Effect of Carbohydrate Intake During Warming-up on the Regulation of Blood Glucose During Exercise


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Abstract


It has been shown that the intake of carbohydrate (CHO)-containing beverages under resting conditions may lead to a rebound hypoglycemia and decreased performance when exercise is performed thereafter.

The aim of the present investigation was to study the effect of CHO beverage consumption with different CHO sources and different concentrations, during warming-up under practice-like circumstances, on the regulation of blood glucose during exercise. Eighteen highly trained cyclists consumed a standardized breakfast at 8:00 AM and performed a warming-up procedure at 10:00 AM for 20 min. Warming-up was followed by a 7-min break after which the subjects cycled for 45 min at a heart rate of 150.

During warming-up a CHO-containing beverage (either sucrose, fructose, maltodextrin, or glucose) or a placebo was consumed in random order. The test was performed twice, with 300 ml and 600 ml intake, to study a possible dose-response effect. The results of the study showed that warming-up and final exercise lead to an increase of the catecholamines and a decrease of insulin.

During the 7-min break this response was reversed. Glucose and maltodextrin induced the same insulin response. Increasing volume and higher CHO concentrations induced a longer increase in blood glucose level compared with the placebo intake.

The results showed that intake of CHO-containing beverages during warming-up followed by a small break does not lead to rebound hypoglycemia, independent of the amount of CHO ingested, but instead increases blood glucose.

Key words

glucoregulation, hypoglycemia, insulin, catecholamines, warming-up

Introduction

It has generally been accepted that the maintenance of a fairly constant blood glucose level is one of the prerequisites for the ability to perform long-lasting intense exercise. It has been shown that performance impairment is often associated with low blood glucose levels, and hypoglycemia has been suggested as one of the causes of central fatigue and exhaustion. In 1924 Levine et al. (36) were the first authors to report that in runners at the finish of a marathon a close relationship was found between blood glucose level and grade of well-being, hypoglycemic runners having the most problems. They therefore suggested that ingestion of carbohydrate (CHO) prior to and during exercise would be of considerable benefit in preventing hypoglycemia.

A few years later, however, it was observed that instead of maintenance of a desired blood glucose level, a reactive hypoglycemia could occur as a result of pre-exercise CHO feedings (3, 14). Since then many studies have been performed in which the effect of CHO ingestion on substrate utilization has been investigated. The outcome of these studies showed considerable disagreement about the effect and value of CHO ingestion in relation to endurance exercise. This has led to confusion among athletes and their advisers. Analysis of the available literature leads to several conclusions:

1. Intake of CHO drinks after an overnight fast in resting conditions may induce hypoglycemia by a rebound mechanism involving insulin secretion (12, 13) especially during subsequent exercise (3, 14, 16, 33).

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2. In contrast to this exercise studies which are carried out in the fed state does not show hypoglycemia after CHO intake at rest (7, 30, 31a, 37).

3. Studies in which CHO solutions are ingested immediately prior to exercise show increased blood glucose and depressed insulin values and no rebound mechanism (7, 8, 31).

4. Intake of CHO solutions during exercise enhances blood glucose values while insulin remains low. In (water) control experiments blood glucose values always tend to be lower (4, 8, 10, 20, 21, 23, 38, 41, 42).

5. Insulin secretion during exercise is inhibited by catecholamines (5, 39, 43, 44) and/or sympathetic pancreas innervation (46).

It is apparent in the available studies that the methodological setup of a number of studies does not simulate the actual situation in sports practice. First of all, the idea to compete after an overnight fast does not seem to be logical compared with the advice generally given that athletes should ingest a light digestible CHO-rich breakfast to restore liver glycogen. Secondly, there is no reason to ingest CHO at rest prior to exercise because muscle glycogen levels should be high as a result of a high CHO intake during the day(s) prior to the competition. With respect to the last point, the question may be raised why drinks should be ingested at all prior to exercise.

There may be an important reason to do so. During most competitions, especially long-distance running (45), athletes drink far less during exercise than the amount of fluid that is lost by sweating, leading to dehydration and performance impairment. Therefore, the measure of prehydration may become very important. After fluid intake there will be a period of overhydration. Whenever this period coincides with the exercise period during which urine production and insulin secretion may be decreased, one may hypothesize that the extra fluid will become available for sweating while the CHO may not elicit an insulin response sufficient enough to induce hypoglycemia, but rather may enhance or maintain blood glucose level.

Because initial gastric emptying and absorption of CHO containing drinks may take place within approximately 7 min (15), the advice should then be to ingest a drink immediately prior to competition or during warming-up, when competition follows immediately thereafter. We therefore decided to study the effect of prehydration with CHO-containing drinks in competition-like circumstances to test the following two hypotheses:

1. Warming-up induced catecholamine secretion will be insufficient to inhibit insulin secretion after intake of CHO-containing drinks.

2. Ingestion of selected CHO-containing drinks during warming-up in trained athletes, in the fed state, leads to a reactive hypoglycemia and results in subjective feelings of fatigue.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Subject characteristics (mean ± SEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>21.7 ± 4.5</td>
</tr>
<tr>
<td>VO2max</td>
<td>53.2 ± 4.6</td>
</tr>
<tr>
<td>Wmax</td>
<td>5.4 ± 0.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Carbohydrate composition of selected drinks (g/100 ml)</th>
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<tbody>
<tr>
<td></td>
<td>Maltoextrin</td>
</tr>
<tr>
<td>1 control</td>
<td>--</td>
</tr>
<tr>
<td>2 <em>FRUC</em></td>
<td>--</td>
</tr>
<tr>
<td>3 <em>SUC</em></td>
<td>1.3</td>
</tr>
<tr>
<td>4 <em>MALT</em></td>
<td>15.2</td>
</tr>
<tr>
<td>5 <em>GLUC</em></td>
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</tr>
</tbody>
</table>

Methods

Subjects

Eighteen highly trained male amateur cyclists participated in this study. Their mean physical characteristics are presented in Table 1. The maximal oxygen uptake and the maximal watt load achieved were determined during an incremental bicycle ergometer test in the week prior to the first test session.

The subjects were asked not to participate in vigorous training or competition on the day prior to the test and to ingest a normal CHO-rich diet. All subjects were informed of the nature, purpose, and possible risks involved in the study, before giving their voluntary written consent to participate.

The study was done in a cross-over setup with each subject being his own control.

Procedure

The subjects were divided into three groups of six subjects. Each group was studied after random ingestion of a placebo drink (control) or a selected CHO drink.

The setup of the treatments was such that information could be gathered on the effect of different commercially available CHO sport drinks with different CHO sources on the regulation of blood glucose. The CHO composition of the drinks is listed in Table 2.

The drinks were: a low-fructose drink (FRUC) (Isostar-Light *), a sucrose, low-maltodextrin drink (SUC) (Isostar *), and a highly concentrated maltodextrin, low-fructose drink (MALT) (Perform *). Six randomly selected subjects performed one extra test in which a free glucose solution was ingested (GLUC).

In SUC the fructose content, derived from the sucrose, was equal to that in FRUC (3 g). In GLUC the amount of glucose units was kept equal to the amount present in MALT. This was done to compare the effects induced by a glucose polymer to those induced by a free glucose solution with an equal amount of glucose units.
The data in the text, tables, and figures are given as means ± SEM of the delta changes relative to time zero (rest value) for each individual within each treatment group. These delta values were also used for further analyses.

Standard statistical methods were employed using paired t-test student's, with each subject's control values being compared with values obtained (from the same subject) after ingestion of a selected CHO drink.

A regression analysis was performed to determine possible relationships between insulin on the one hand and epinephrine, norepinephrine, or dopamine on the other hand in the different treatments. A stepwise regression was performed to see if the best single correlation could be improved by including one or both of the other independent variables.

Results

Hormones

Blood insulin levels decreased in control trials as a result of warming-up (Fig. 2a and c). At the same time the catecholamine levels were increased (Fig. 3a). The ingestion of the 300 ml SUC and FRUC did not influence this blood insulin fall during warming-up. However, when the volume of the drink was doubled, a marked reduction of this decrease was observed with the glucose and maltodextrin drink but not with the fructose drink (Fig. 2b, 2d).

As a result of the 7-min break between warming-up and final exercise, insulin levels increased in all treatments including the control trials.

The increase of insulin was more pronounced with the more concentrated CHO solutions (Fig. 2b), whereas doubling the dose further potentiated the insulin response (Fig. 2d).

We could not detect a quantitative difference in insulin response between the GLUC and MALT trial when 600 ml was drunk (Fig. 2d), although insulin response in the glucose trial was initially somewhat faster and significantly increased at all times (relative to the control drink), whereas increase in the MALT trial was only significant at the onset of exercise. Norepinephrine levels rapidly decreased during the 7-min break to the same extent in control as in CHO trials (Fig. 3a, c). In the control trial epinephrine showed the same response, but in all CHO trials the epinephrine increase was markedly blunted as a result of CHO intake except for the glucose trial (Fig. 3c). Linear regression analysis performed over all times showed that a good correlation existed between response of insulin and norepinephrine but less between insulin and epinephrine (Table 2).

When stepwise regression analysis was performed it was found that, with the inclusion of both norepinephrine and epinephrine, the correlation coefficient decreased to -0.71 and -0.82 in the maltodextrin and free glucose drink trials, respectively. During the first part of the heavy exercise period both insulin and catecholamines showed the same response as during warming-up. However, after 20 min of exercise norepinephrine reached a plateau level. From that mo-
Blood Glucose

Blood glucose remained constant during warming-up in both control trials. There was a small rise during the 7-min break followed by a decrease below baseline values during the following exercise task (Fig. 4a, 4c). In the 300 ml CHO trials blood glucose increased significantly following the SUC and MALT ingestion but not following the FRUC ingestion (Fig. 4b). However, when the amount of FRUC was doubled to 600 ml, blood glucose values were significantly higher than during the control (Fig. 4d). In the 300 ml CHO drink trials blood glucose decreased to the values of the control trial after approximately 20 min of exercise and remained stable thereafter. However, after ingestion of 600 ml of the highly concentrated CHO drinks blood glucose values remained above the control values for a longer period of time (Fig. 4d).

Hypoglycemia (< 2.5 mmol·l⁻¹) did not occur at all. In the 36 control trials blood glucose fell 7 times below 3 mmol·l⁻¹. In the 42 CHO drink trials blood glucose fell 3 times below 3 mmol·l⁻¹. In both cases the lowest measured blood glucose value was 2.7 mmol·l⁻¹. In the fructose trials blood glucose always remained above 3 mmol·l⁻¹.

The Borg scale score for subjective fatigue did not reveal any difference between the trials.

Discussion

The intake of CHO-containing drinks has been promoted to maintain or enhance blood glucose values and to spare muscle glycogen so that performance can be maintained at a high level and for a longer period of time. However, intake of CHO solutions in resting conditions after an overnight fast may induce a reactive hypoglycemia (3, 14, 16, 33) which may be mediated by enhanced insulin secretion (33).

Such a hypoglycemic reaction does not seem to occur when the exercise is performed in the fed state (7, 30, 31, 37) or when CHO is ingested immediately prior to exercise (7, 8, 31) or during exercise (4, 8, 10, 20, 21, 25, 38, 41, 42). The differences may be explained by differences in feeding status, gastric emptying, and substrate-receptor regulation.

In the fed state gastric emptying may be decreased compared with the fasting state because of receptor feedback from the duodenum due to food substances present (11). As a result of this and also because of mixing with food remnants in the stomach, gastric emptying of the initial bolus of the drink may be quantitatively less, which will have its consequences for the magnitude of receptor activation and in turn...
will affect insulin secretion. Another factor which may induce differences in the regulation of blood glucose may be the difference in the insulin status between the fed and fasted state, as well as the difference in liver glycogen level, which will be substantially reduced after an overnight fast (29).

Differences in pre-exercise insulin status can affect blood glucose levels during exercise by modification of insulin receptor binding (1). It has been shown that insulin can down- or upregulate its receptor number depending upon previous food intake and related blood glucose and insulin levels (26, 27, 28). As a result of this the insulin receptor number at the cell surface will be increased after an overnight fast while insulin levels are low. If CHO is then introduced in the gut and blood glucose increases rapidly, it may be assumed that "massive" insulin binding takes place leading to a strongly enhanced blood glucose withdrawal while at the same time glucose output from the liver is largely inhibited by an increase of the insulin-glucagon ratio (21, 47, 48). In fact, it has been shown that a close correlation exists between fasted pre-exercise blood glucose and insulin levels and the magnitude of blood glucose decrease at the beginning of exercise (33).
Whenever blood glucose increases during exercise there will be no strong insulin response because insulin secretion is inhibited as a result of increased catecholamine levels (5, 39, 43, 44). In our study we wanted to test the hypothesis that warming-up prior to exercise is an insufficient stress to cause a catecholamine increase large enough to inhibit insulin secretion. We also wanted to test if ingestion of CHO-containing drinks (with differing concentration and CHO sources) in the fed state during warming-up induces a reactive hypoglycemia and results in feelings of fatigue during the following endurance exercise.

After analysis of the data we had to reject these null hypotheses. The results demonstrated that the catecholamines increase as a result of warming-up and continued (strenuous) exercise and that this increase is accompanied by a decrease in insulin concentration. By their nature catecholamines are involved in the regulation of rapid adjustments to a changing environment such as homeostatic disturbance. Accordingly, their effects are induced rapidly and dissipated quickly (34). From the data it can be seen that a warming-up procedure of 20 min with a heart rate of approximately 130–140 bts/min and including three acceleration sprints is sufficient to cause catecholamines to rise and insulin to drop. During the 7-min break and following strenuous exercise this pattern was subsequently and quickly reversed. The drop in insulin concentration may be explained by the inhibiting effects of both epinephrine and norepinephrine on insulin secretion in combination with insulin binding at the site of muscle tissue (1, 19, 35), rather than by changes in insulin clearance which does not seem to be increased as a result of exercise (23a, 25a).

Innervation of sympathetic nerve endings in the pancreas may also be involved (46). Norepinephrine appears to inhibit insulin secretion in a manner similar to epinephrine. However, when equivalent doses are infused the effects of norepinephrine are quantitatively less (44).

From this finding one may conclude that epinephrine is more important with respect to modifying liver glucose production and blood insulin levels.

However, norepinephrine levels increase more quickly and reach higher levels than epinephrine which only seems to increase significantly later during exercise when blood glucose levels tend to drop (24, 28a, 40). In this study we found the best correlation between the norepinephrine and insulin response (Table 3). This relation is further underlined by the fact that insulin did not fall to lower levels after norepinephrine reached a plateau level after approximately 20 min of exercise, at a time that epinephrine further increased.

This is in line with the findings of Galbo et al. (24) who found that early in exercise insulin levels decreased at the same time as norepinephrine increased and epinephrine remained stable and that variations in epinephrine concentrations during exercise are not accompanied by insulin variations (25). The fact that the insulin decrease was suppressed after ingestion of the more concentrated CHO solutions may be explained by the fast increase in blood glucose which may have had a stronger effect on insulin secretion than the counteractive hormone during warming-up of this intensity.
Table 3  Correlation coefficients of insulin and catecholamines in the different treatment groups with insulin as dependent variable

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Epinephrine</th>
<th>Norepinephrine</th>
<th>Dopamine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fructose dr.</td>
<td>0.21</td>
<td>0.06</td>
<td>0.19</td>
</tr>
<tr>
<td>Sucrose dr.</td>
<td>-0.30</td>
<td>-0.60 P &lt; 0.01</td>
<td>0.06</td>
</tr>
<tr>
<td>Maltodextrin dr.</td>
<td>-0.47</td>
<td>-0.62 P &lt; 0.01</td>
<td>-0.15</td>
</tr>
<tr>
<td>Free glucose dr.</td>
<td>-0.33</td>
<td>-0.76 P &lt; 0.01</td>
<td>-0.27</td>
</tr>
</tbody>
</table>

During the more intense final exercise this effect was not present anymore.

No apparent difference was observed in blood insulin level between the fructose drink and controls supporting the findings that fructose exerts only a very small effect on insulin secretion (2, 17, 32).

Although a quick increase in blood insulin occurred during the break after warming-up, especially in the concentrated CHO trials, we did not find a reactive hypoglycemia as described by Kolivisto (33).

In all cases insulin dropped again below baseline levels within 10-15 min of exercise, whereas blood glucose levels remained elevated for a prolonged time. The fact that blood glucose remained elevated for a longer period of time after ingestion of 600 ml boil can be explained by the fact that a phased gastric emptying takes place so that CHO are introduced into the gut over a prolonged period of time, especially if gastric emptying rate is further depressed by higher CHO concentrations (11).

The fact that hypoglycemia did not occur and that lowered blood glucose values occurred more frequently during the control trials than during the CHO trials underlines the assumption that the intake of CHO-containing drinks during warming-up in athletes who are not in the fasted state is not detrimental with respect to the regulation of blood glucose and enhances blood glucose levels as long as CHO absorption from the gut takes place. Although the cyclists consumed only one bolus of drink during warming-up, it can be assumed that whenever the ingestion of CHO-containing drinks is continued throughout the duration of the exercise period, the drop in blood glucose levels to baseline levels, as seen after 15-20 min with the low-concentrated drinks supplied in 300 ml boill, will not occur. The validity of this assumption is underlined by a number of studies (4, 8, 10, 21, 23, 41).

In summary, the effect of CHO drink ingestion on blood glucose regulation during exercise was tested in 18 highly trained amateur cyclists. Ingestion of the drinks took place during warming-up after having consumed a solid-liquid breakfast.

In contrast to other studies where drinks were ingested after an overnight fast, in a resting condition, no negative effects on the blood glucose level were observed.

A close relationship was found between the changes in insulin and the catecholamines, norepinephrine being the most important inhibiting hormone.

Catecholamines increased as a result of exercise while insulin decreased.

Conclusions

- The study shows that prehydration with CHO-containing drinks during warming-up in the fed state does not affect glucose regulation or subjective fatigue negatively during endurance exercise performed thereafter.
- The effect of glucose polymers and free glucose, on blood glucose and insulin, is not different.
- A larger volume of CHO-containing drink leads to a longer response in blood glucose (increase).
- Prehydration, 3-5 min prior to the start or during warming-up, and repeated drinking while competing will be an optimal measure to avoid dehydration and hypoglycemia.

References

Effect of Carbohydrate Intake During Warming-up on the Regulation

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