Original Articles

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Changes in Blood Glucose and Lipid Metabolic Parameters After High-Carbohydrate Diet Ingestion in Athletes with Insulin Resistance

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Objective: We aimed to elucidate changes in blood glucose and lipid metabolic parameters after high-carbohydrate diet ingestion in athletes with insulin resistance.

Methods: Ten throwers belonging to the university track and field club participated in this study. They underwent oral glucose tolerance test and high-carbohydrate test on 2 separate days with a 1-week interval. Serum insulin, lipid indices, and blood glucose levels were determined in both tests.

Result: According to the homeostasis model assessment for insulin resistance (HOMA-IR) score, three participants with HOMA-IR ≥ 2.5 were assigned to the high-HOMA-IR group and the remaining seven to the low-HOMA-IR group. The high-HOMA-IR group showed higher insulin and triglyceride levels after consuming the high-carbohydrate diet. Significant correlations were found between insulin and triglyceride levels and between HOMA-IR score and triglyceride levels after 180 min of a high-carbohydrate diet ingestion ($r=0.80$, and $r=0.70$, respectively).

Conclusion: The results of this study suggest that a high-carbohydrate diet results in high insulin levels in athletes with insulin resistance, which could lead to a state of high triglyceride levels.

Key words: high-carbohydrate diet, thrower, insulin resistance, hyperinsulinemia, postprandial triglyceride

Introduction

Regular exercise prevents factors that cause insulin resistance, such as obesity. Athletes have higher cardiopulmonary function and lower body fat percentage than do non-athletes. In addition, athletes have higher insulin sensitivity in the skeletal muscle, which allows enhanced glucose uptake from the circulation, thereby lowering the risk of development of insulin resistance[1-3].

Athletes whose performance relies on their weight, such as throwers, maintain their weight by increasing the amount of energy intake from meals in comparison with the energy consumed during training[4-6]. Thus, these athletes are more prone to the development of diseases such as insulin resistance, diabetes, and hyperlipidemia; these diseases are evaluated based on blood examinations after a period of fasting[6-8]. The oral glucose tolerance test (OGTT) is frequently used clinical tool for assessment of glucose metabolism, including in athletes[9-11]. Few studies, to our knowledge, have assessed insulin resistance in athletes using the homeostasis model assessment for insulin resistance (HOMA-IR) in conjunction with OGTT.

Meals do not consist of glucose alone but contain a combination of a variety of nutrients. Athletes are recommended to take a high-carbohydrate diet to improve performance and recover from fatigue[4, 12, 13]. Their levels of energy and nutrient

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Table-1 Glucose metabolic parameters in study subjects

	Glucose (mg/d*l*)	Insulin (μlU/m*l*)	HOMA-IR
A	81	15.3	3.06
B	93	11.9	2.71
C	84	12.4	2.57
D	88	7.2	1.62
E	90	6.9	1.51
F	77	6.4	1.21
G	82	5.2	1.05
H	86	5.0	1.04
I	92	4.2	0.94
J	82	4.1	0.83
Mean±SD	85±5	7.8±3.9	1.65±0.82

When the value of HOMA-IR, the index for insulin resistance, was ≥2.5, the subject was assigned to the high-HOMA-IR group (A, B, C).

intake are higher than those in non-athletes. Thus, it is unlikely that changes in athletes' glucose and insulin levels after OGTT are similar to those after a high-carbohydrate diet.

If the changes in blood glucose and lipid metabolic parameters in athletes with insulin resistance after a high-carbohydrate diet, in addition to those after the 75-g OGTT, are elucidated, the resulting data could serve as a basis for providing nutritional support to athletes with insulin resistance. Therefore, in the present study, we aimed to elucidate changes in blood glucose and lipid metabolic parameters after high-carbohydrate diet ingestion in athletes with insulin resistance.

Methods

1. Subjects

Ten throwers belonging to the Juntendo university track and field club, who participated in regional (Kanto region) or national competitions, were recruited in the present study. Our study protocol was approved by the ethics committee of the Juntendo University (26-62). The subjects provided informed consent to participate in this study.

2. Weight and body composition

Body Composition Analyzer InBody730 (Biospace Co., Ltd., Tokyo, Japan) was used to measure weight and body composition in the early morning after an overnight fast based on an impedance method.

3. Blood test

To evaluate glucose and lipid metabolic parameters, approximately 10 m*l* of blood was collected from the cubital vein in the early morning after an overnight fast. Glucose and insulin levels were assessed as glucose metabolism variables, and triglyceride (TG), total cholesterol (T-CHO), High density lipoprotein cholesterol (HDL-CHO), and free fatty acid (FFA) levels were assessed as lipid metabolism variables. Low-density lipoprotein cholesterol (LDL-CHO) was calculated based on the Friedewald equation[14] given below.

$$\text{LDL-CHO} = \text{T-CHO} - \text{HDL-CHO} - \text{TG}/5$$

The blood analyses were performed by a clinical laboratory SRL Inc. (Tokyo, Japan).

4. Group assignment

To examine whether a subject has insulin resistance, HOMA-IR was calculated from the glucose and insulin levels in the early morning after an overnight fast using the following equation.

$$\text{HOMA-IR} = (\text{fasting glucose} \times \text{fasting insulin})/405$$

Measurement of HOMA-IR for each subject was conducted twice with a 1-week interval, and mean values were calculated. In accordance with guidelines for diabetes treatment from 2014 to 2015[15], those with a mean value of ≥2.5 were classified into the high-HOMA-IR group and those with values below this into the low-HOMA-IR group. Among the 10 subjects, three (A, B, and C) were assigned to the high-HOMA-IR group and the remaining seven to the low-HOMA-IR group (Table-1).

5. The 75-g oral glucose tolerance test

The 75-g OGTT was conducted to assess glucose metabolism. The subjects were requested to consume a prescribed meal as supper by 21:00 the day before the test (1,361 kcal; protein, 44.8 g; fat, 43.4 g; carbohydrate, 179.5 g; protein percentage of energy (%EN), 13.2%; fat %EN, 28.7%; and carbohydrate %EN, 52.8%) and then to fast overnight. The subjects visited the laboratory in the fasting state, and approximately 10 m*l* of blood was collected from the cubital vein. Then, they consumed a drink containing 75-g glucose within 10 min, and blood was again collected 30, 60, and 120 min later. The following parameters were analyzed: glucose, insulin, FFA, and TG.

Table-2 Energy and nutrient levels in study subject after a high-carbohydrate diet

Test diet	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)	Fib er (g)	Saccharides (g)
White rice	420-672	6.3-10.0	0.8-1.2	92.8-148.4	0.8-1.2	1.8-2.8
Fried Chicken	276-420	15.6-22.0	17.6-23.5	11.2-26.1	0.0-0.4	5.4-7.4
Wonton-soup	165	3.7	10.3	13.5	0.6	0.5
100% orange juice	84	1.4	0.2	21.4	0.4	21.0
Total	945-1341	27.0-37.1	28.9-35.2	138.9-209.4	1.8-2.6	28.7-31.7
% EN		11.2% (11.1-11.4%)	25.6% (23.6-27.5%)	63.1% (61.1-65.0%)		

The standard level of carbohydrate was set by converting the value of 5 g of carbohydrate in a meal per kg of body weight, adjusting to each subject depending on their body type, into the value per meal.

Table-3 Physical characteristics and lipid profile in study subjects

		high-HOMA-IR group (n=3)	low-HOMA-IR group (n=7)	p value
Height	(cm)	178.6±4.9	178.4±5.0	0.937
Body Weight	(kg)	112.4±10.8	101.2±11.7	0.175
Body Mass Index	(kg/m^2)	35.2±1.5	31.8±3.2	0.126
Lean Body Mass	(kg)	80.1±7.1	78.9±6.5	0.799
Skeletal Muscle Mass	(kg)	46.7±4.1	45.8±3.6	0.726
Body Fat Percentage	(%)	28.4±1.1	21.7±4.6	0.045
TG	(mg/d*l*)	136±34	91±28	0.057
T-CHO	(mg/d*l*)	203±43	180±32	0.375
LDL-CHO	(mg/d*l*)	130±34	109±30	0.361
HDL-CHO	(mg/d*l*)	46±4	53±5	0.050

Mean±SD
Unpaired t-test was used to examine differences between two groups.
TG: Triglyceride, T-CHO: Total cholesterol,
LDL-CHO: Low-density lipoprotein cholesterol, HDL-CHO: High-density lipoprotein cholesterol,
LDL-CHO was calculated to use Friedewald equation. LDL-CHO=T-CHO−HDL-CHO−TG/5

6. High-carbohydrate test

High-carbohydrate test was conducted at least 1 week after the completion of the 75-g OGTT. The high-carbohydrate test meal in the present study contained the required level of carbohydrate of 5 g/kg/day, which was converted to an appropriate amount per meal, in accordance with the guidelines concerning meals for strength athletes[4) 9)]. The %EN of nutrients were as follows: 11.2% protein, 25.6% fat, and 63.1% carbohydrate (Table-2).

As is the case with the 75-g OGTT, the subjects were requested to fast overnight after a prescribed supper the previous day, and on the day of measurement, approximately 10 m*l* of blood was collected from the cubital vein in the fasting state. Within 10 min, a high-carbohydrate meal was consumed, and blood was collected 30, 60, 120, and 180 min later. The following parameters were analyzed: glucose, insulin, FFA, and TG.

7. Statistical analysis

All of the measured values are shown as mean ± standard deviation. For body composition, unpaired t-test was used to test the difference between the two groups. Two-way ANOVA was used to examine two factors (between groups × time) in the 75-g OGTT and the high-carbohydrate test, and for variables whose effect was significant, the Bonferroni method was further employed for multiple comparisons. The relationships of insulin and insulin resistance with TG after a meal in the high-carbohydrate test were examined based on Pearson's correlation coefficient. A statistical significance was set at $p<0.05$. SPSS Ver. 17.0 (Japan

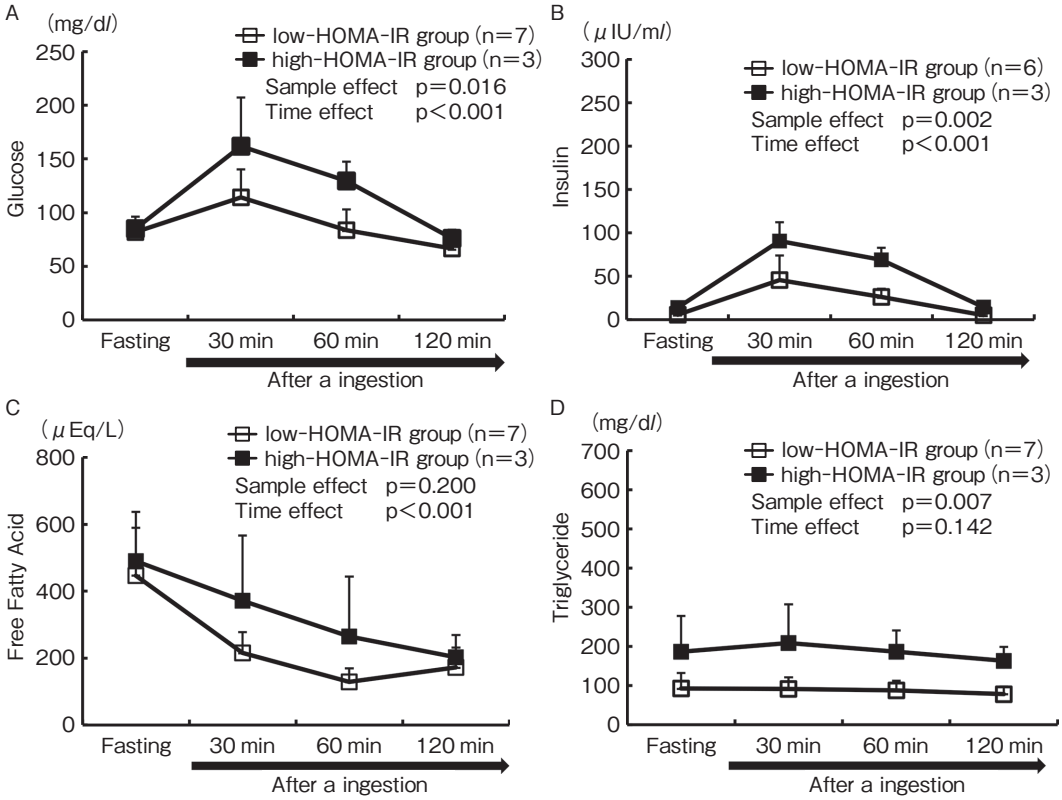

Figure-1 Changes in blood glucose and lipid metabolic parameters in the 75-g oral glucose tolerance test
A. Glucose, **B.** Insulin, **C.** Free fatty acid, **D.** Triglyceride
Two-way ANOVA was conducted, and multiple comparisons were further conducted using the Bonferroni method for variables that showed a significant effect. One insulin value for is missing because a subject in the low-HOMA-IR group showed hemolysis 30 min after 75-g glucose ingestion.

IBM Ltd.) was used for all statistical analyses.

Results

1. Physical characteristics and lipid profile of subjects

Table-3 shows the physical characteristics and lipid profile of both groups. No significant differences were observed between the two groups in terms of height, weight, body mass index, lean body mass, and skeletal muscle mass. Body fat percentage was found to be significantly higher in the high-HOMA-IR group than in the low-HOMA-IR group ($p<0.05$). No significant differences were found in blood lipid profile levels: TG, T-CHO, LDL-CHO, and HDL-CHO.

2. Changes in blood glucose and lipid metabolic parameters using the 75-g oral glucose tolerance test

Figure-1 indicates the changes in glucose, insulin, FFA, and TG levels during the 75-g OGTT. The results from two-way ANOVA showed a significant difference between the groups and time. FFA levels were significantly different with regards to time, whereas TG levels were significantly different only between the groups. The high-HOMA-IR group had a higher glucose level than the low-HOMA-IR group; however, the levels decreased to those in the fasting state at 120 min after 75-g glucose ingestion in both groups, confirming that the glucose levels fluctuate within the normal range, as described in guidelines for diabetes treatment from 2014 to 2015[15] (Figure-1A).

Insulin levels were found to be twice as high in the high-HOMA-IR group as in the low-HOMA-IR group at 30 min after 75-g glucose ingestion but decreased to those in the fasting state at 120 min (Figure-1B). As for the insulin level in the low-HOMA-IR group at 30 min, a case of hemolysis was found; therefore, one of the values is missing. Significantly higher levels of TG were observed in the high-HOMA-IR group than in

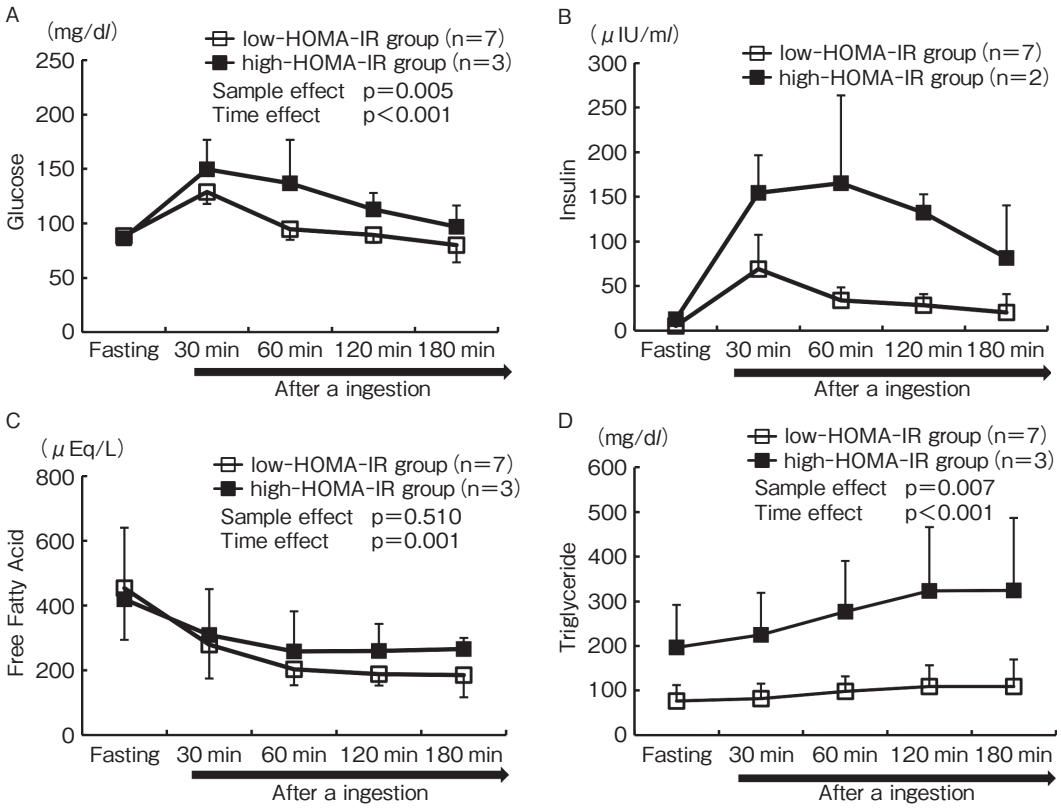

Figure-2 Changes of blood glucose and lipid metabolic parameters in the high-carbohydrate test
A. Glucose, **B.** Insulin, **C.** Free fatty acid, **D.** Triglyceride
One insulin value for a subject is missing, as a subject in the high-HOMA-IR group showed hemolysis 60 min after high-carbohydrate diet ingestion.

the low-HOMA-IR group; however, no change was observed (Figure-1D).

Changes in blood glucose and lipid metabolic parameters in the high-carbohydrate test Figure-2 shows the changes in the blood glucose and lipid metabolic parameters after consuming the high-carbohydrate meal. The results of two-way ANOVA showed a significant difference between the groups and time for both glucose and TG (Figure-2A, D). In contrast, a significant difference was only observed over time for FFA (Figure-2C).

No statistical examination was conducted for insulin because one value was missing in the high-HOMA-IR group 60 min after a meal; however, in the low-HOMA-IR group, a decline to a level equivalent to that in the fasting state was observed at 180 min after consuming the high-carbohydrate meal. Although with preliminary data from a small sample size, the high-HOMA-IR group showed higher levels than the peak values in the low-HOMA-IR group (Figure-2B).

No changes were observed in TG levels after the meal in the low-HOMA-IR group; however, the high-HOMA-IR group showed a significant increase over time, and at 180 min, the TG levels reached approximately 1.7-fold of that in the fasting state (Figure-2D).

3. Relationship between insulin and TG after the high-carbohydrate test

Significant positive correlations were observed between insulin and TG levels ($r=0.80$, $p<0.001$) (Figure-3) and between insulin resistance and TG levels 180 min after consuming the high-carbohydrate meal ($r=0.70$, $p<0.05$) (Figure-4).

Discussion

In the present study, we conducted the 75-g OGTT and high-carbohydrate test in ten throwers belonging to the university track and field club to elucidate changes in blood glucose and lipid metabolic parameters in athletes with insulin

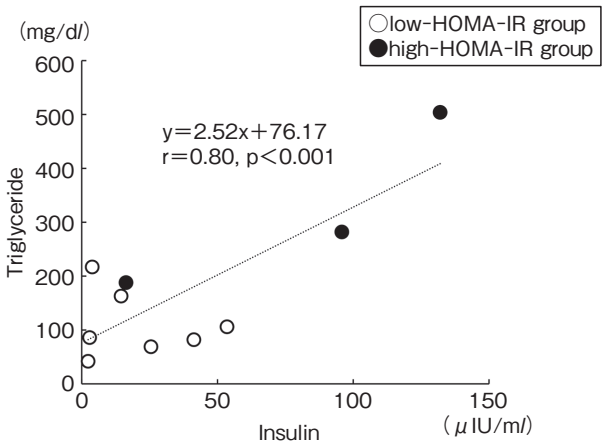

Figure-3 Relationship between insulin and triglyceride after the high-carbohydrate test
Data were analyzed using Pearson's correlation coefficient. Insulin and triglyceride values at 180 min after high-carbohydrate diet ingestion were used.

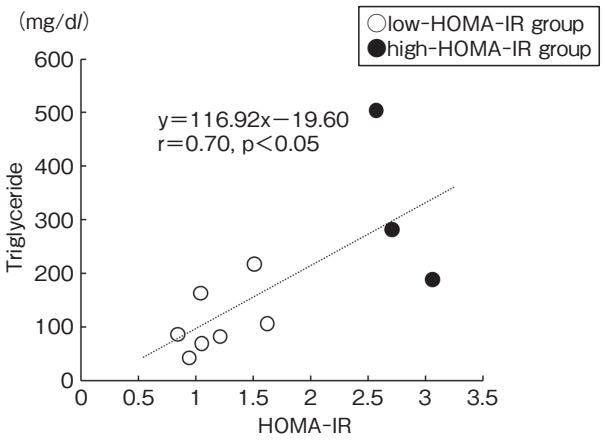

Figure-4 Relationship between insulin resistance and triglyceride after the high-carbohydrate test
Data were analyzed using Pearson's correlation coefficient. HOMA-IR, the index for insulin resistance, and triglyceride levels at 180 min after high-carbohydrate diet ingestion was used.

resistance after high-carbohydrate diet ingestion. Among the 10 subjects in this study, three had insulin resistance. The level of glucose fluctuated within the normal range during the 75-g OGTT. However, the high-HOMA-IR group showed higher insulin levels after 75-g glucose ingestion. In addition, the glucose level fluctuated within the normal range in the high-carbohydrate test, a high-insulin state was observed, and the level of TG was also found to be high (Figure-2B, 2D), although these are only preliminary data from a small sample size.

Previous studies that conducted the 75-g OGTT on athletes undergoing resistance training reported normal glucose levels in them[9) 16)]. Similar to these studies, the present study also demonstrated that during the 75-g OGTT, changes in glucose levels were within the normal range in both groups (Figure-1). Glucose is stored in the liver and skeletal muscle. Liver can store glycogen at approximately 3%-7% of its weight[17)], whereas skeletal muscle can store glycogen at approximately 1.7% of its weight[18) 19)]. Thus, subjects in the present study are considered to be able to store approximately 100 g and 780 g of glycogen in liver and skeletal muscle, respectively, based on their physical data. Therefore, it is possible that the athletes with insulin resistance demonstrated normal glucose level because they had a large amount of skeletal muscle in which glycogen could be stored or because the intake of glucose had been accelerated due to training when they ingested 75 g of glucose. However, the insulin level in the high-HOMA-IR group remained high even 180 min after the high-carbohydrate diet ingestion compared with the peak value in the low-HOMA-IR group, suggesting that insulin was not maintained at a normal level and that it was in fact excessively secreted. The high-carbohydrate diet used in the present study was prepared by converting the necessary amount of carbohydrate per meal for performance and muscle glycogen, which is described in the guidelines for strength athletes[4) 5) 12) 13)]. However, in athletes with insulin resistance, an amount of carbohydrate of approximately 130-210 g resulted in hyperinsulinemia due to the excess secretion of insulin to maintain a normal glucose level, and led to a high TG value (Figure-4). Several prospective epidemiological studies have shown that hyperinsulinemia predicts the risk of coronary heart disease in non-diabetic subjects[20) 21)]. This suggest that a low-glycemic index diet, depending on the status of glucose metabolism in each athlete, the necessary amount of carbohydrate, and the timing for meals and training, needs to be implemented to suppress the excessive secretion of insulin. Athletes with insulin resistance should be counseled about the associated risks and educated about lifestyle choices that may reduce these risks.

The present study had some limitations. First, a major limitation was the small sample size of each group and consequent low statistical power. A sufficient sample size of the athletes with insulin resistance would be necessary to conduct. Second, the present study only targets throwers. Athletes engaged in other sports may demonstrate different results.

In conclusion, in athletes with insulin resistance, a high-carbohydrate diet was shown to cause hyperinsulinemia, which could lead to hyperlipidemia.

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