerance in obese adults. We noted that the glycemic homeostasis of the participants improved significantly immediately and 24 hours after the exercise. The current findings are noteworthy, especially when considering the study design, where the influences of pre-OGTT diet and any diurnal variation in glucose tolerance of the subjects were strictly controlled. In all experimental trials, the participants consumed identical meals on the day preceding each OGTT. This was observed to minimize the effects of pre-OGTT meals with a varied glycemic index that might interfere with the subsequent OGTT results.[13,14] Further, given the existence of normal diurnal variation in glucose tolerance,[15,16] all of the experimental trials and subsequent OGTTs in the present study were performed at the same time of day (i.e., intervention: 09:00–09:14 AM; and OGTT: 09:20–11:20 AM) on different days.

It has been reported that a single bout of classic time-consuming aerobic or strength exercise might improve glucose tolerance for more than 24 hours[17]; however, the notion has not been strongly supported by follow-up studies. Zhu et al[18] found that 45 minutes of treadmill exercise commenced immediately after 75-g of glucose was ingested did not suppress the resultant increase in blood glucose compared with a CON trial on the same subjects. Further, Mitchell et al[19] did not observe any significant change in OGTT-associated AUC of blood glucose 24 hours after 60 minutes of aerobic exercise in comparison to the absence of such exercise the day before on the same individuals. The cause of the equivocal findings in the effects of prior aerobic exercise on glycemic homeostasis is not known, and may be multifactorial. Nevertheless, the intensity of exercise might be an essential factor, as exercise improves insulin sensitivity by depleting muscle glycogen, which occurs at a faster rate during high- compared with low-intensity exercise.[20,21] It has been demonstrated that four 30-second maximum exercise bouts performed intermittently on a cycle ergometer can reduce the glycogen storage of active muscles by almost 30%, while enhancing the activation of adenosine monophosphate-activated kinase in the tissues.[22] Such acute glycogen depletion and enhanced adenosine monophosphate-activated kinase activation consequent to heavy exercise may promote glycogen synthase activity, which plays a key role in mediating the translocation of glucose transporter 4 in active muscles.[23,24] As a result, the rate of glucose uptake in the muscles increases.[25] Moreover, the time required for full restoration of muscle glycogen in response to the carbohydrate depletion resulting from intense intermittent exercise has been demonstrated to take more than 20 hours.[26] This may explain, at least in part, the maintenance of the increased glucose uptake postexercise for 24 hours, as observed in the present study.

Regardless of the mechanisms responsible, the current findings are in line with the enhanced insulin sensitivity and glycemic control reported following high-intensity interval training.[8–10] The acute responses following brief intense intermittent exercise add to the scientific body of evidence. The findings from this study indicate that, in obese adults without any training experience, the observed adaptations following intense interval training in glycemic homeostasis can be achieved rapidly. In addition to the findings of Whyte et al,[10] that the effects of high-intensity interval training on enhanced glucose tolerance in obese men became insignificant 24 hours after cessation of the exercise training, the current findings show that the improvements in glycemic control noted subsequent to high-intensity interval training may be the result of the residual effects of a previous bout of exercise rather than any long-term adaptations to training. Such acute glucoregulatory effects of brief, intense, intermittent exercise suggest that low-volume, high-intensity interval training regimes could act as time-efficient lifestyle intervention strategies for improving obesity-related risk factors for diabetes. The present findings also demonstrate the potential testing error that exists in clinical settings when the OGTT is utilized for the purposes of pre-diabetes screening or the diagnosis of diabetes. To avoid the

rise in blood glucose level in response to OGTT that may be lessened by unpremeditated physical activity (intermittent as well as continuous types), patients should abstain from any type of strenuous physical activity for at least 24 hours prior to the OGTT being administered.

In the present study there are several caveats that deserve discussion. First, we used arterialized venous blood from capillary finger-prick samples as opposed to venous blood samples because we determined that the arterialized venous blood would provide more accurate information on glycemic alteration during the OGTT.[27] Our findings provide reasonable information regarding the acute changes in glucose tolerance in response to the OGTT following brief intense intermittent exercise in obese adults. Further interpretation of the current findings is therefore limited by the lack of data related to the changes in insulin and C-peptide, which are commonly assessed through venous blood sampling. Other possible limitations to our study are the small sample size and the normoglycemic characteristic of most of the participants. Further clarification of the effectiveness of brief, intense, intermittent exercise on glycemic homeostasis with augmented sample size and in different populations, such as pre-diabetic individuals, is recommended. Finally, the Wingate-based exercise model we used requires participants to exercise with maximum physical exertion and to have an extremely high level of motivation. Given the extreme nature of the exercise, the present study raised questions as to the feasibility of low-volume, high-intensity interval training as a realistic alternative to traditional time-consuming exercise training for promoting physical health in obese people. Nevertheless, our observations following the extreme form of high-intensity intermittent exercise may stimulate follow-up research into interval-based approaches for identifying the optimal combination of exercise intensity and volume necessary to induce health benefits in the obese population in a practical, time-efficient manner.

In conclusion, glucose tolerance in response to OGTT in obese men was improved immediately after brief (14 minutes) intermittent exercise comprising four 30-second all-out cycling exercise bouts. Such an acute effect appeared to be maintained for at least 24 hours postexercise.

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