Carbohydrate Gel Ingestion Immediately before Prolonged Exercise Causes Sustained Higher Glucose Concentrations and Lower Fatigue

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Purpose: The present study determined the effects of the timing of carbohydrate gel ingestion before exercise on metabolic responses and exercise performance during prolonged exercise.

Methods: Seven male triathletes completed 4 different trials in a randomized order. Subjects ingested placebo immediately before the exercise (P0), or carbohydrate gel (180 kcal) immediately before exercise (C0), 45 min before exercise (C45) or 120 min before exercise (C120). Time-course changes in metabolic, hormone and subjective fatigue during 80 min of exercise (80-60% of maximal oxygen uptake) were compared among 4 trials. A 40 s maximal pedaling test was conducted immediately after 80 min of exercise.

Results: Serum insulin concentrations immediately before exercise were significantly higher in the C45 trial than in the other trials (P<0.05). Blood glucose concentrations were significantly lower in the C45 trial than in the P0 and the C0 trials during the initial part of the exercise (P<0.05). During exercise, the C0 trial showed highest glucose concentration (P<0.05 vs. the other trials). The rating of perceived exertion (RPE) at 40-80 min during the exercise was significantly lower in the C0 and C120 trials than in the P0 trial (P<0.05), with no significant difference between the P0 and C45 trials. Power output during 40 s of maximal pedaling was not significantly different among the trials.

Conclusions: Carbohydrate ingestion immediately before prolonged exercise resulted in higher glucose concentrations and lower subjective fatigue, especially during the last 40 min of the exercise period. However, peak and average power output during 40 s maximal pedaling immediately after the 80 min of exercise did not differ significantly among the trials.

Keywords: prolonged exercise, rating of perceived exertion, blood glucose, carbohydrate, athletes

1. Introduction

Many exercise physiologists and sports nutritionists have examined the effects of ingesting carbohydrate before prolonged exercise. However, the results from previous studies were inconsistent. For example, some studies revealed that pre-exercise carbohydrate ingestion might impair exercise performance by causing transient hypoglycemia, and increasing muscle glycogen utilization and glucose uptake (Costill et al., 1977; Foster et al., 1979). Costill et al. (1977) reported that carbohydrate ingestion 45 min before starting exercise increased muscle glycogen utilization and led to early onset of fatigue during prolonged exercise. Foster et al. (1979) revealed that the cycling time to exhaustion was reduced by 19% when the subjects ingested glucose solution 30 min before the exercise. By contrast, Sherman et al. (1991) reported that the ingestion of 78 g or 156 g carbohydrate at 60 min before cycling significantly improved time-trial performance. Furthermore, glucose ingestion 15 min be-
fore treadmill running at 60%-80% of maximal oxygen uptake (\(\dot{V}O_2\text{max}\)) increased endurance running performance (Sherman et al., 1991). Therefore, the effects of carbohydrate ingestion at 15-60 min before exercise on endurance performance remain unclear, even though carbohydrate ingestion in this period of time is prevalent.

A possible reason for impaired exercise performance by carbohydrate ingestion before prolonged exercise is hypoglycemia by elevated insulin concentration at the start of the exercise. Because insulin concentration generally increases about 30 min after carbohydrate ingestion, carbohydrate ingestion immediately before exercise may be beneficial. However, the influence of carbohydrate ingestion immediately before prolonged exercise has not been fully determined so far. Furthermore, majority of the previous studies utilized liquid form of carbohydrate supplementation, but effects of other type of carbohydrate ingestion (e.g., gel) are obscure.

In the present study, we compared the effects of carbohydrate gel ingestion immediately before, 45 min before, or 120 min before exercise on the metabolic responses and exercise performance during prolonged high-intensity exercise in trained endurance athletes. Because elevated blood glucose and insulin concentrations before exercise can cause a rapid decrease in blood glucose concentrations during exercise, we hypothesized that carbohydrate ingestion immediately before exercise would maintain blood glucose concentrations throughout the exercise and reduce subjective fatigue.

2. Methods

2.1. Subjects

Seven male college triathletes were recruited to take part in this study. Their mean ± standard error (SE) height, weight and maximal oxygen uptake (\(\dot{V}O_2\text{max}\)) were 172.6±2.6 cm, 61.0±2.3 kg, and 63.4±3.0 ml/kg/min, respectively. All of the subjects gave informed consent after being informed of the purpose and risks associated with the study. This study was approved by the Ethics Committee of the Ritsumeikan University, Japan.

2.2. Experimental design

The present study was conducted with a randomized, placebo-controlled, double-blinded design. Subjects visited the laboratory five times throughout the experimental period. On the first visit, \(\dot{V}O_2\text{max}\) was measured using a cycle ergometer (Aerobike 75xIII; Combi Wellness Corporation, Tokyo, Japan). The test began at 70 W and the load was progressively increased in 35 W increments every 2 min until exhaustion. The test was terminated when the subject failed to maintain the prescribed pedaling frequency of 80 rpm or reached a \(\dot{V}O_2\) plateau. Respiratory gases were collected and analyzed using an automatic gas analyzer (AE300S, Minato Medical Science Co., Ltd, Tokyo, Japan). The collected data were averaged every 30 s. The subject’s heart rate (HR) was continuously measured using a wireless HR monitor (RS400; Polar Electro OY, Finland).

2.3. Experimental trial

Four experimental trials were conducted in a random order during visits 2-5, which were separated by approximately 7 days: 1) placebo ingestion immediately before the exercise (P0); 2) carbohydrate ingestion immediately before the exercise (C0); 3) carbohydrate ingestion 45 min before the exercise (C45); and 4) carbohydrate ingestion 120 min before the exercise (C120) (Figure 1). The carbohydrate gel consisted of maltodextrin (45 g), and its total calorific value was 180 kcal. The dextrose equivalent for maltodextrin in the present study was 22-25. The placebo gel was prepared by company with same texture and flavor using artificial sweetener, without maltodextrin (total calorific value was 0 kcal).

On each experimental trial day, the subjects arrived at the laboratory after an overnight fast and rested for 20 min before the first blood collection.
An indwelling cannula for blood collection was subsequently inserted into the antecubital vein. After the first blood collection, the subjects consumed the carbohydrate or placebo gel at the prescribed time before commencing the exercise. The second blood sample was collected immediately before the exercise.

The exercise protocol consisted of 20 successive sets of 4 min bouts of exercise (80 min in total). Each set of exercise consisted of 1 min of pedaling at 80% of $\overline{VO}_2\text{max}$ followed by 3 min of pedaling at 60% of $\overline{VO}_2\text{max}$. The pedaling frequency was set at 80 rpm throughout the exercise. In the present study, prolonged, high-intensity interval exercise was adopted to mimic most of ball games consisting of high- and moderate-intensity exercises.

The subjects were allowed to drink water ad libitum during the exercise period. The room temperature was maintained at 24°C.

Venous blood samples were collected every 4 min throughout the exercise to measure blood glucose concentrations. Blood lactate, serum insulin, and free fatty acid (FFA) concentrations were measured every 16 min (every 4 sets) during the exercise. The rating of perceived exertion (RPE), as an index of subjective fatigue (Borg, 1973), was recorded every 4 min. HR data were recorded in 1-min intervals.

Immediately after the 80 min exercise, the subjects performed maximal pedaling for 40 s at 7.5% of body weight to determine peak and average power output during the exercise.

2.4. Blood analysis

Blood glucose and lactate concentrations were measured using an automatic glucose analyzer (Free style, Nipro Corporation, Osaka, Japan) and lactate analyzer (Lactate pro, Arkray Inc, Kyoto, Japan), respectively. Blood samples for serum insulin and FFA measurements were centrifuged at 3000 rpm for 10 min at 4°C. The resulting plasma and serum samples were stored at −80°C. Serum insulin was measured using a radioimmunoassay. Serum FFA was determined using an enzymatic method. Serum insulin and FFA assays were conducted at a clinical laboratory (SRL Inc, Tokyo, Japan).

2.5. Statistical analysis

All data are reported as means ± SE. The metabolic and performance data recorded during the exercise were analyzed using two-way (trial×time) repeated-measurements analysis of variance (ANOVA). When the analysis of variance revealed a significant interaction or main effect, the Tukey-Kramer post-hoc test was applied to identify the differences. Peak and average power output during the 40 s maximal pedaling test were analyzed by one-way repeated measures ANOVA. For all tests, $P<0.05$ was considered significant.

3. Results

Time-course changes in blood glucose concentrations are presented in Figure 2A. There were no significant differences in glucose concentrations at baseline. Blood glucose concentrations immediately
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Figure 2B shows the areas under the curve (AUC) of blood glucose concentrations throughout the exercise. The AUC was significantly greater in the C0 trial than in the other three trials. However, the AUCs in the C45 and C120 trials were not significantly different from that in the P0 trial.

Figure 3A shows lactate concentrations increased significantly during exercise in all four trials (\(P<0.05\)). However, there was no significant interaction (trial \(\times\) time) or main effect for trial. Time-course changes in serum insulin concentrations are presented in Figure 3B. There was no significant difference at baseline among the four trials. Serum insulin concentrations immediately before the exercise were significantly higher in the C45 trial than in the other trials (\(P<0.05\)). However, insulin concentrations decreased rapidly after the onset of exercise in the C45 trial, and there were no differences in serum insulin concentrations during exercise among the four trials.

As shown in Figure 3C, there were no significant differences in serum FFA concentrations among the four trials at baseline. However, during the last 40 min of the exercise, FFA concentrations were significantly lower in the C0, C45, C120 trials than in the P0 trial (\(P<0.05\)).

Figure 4A shows the RPE in each set throughout the exercise. Although the RPE increased gradually with progress of exercise in each trial (main effect for time, \(P<0.05\)), there was no significant interaction (trial \(\times\) time) or main effect for trial. In addition, the average values of RPE over 0-40 min were similar among the trials (Figure 4B). However, the average values of RPE over 40-80 min were significantly lower in the C0 (15.0 ± 1.5) and the C120 (15.1 ± 1.5) trials than in the P0 (16.8 ± 1.1) trial (\(P<0.05\); Figure 4B). In the C45 trial, the average RPE over 40-80 min (15.5 ± 1.3) was not significantly different from that in the P0 trial.

Two subjects could not complete 40 s maximal pedaling test immediately after the 80 min exercise, due to severe fatigue. Therefore, the results from five subjects were analyzed. In these five subjects,
there were no significant differences in peak (P0: 711 ± 45, C0: 710 ± 49, C45: 715 ± 48, C120: 717 ± 50 W) or average power output (P0: 508 ± 34, C0: 513 ± 54, C45: 510 ± 56, C120: 518 ± 47 W) during 40 s maximal pedaling among the fours trials.

There were no significant differences in mean HR during the 80 min exercise among the trials.

4. Discussion

The major findings of the present study was that carbohydrate ingestion immediately before 80 min of high-intensity exercise resulted in higher glucose concentrations and lower subjective fatigue, especially during the last 40 min of the exercise period. However, exercise performance immediately after 80 min of exercise did not differ significantly among the trials.

Several studies have examined the effects of carbohydrate ingestion at 30-120 min before exercise. Tokmakidis and Karamanolis (2008) demonstrated that carbohydrate ingestion 15 min before exercise did not cause a rapid increase in insulin concentrations at the onset of the exercise. Another experiment using the same timing of ingesting was performed by Sugiura and Kobayashi (1998). In their study, the subjects were given glucose, fructose, or placebo while resting for 15 min in the middle of 90 min of continuous or intermittent exercise. In the intermittent trial, sprint capacity was significantly greater in the glucose ingestion trial than in the placebo and fructose trials. In addition, the RPE averaged over the latter half of the exercise was significantly lower in the glucose ingestion trial than that in the placebo trial. Furthermore, the glucose concentrations did not rapidly decline in the glucose ingestion trial because the increase in insulin concentrations at the start of the latter half of the exercise was modest. Similarly, in the present study, insulin concentration was still low at the start of the exercise in the C0 trial, resulting in higher glucose concentrations for the entire duration of the 80 min exercise.
Beneficial effects of carbohydrate ingestion more than 120 min before prolonged exercise was reported in some studies (Little et al., 2010; Wee et al., 2005). Of note, carbohydrate ingestion more than 120 min before exercise significantly increased muscle glycogen content as compared with fasting. It is generally thought that glucose uptake by muscle for use in glycogen synthesis occurs within 120 min of carbohydrate ingestion, and that increasing muscle glycogen content by carbohydrate ingestion delays fatigue during prolonged exercise (Coyle et al., 1985; Coyle, 1992). The results of the present study partly support this concept as the C120 trial showed significantly lower values of RPE compared with the P0 trial.

Carbohydrate ingestion before exercise causes exercise-induced reduction of blood glucose concentrations (Chryssanthopoulos et al., 1994; Mondazzi and Arcelli, 2009; Short et al., 1997). Although insulin and exercise stimulate glucose uptake via independent pathways, they have a strong synergetic effects on promoting glucose uptake into muscle cell (Wasserman et al., 1991). Increased glycogen utilization within working muscle is linked to muscle glycogen depletion and premature fatigue (Costill et al., 1977). In the present study, we observed a rapid decrease in blood glucose concentrations in the C45 trial during the exercise. Consequently, the RPE in the C45 trial was similar to that in the P0 trial at 20-36 min period (i.e., sets 5-9), and the average values of RPE during latter 40 min of exercise were not significantly different between the C45 and P0 trials. Serum insulin concentrations immediately before exercise were higher in the C45 trial than in the other trials ($P<0.05$). Therefore, exaggerated glucose uptake by working muscle and the subsequent decrease in muscle glycogen content might explain greater level of fatigue in the C45 trial. In future studies, it would be useful to monitor change in muscle glycogen utilization following exercise to determine muscle glucose metabolism.

The subjects performed 40 s maximal pedaling immediately after the 80 min exercise to determine exercise capacity. However, only five subjects could complete the maximal pedaling exercise in all four trials; two subjects did not complete the test because of severe fatigue. It is difficult to explain clearly the reason for severe fatigue for these two subjects because of lack of marked differences in blood glucose and lactate concentrations compared with other subjects who completed 80 min of exercise. However, lower muscle glycogen during exercise may be involved. According to the results for the five subjects who completed all tests, there were no significant differences in either peak or average power output among the four trials. These findings imply that the difference in metabolic responses during prolonged exercise did not affect greatly exercise capacity for supramaximal pedaling. However, due to limited data, the results of the 40 s maximal pedaling test must be interpreted with caution.

The present findings provide useful information for coaches and athletes involved in high-intensity endurance activity. Although consuming carbohydrate ingestion at 15-60 min before prolonged exercise is very common, Jeukendrup and Killer (2010) reported that a rapid decrease in blood glucose concentration during prolonged exercise was inevitable if the carbohydrate (approximately 22-155 g) was ingested within 1 hour of starting the exercise. Accordingly, it seems that the usefulness of pre-exercise carbohydrate ingestion is dependent on the timing of ingestion. Finally, we can not assess the impact of carbohydrate gel compared with other forms of carbohydrate. Although we expect that a carbohydrate gel may be more beneficial than an aqueous carbohydrate solution in terms of absorption and maintaining glucose concentrations throughout prolonged exercise, a previous study showed similar glucose metabolism during exercise between carbohydrate gel and carbohydrate drink (Pfeiffer et al., 2010). Further studies are necessary to clarify this hypothesis.

In the present study, we confirmed that the RPE in the last 40 min of the exercise period was markedly affected by the timing of carbohydrate ingestion before starting the exercise. When carbohydrate is ingested immediately before exercise, the subjects start the exercise before any increase in insulin concentrations. Based on the present data, carbohydrate ingestion immediately before the exercise provides higher glucose concentrations throughout prolonged exercise, while minimizing the risk of transient hypoglycemia. By contrast, carbohydrate ingestion at 45 min before exercise has much weaker effects on maintaining high blood glucose concentrations. In this situation, the athlete may need to ingest further carbohydrate to maintain normoglycemic during exercise.

In conclusion, carbohydrate ingestion immedi-
ately before 80 min of prolonged high-intensity exercise resulted in higher blood glucose concentrations with lower RPE over the last 40 min of the exercise. By contrast, carbohydrate ingestion 45 min before exercise had no beneficial effects on blood glucose concentration or RPE during exercise.

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Reference


