The Influence of Low Versus High Carbohydrate Diet on a 45-min Strenuous Cycling Exercise

Stavros A. Kavouras, John P. Troup, and Jacqueline R. Berning

To examine the effects of a 3-day high carbohydrate (H-CHO) and low carbohydrate (L-CHO) diet on 45 min of cycling exercise, 12 endurance-trained cyclists performed a 45-min cycling exercise at 82 ± 2% VO_{2peak} following an overnight fast, after a 6-day diet and exercise control. The 7-day protocol was repeated under 2 randomly assigned dietary trials H-CHO and L-CHO. On days 1–3, subjects consumed a mixed diet for both trials and for days 4–6 consumed isocaloric diets that contained either 600 g or 100 g of carbohydrates, for the H-CHO and the L-CHO trials, respectively. Muscle biopsy samples, taken from the vastus lateralis prior to the beginning of the 45-min cycling test, indicated that muscle glycogen levels were significantly higher (p < .05) for the H-CHO trial (104.5 ± 9.4 mmol/kg wet wt) when compared to the L-CHO trial (72.2 ± 5.6 mmol/kg wet wt). Heart rate, ratings of perceived exertion, oxygen uptake, and respiratory quotient during exercise were not significantly different between the 2 trials. Serum glucose during exercise for the H-CHO trial significantly increased (p < .05) from 4.5 ± 0.1 mmol·L^{-1} (pre) to 6.7 ± 0.6 mmol·L^{-1} (post), while no changes were found for the L-CHO trial. In addition, post-exercise serum glucose was significantly greater (p < .05) for the H-CHO trial when compared to the L-CHO trial (H-CHO, 6.7 ± 0.6 mmol·L^{-1}; L-CHO, 5.2 ± 0.2 mmol·L^{-1}). No significant changes were observed in serum free fatty acid, triglycerides, or insulin concentration in either trial. The findings suggest that L-CHO had no major effect on 45-min cycling exercise that was not observed with H-CHO when the total energy intake was adequate.

Key Words: high fat diet, muscle glycogen, glucose, FFA, carbo-loading

Introduction

The importance of carbohydrate metabolism during exercise was heavily investigated after the reintroduction of the needle biopsy technique (7) by Bergström in...
1962 (3). Human muscle samples have provided considerable insights into the understanding of muscle carbohydrate metabolism during the last three decades. Since then, numerous studies have suggested not only that muscle glycogen stores can be influenced by diet and exercise, but also that these stores may play a critical role during endurance exercise (4, 16, 17, 19). During intense exercise, including prolonged exercise performance (i.e., marathon running), muscle glycogen is the preferable energy source (2, 24). Increased carbohydrate intake for several days along with decreased training can elevate or super-compensate muscle glycogen levels above normal (30). Thus, increased carbohydrate intake seems to influence muscle glycogen stores while potentially enhancing endurance exercise.

In this regard, there is strong empirical evidence that elevated pre-exercise muscle glycogen level improves endurance exercise performance for events lasting more than 90 min (4, 5, 9, 19–21, 28, 34, 35). However, for events lasting between 60–90 min, it seems that muscle glycogen super-compensation may not play an ergogenic role (14, 22, 30). Yet, more recently, it was also hypothesized that increased muscle glycogen stores or high carbohydrate diet might have an ergogenic effect on high intensity, short duration exercise performance that lasts under 5 min. Some studies have shown positive results (10–12, 27, 29), while others have demonstrated no effect (13, 31, 33). In a critical review of the literature, Hawley et al. stated “the availability of muscle glycogen does not limit exercise capacity at work rates eliciting ≥ 100% VO_{2max} when that exercise is commenced with normal (i.e., 85 to 100 mmol/kg ww) muscle glycogen content” (15). Although the subject remains controversial, the majority of the experimental data suggest that a high carbohydrate diet and resulting high muscle glycogen stores may have no significant effect on high intensity, short duration exercise performance.

Thus, considering the above, it is observed that little attention has been devoted to whether high carbohydrate diet affects moderate duration exercise that lasts 20 to 60 min. For this reason, the purpose of this investigation was to examine the effects of a high versus low carbohydrate diet during a moderate duration (45-min) strenuous cycling exercise (82% VO_{2peak}). We hypothesized that a high carbohydrate diet will increase pre-exercise muscle glycogen stores and will provide better physiological and perceptual responses in comparison to the low carbohydrate diet during a 45-min strenuous cycling exercise.

**Methods**

**A. Subjects-Experimental Protocol**

Twelve trained male cyclists volunteered to participate in this investigation. The men (a) trained regularly, (b) competed in road cycling or mountain biking races, (c) were non-smokers, and (d) reported a history free of endocrine, cardiovascular, renal, and thermoregulatory disorders. Before the participants signed their written informed consent, approved by the Institutional Review Board, they were informed of the nature, purpose, and possible risks involved in the study. These men had been residing in town (altitude, 1870 m) for more than 4 years, and they were competitive cyclists for at least 4 years. Selected subjects characteristics are presented in Table 1.

Subjects performed a 45-min cycling trial at 82 ± 2% of VO_{2peak}, after a 6-day diet and exercise control. The 7-day trial was repeated under the two randomly assigned dietary trials: high carbohydrate (H-CHO) and low carbohydrate (L-CHO).
Table 1  Subjects’ Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SE</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>28 ± 1</td>
<td>20–33</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73 ± 2</td>
<td>61–82</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>181 ± 2</td>
<td>173–191</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>9.6 ± 0.3</td>
<td>7.9–12.0</td>
</tr>
<tr>
<td>VO$_{2\text{peak}}$ (l/min)</td>
<td>4.19 ± 0.15</td>
<td>3.28–4.97</td>
</tr>
<tr>
<td>VO$_{2\text{peak}}$ (ml · kg$^{-1}$ · min$^{-1}$)</td>
<td>57.6 ± 1.9</td>
<td>48.0–71.0</td>
</tr>
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</table>

B. Preliminary Testing

Body Composition. The skinfold measurement of four sites was used to determine body density based on the Jackson and Pollock’s equation (18). Calculation of the percentage of body fat from body density was derived using the Brozek equation (6).

Peak Oxygen Consumption (VO$_{2\text{peak}}$) Test. VO$_{2\text{peak}}$ was determined in a cool environment (21 °C) using an incremental difficulty exercise test on an electronically braked cycle ergometer. Prior to the test, subjects warmed up for approximately 10 min. The exercise test consisted of continuous cycling at constant cadence (80–100 revolutions/min), while power output was increased by 50 W every 2 min until volitional exhaustion. Expired gases were sampled and analyzed from a mixing chamber every 10 s during exercise via an open circuit respiratory apparatus (P.K. Morgan, Gillam, UK), which was interfaced to a computer. Three of the following four criteria were used to verify attainment of VO$_{2\text{peak}}$: (a) volitional exhaustion, (b) no further increase in oxygen uptake (less than 150 ml/min) with an increase in work output, (c) heart rate greater than 90% of predicted maximal value (220 – age), and (d) respiratory exchange ratio greater than 1.1.

C. Pre-trial Diet and Depletion-Taper Exercise

The purpose of the H-CHO trial was to increase muscle glycogen levels and, for this reason, a previously established diet and exercise regime by Sherman et al. was utilized (30). On days 1–3 (depletion phase), subjects consumed a mixed diet (50% carbohydrate, 35% fat, and 15% protein) for both trials. Diet for days 4–6 consisted either of 600 g of carbohydrate and 46 g of fat or 100 g carbohydrate and 245 g of fat for the H-CHO and L-CHO diets, respectively. Meals for the L-CHO diet (12% carbohydrate, 66% fat, and 22% protein) were provided to the subjects as dated coupons for a fixed menu in a local restaurant. The H-CHO diet was standardized by giving to each subject a menu (describing food composition and amount) to consume (75% carbohydrate, 13% fat, and 12% protein). A commercially available dietary carbohydrate supplement was also provided to the subjects for the H-CHO trial. Both the H-CHO and L-CHO diets were isocaloric (~13.4 MJ).

A sequence of depletion-taper rides, standardized on an electronically braked cycle ergometer, began 6 days prior to the performance trial. The rides were per-
formed in laboratory facilities, under supervision, at 76 ± 2% of VO\textsubscript{2peak}. For day 1 subjects cycled continuously for 90 min where, for days 2 and 3, they cycled for 60 min. The exercise for days 4 and 5 lasted 20 min each, while no physical activity was performed during day 6. A diagram of the exercise and dietary protocol is presented in Figure 1. During the rides, an electric fan circulated air continuously over the subjects, and the laboratory temperature was standardized (temperature = 21 ± 1 °C). During these rides, subjects were allowed to drink water ad libitum. The supervised depletion rides were the only physical activity that were allowed during these 6 days in order to standardize the total daily and weekly amount of work performed by each subject.

D. Testing Protocol

On the 7th day of each trial, subjects arrived at the lab in the morning after an overnight fast to perform a 45-min ride at 82 ± 2% VO\textsubscript{2peak} on an electronically braked cycle ergometer. During the test, the only available feedback to the subjects was the cadence (revolutions per minute, rpm) and the time. Subjects were verbally encouraged throughout each test in order to complete the 45-min ride. During the period between the experimental trials (2–3 weeks), subjects were instructed to maintain their normal level of physical activity and not to change their training mileage or intensity.

E. Respiratory and Perceptual Measurements

During the 45-min performance trial, respiratory data (oxygen uptake, carbon dioxide production, and respiratory quotient) were collected in three 5-min periods (10–15 min, 25–30 min, and 40–45 min). From the respiratory data, whole body oxidative energy expenditure, oxidative energy expenditure derived from carbohydrates, and grams of carbohydrates oxidized were estimated based on the Peronnet
and Massicotte table (26). Heart rate data were collected in conjunction with the respiratory data using a three-lead ECG. Subjects were also asked for their ratings of perceived exertion (Borg’s RPE scale, 6–20) every 15 min. The subjects became familiar with the RPE scale during the depletion-taper rides.

F. Venous Blood Sample

Blood samples were taken from an antecubital vein without stasis and in sitting position, before and immediately following the 45-min cycling test. The blood samples were allowed to coagulate and then centrifuged at 1500 \( \times g \) for 15 min at 4 °C. The serum was removed and stored at –20 °C until subsequent analysis of glucose, free fatty acids, and triglycerides was performed using an Abbott Spectrum (high performance diagnostic system). Insulin levels were analyzed via a radio immunoassay (Coat-A-Count®, Diagnostic Product Corporation, Los Angeles, CA, USA).

G. Muscle Biopsies

Muscle biopsies were obtained from the vastus lateralis before the performance trial using the percutaneous needle biopsy technique with suction (8). The biopsy site (12–16 cm above the patella in the lateral portion of the thigh) was anesthetized with 2 ml of 2% Xylocaine (containing 1:100,000 parts epinephrine). An incision was made through the skin and fascia overlying the vastus lateralis with a scalpel blade, and a 5-mm biopsy needle was inserted 3–4 cm into the muscle for sampling. Following withdrawal, the muscle sample was cleaned from fat and fascia and immediately frozen in liquid nitrogen and stored at –80 °C until analysis. Samples were analyzed for glycogen concentration using the method described by Passonneau and Lauderdale (25).

I. Statistical Analysis

Variables were analyzed using two-way analysis of variance (treatment \( \times \) time) for repeated measures. Significant differences between the means were determined by the use of Tukey’s post hoc analysis, accepted at the \( p < .05 \) level. All values were expressed as the mean ± standard error of the mean (SEM).

Results

As a result of the 6-day exercise and diet manipulation, pre-exercise muscle glycogen concentration during the H-CHO trial (104.5 ± 9.4 mmol/kg wet wt) was significantly (\( p < .05 \)) greater than the L-CHO (72.2 ± 5.6 mmol/kg wet wt) trial. Figure 2 illustrates the pre-exercise muscle glycogen values for the two experimental trials.

Heart rate during the L-CHO trial was not different from the H-CHO trial (Figure 3). Subjects also rated their perceived exertion similarly for both the H-CHO and L-CHO trials. RPE was significantly (\( p < .05 \)) higher at 25 min and at 40 min when compared to the previous time point. These data show a gradual increase from the initial to the final part of each trial (Figure 3).

Oxygen consumption and the respiratory quotient (RQ) during the cycling exercise did not differ significantly (\( p > .05 \)) between the trials or within each ride.
Figure 2 — Muscle glycogen concentration prior to the 45-min exercise test during the high carbohydrate (H-CHO) and the low carbohydrate (L-CHO) trials. *Denotes statistically significant ($p < .05$) difference from the L-CHO trial.

Estimated whole body oxidative energy expenditure, oxidative energy expenditure derived from carbohydrates, and grams of carbohydrates oxidized during exercise were not significantly different between the H-CHO and L-CHO trials (Table 2).

Serum glucose analysis showed that euglycemia was maintained during exercise for both conditions. At the end of the H-CHO trial blood glucose was significantly higher ($p < .05$) than the pre-exercise level. During the L-CHO trial, the blood glucose levels did not change (Table 3). Plasma triglycerides were significantly greater during the H-CHO trial both before and after the exercise test when compared to the L-CHO trial (Table 3). No statistically significant differences were found for serum insulin or free fatty acids between Condition and Time (Table 3).

**Discussion**

The results of this study showed that a high carbohydrate diet (H-CHO) induced a 45% higher muscle glycogen levels than the low carbohydrate diet (L-CHO). However, it did not induce any significant physiological or perceptual responses during a 45-min strenuous cycling exercise that were not observed during the low carbohydrate diet when energy intake was adequate. Although we had hypothesized that the H-CHO diet will be more beneficial than the L-CHO diet during the exercise test, no significant differences were found regarding rating of perceived exertion, heart rate, oxygen uptake, and respiratory quotients. These findings could be related to the fact that although the muscle glycogen levels were significantly different, they were not as different as expected. We also assumed that the baseline muscle glycogen levels before the beginning of the 7-day protocol were similar for each trial, although no actual measurements were performed. Volunteers were asked to maintain their
normal dietary and training habits during their participation in the study. Additionally, prior to the 3-day high or low carbohydrate diet, a 3-day mixed diet was used in order to assist in eliminating possible differences among the baseline muscle glycogen levels.

These findings are in agreement with other studies where exercise lasted 60 to 90 min. Sherman et al. showed that muscle glycogen super-compensation did not improve exercise performance during a 20.9-km run, in comparison to the control trial (30). In a separate study, 6 highly trained endurance runners ran to exhaustion at 75–80% of their VO$_{2\text{max}}$ with normal muscle glycogen stores or after a diet- and training-induced muscle glycogen super-compensation (22). The exercise time to exhaustion did not improve endurance capacity in these individuals. Moreover, Hawley et al. (14) studied the effect of a supplementary carbohydrate diet on a 1-h cycling time trial. They reported that a carbohydrate supplement diet did increase pre-exercise muscle glycogen levels but did not improve performance.

As mentioned before, the focus of this study was the examination of the effect of a high carbohydrate diet upon strenuous exercise of 30–45 min in duration when

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**Figure 3** — Heart rate (HR) and rating of perceived exertion (RPE) during exercise for the high carbohydrate (H-CHO) and the low carbohydrate (L-CHO) trials. *Denotes statistically significant ($p < .05$) difference from 10 min and †25 min within each trial.
no previous investigation had done so. Additionally, most previous studies have investigated the effect of high carbohydrate diet in comparison with mixed diet. In the present study an isocaloric, low carbohydrate diet was compared to a high carbohydrate diet.

Results of this study indicated that oxygen consumption and respiratory quotient were not significantly different for the two trials. Furthermore, no differences

**Table 2** Whole Body Oxidative Energy Expenditure (EE), Oxidative Energy Expenditure Derived From Carbohydrates (CHO), and Carbohydrates Oxidized During 45 Minutes of Cycling Exercise

<table>
<thead>
<tr>
<th>Experimental trial</th>
<th>EE (MJ)</th>
<th>EE from CHO (MJ)</th>
<th>CHO utilized (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High carbohydrate</td>
<td>3.31 ± 0.10</td>
<td>2.80 ± 0.17</td>
<td>161.7 ± 10.6</td>
</tr>
<tr>
<td>Low carbohydrate</td>
<td>3.28 ± 0.11</td>
<td>2.89 ± 0.11</td>
<td>166.9 ± 6.9</td>
</tr>
</tbody>
</table>

*Note.* Values were calculated from oxygen consumption and respiratory quotient values, obtained from respiratory gas analysis.
were found between the two conditions for the total energy expenditure, oxidative energy expenditure derived from carbohydrate, or grams of carbohydrate utilized during the ride. Similar findings were presented by Hawley et al. (14) during a 1-h cycling exercise with normal and elevated pre-exercise muscle glycogen levels.

In this study heart rate during the exercise test was almost identical between the two trials. The rating of perceived exertion was not significantly different between the H-CHO and the L-CHO, but it was increasing in both trials during the 45-min test. The plasma glucose level at the end of exercise was significantly greater in H-CHO versus the L-CHO probably due to greater endogenous carbohydrate availability in the H-CHO trial. Additionally, the pre-exercise plasma triglycerides level was significantly elevated at the baseline for the H-CHO trial. This effect of a short-term high carbohydrate diet on plasma triglycerides has been described and explained as a result of the accelerated VLDL-triglyceride secretion (23).

Despite the fact that muscle glycogen levels were not measured at the end of the exercise, we hypothesized that there were enough glycogen stores left at the end to sustain intense exercise. This has been previously documented for exercise lasting between 60–90 min (5, 14, 30) and under 20 min (20, 32). In other words, muscle glycogen availability was probably not the limiting factor for exercise performance of that intensity and duration.

In their classic textbook of work physiology, Åstrand and Rodahl state the following regarding the role of diet on exercise performance: “In very intense physical exertion or athletic events lasting less than 1 hour, the available supply of stored energy fuel is generally ample to cover the need. Under such conditions a special diet is unnecessary” (1). In conclusion, low carbohydrate diet decreased

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**Table 3 Serum Glucose, Insulin, Triglycerides, and Free Fatty Acids Pre- and Post-exercise During the H-CHO and L-CHO Trials**

<table>
<thead>
<tr>
<th>Variables</th>
<th>H-CHO trial</th>
<th></th>
<th>L-CHO trial</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Ex</td>
<td>Post-Ex</td>
<td>Pre-Ex</td>
<td>Post-Ex</td>
</tr>
<tr>
<td>Glucose (mmol/L)</td>
<td>4.5 ± 0.1</td>
<td>6.7 ± 0.6*</td>
<td>4.9 ± 0.3</td>
<td>5.2 ± 0.2</td>
</tr>
<tr>
<td>Insulin (pmol/L)</td>
<td>55.4 ± 7.2</td>
<td>78.3 ± 14.2</td>
<td>68.9 ± 9.9</td>
<td>55.6 ± 8.5</td>
</tr>
<tr>
<td>Triglycerides (mmol/L)</td>
<td>1.47 ± 0.28†</td>
<td>1.67 ± 0.24§</td>
<td>1.03 ± 0.14</td>
<td>1.14 ± 0.09</td>
</tr>
<tr>
<td>FFA (mmol/L)</td>
<td>0.41 ± 0.08</td>
<td>0.29 ± 0.07</td>
<td>0.44 ± 0.09</td>
<td>0.26 ± 0.04</td>
</tr>
</tbody>
</table>

*Denotes statistically significant difference from the pre-exercise value; †denotes statistically significant difference from the pre-exercise value of the other trial; §denotes statistically significant difference from the post-exercise value of the other trial.
muscle glycogen level but did not induce any response that was not observed during the high carbohydrate diet, when total energy intake was adequate.

References


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