The Effect of Encapsulated Soluble Fiber on Carbohydrate Metabolism During Exercise

Allen C. Parcell, Melinda L. Ray, Kristine A. Moss, Timothy M. Ruden, Rick L. Sharp, and Douglas S. King

Previous investigations have reported that soluble fiber reduces the plasma glucose and insulin changes after an oral glucose load. To improve the palatability of a soluble-fiber feeding, this study addressed how a combined, soluble fiber (delivered in capsule form) and a preexercise CHO feeding would affect metabolic responses during exercise. On 3 different days, participants ingested a placebo (CON), 75 g liquid CHO (GLU), or 75 g liquid CHO with 14.5 g encapsulated guar gum (FIB) 45 min before cycling for 60 min at 70% VO₂ peak. Peak concentrations of plasma glucose and insulin were similar and significantly greater than CON preexercise (p < .05). Similarities in carbohydrate reliance were observed in GLU and FIB. Muscle glycogen use did not differ significantly among trials. These results demonstrate that encapsulated soluble fiber delivered with a liquid CHO feeding does not affect plasma glucose, insulin, or muscle glycogen utilization during exercise.

Key Words: muscle glycogen, blood glucose, insulin, soluble fiber, cycling

Carbohydrate reserves in the liver and muscle are important energy sources during prolonged exercise. Early research on carbohydrate metabolism during exercise demonstrated that adequate muscle glycogen stores are necessary for optimal performance (3, 13). Consecutive days of endurance performance, an early-morning competition after an overnight fast, or a diet that is inadequate in carbohydrates may compromise the body’s carbohydrate energy stores. In such situations, providing carbohydrates before exercise may offer ergogenic benefits.

Preexercise carbohydrate ingestion causes increased plasma insulin levels. The combined effects of hyperinsulinemia and contraction-induced increases in glucose uptake may produce a precipitous decline in plasma glucose concentrations at the start of exercise (7, 8). Furthermore, increased plasma concentrations of insulin inhibit the release of free fatty acids (FFA). Earlier research suggested that this reduced availability of plasma glucose and FFA increases reliance on muscle

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glycogen stores and may result in decreased endurance exercise performance (7, 11). However, more recent evidence suggests that preexercise feedings may not influence muscle glycogen use (10).

Adding soluble dietary fiber to carbohydrate feedings attenuates the changes in postprandial concentrations of plasma glucose and insulin in healthy individuals (6). Soluble fiber affects carbohydrate absorption by increasing the viscosity of gastric contents, which slows gastric emptying and reduces the rate of convection from the lumen to the epithelial surface of the small intestine (4, 14, 16).

Previous research on the addition of soluble fiber to a carbohydrate feeding suggests that combining soluble fiber and carbohydrates results in an unpalatable feeding that may require a considerable amount of time for consumption (6, 17, 20) and may be refusal by participants (6, 14). The primary intent of the current investigation was to deliver soluble fiber in capsule form to determine if a more palatable feeding results in reduced postprandial changes in plasma glucose and insulin. Providing the fiber in capsule form also ensured that investigator and participant were both blind to the treatments. MacLaren et al. (20) demonstrated no effects on plasma glucose and insulin changes when soluble fiber was added to a preexercise carbohydrate feeding. However, this feeding was delivered immediately prior to exercise. A secondary aim of the current study was to provide a combined feeding of soluble fiber and carbohydrate 45 min before exercise. This time frame was selected because it most likely represents a regimen that an athlete would follow precompetition. It also provided adequate time for gastric contents to mix.

**Methods**

**Participants**

Participants were 8 male college students (age = 21–29) who volunteered to participate in this study, which was approved by the Human Subjects Review Committee of Iowa State University. Before participating, participants were informed of the requirements and risks associated with this research and gave written consent. Although all participants were physically active and participated in activities such as running, cycling, and weightlifting, none were involved in a regular exercise training program. Participants had a mean $\overline{\text{VO}}_2$ peak of $3.74 \pm 0.15$ L/min and averaged $8.2 \pm 1.0\%$ body fat as determined by skinfold analysis (15).

**Table 1  Participant Characteristics ($n = 8$)**

<table>
<thead>
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<th>Characteristic</th>
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<td>Height (cm)</td>
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<td>Weight (kg)</td>
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<td>Body fat (%)</td>
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<tr>
<td>$\overline{\text{VO}}_2$ peak (L/min)</td>
<td>3.74</td>
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**Preliminary Testing**

Prior to testing, VO\textsubscript{2} peak was determined during a graded exercise test on an electronically braked cycle ergometer (Lode Excalibur, Cal Med, Brea, CA). Participants began cycling at a load of 50 W at 80 rpm. Power output was increased by 50 W every 3 min until volitional exhaustion. Expired gases were conducted through a 3-L mixing chamber and analyzed for oxygen (Applied Electrochemistry SA-2 oxygen analyzer) and carbon dioxide (Beckman LM-1 CO\textsubscript{2} analyzer) fractions. The gas analyzers were calibrated with a known standard before each trial. Data from these instruments were directed to a DOS-based computer to calculate oxygen consumption (VO\textsubscript{2}) and respiratory exchange ratio (RER) (Turbofit, Vacumed, Ventura, CA).

**Experimental Protocol**

On three separate occasions assigned in a random, counterbalanced fashion, participants reported to the laboratory after an overnight fast and consumed one of three lemon-flavored drinks with 15 opaque capsules (gelatin capsule NO. 00, Eli Lilly and Co., Indianapolis, IN) 45 min before exercise. In the fiber trial (FIB), participants consumed 75 g of glucose in 300 ml of water and 15 capsules containing 14.5 g of guar gum, a soluble fiber. Research shows that this dose of soluble fiber reduces postprandial increases in plasma glucose concentrations (6). The glucose trial (GLU) consisted of 75 g of glucose in 300 ml of water and 15 capsules containing calcium carbonate. In the control trial (CON), participants consumed 300 ml of a placebo sweetened artificially with NutraSweet and 15 capsules containing calcium carbonate, which was selected as the placebo because of its similar appearance to guar gum and a lack of interference with glucose absorption. All capsules and fluid were ingested within a 2-min period. After the feeding, participants rested for 45 min before cycling for 60 min at 70% of VO\textsubscript{2} peak on the cycle ergometer.

**Physiologic and Metabolic Measures**

Expired air was collected at 15-min intervals during the cycling bout to determine VO\textsubscript{2} and RER. Ratings of perceived exertion (RPE) were also obtained from participants at these time points. For blood sampling, a flexible catheter was inserted into a forearm vein prior to the preexercise feeding and kept patent with 5-ml injections of 0.9% NaCl after each blood withdrawal. A 5-ml blood sample was collected every 15 min, beginning at the time of carbohydrate ingestion and continuing throughout the cycling bout. A 1-ml aliquot was taken from the collected blood, immediately centrifuged, and analyzed for glucose and lactate concentrations using a YSI 2300 Stat Glucose/L-Lactate analyzer (Yellow Springs Instruments, Yellow Springs, OH). Glucose and lactate measurements were performed twice. The remainder of the blood sample was centrifuged. The plasma was separated and frozen for subsequent analysis of plasma insulin and free fatty acid (FFA) concentrations, performed in triplicate. Plasma insulin concentrations were determined by radioimmunoassay, using a commercially available kit (Diagnostic Products, Los Angeles). Plasma FFA concentrations were determined enzymatically with a spectrophotometric method (22). To eliminate intra-assay variability during insulin and FFA analyses, all samples for each participant were run in the same assay.
Muscle biopsies were taken from the vastus lateralis using needle biopsy techniques as described by Bergstrom (2). Biopsies were performed prior to the feeding and before and immediately following 60 min of cycling. The muscle samples were immediately frozen and stored in liquid nitrogen for subsequent analysis. During a trial, all muscle samples were taken from the initial incision, and we tried to take subsequent samples proximal to the preceding biopsy. Prior to analysis, muscle samples were freeze-dried (Tis-U-Dry, FTS Systems, Stone Ridge, NY) and assayed in triplicate for muscle glycogen content using enzymatic fluorometry techniques (19).

**Dietary and Exercise Control**

To control preexercise muscle glycogen concentrations, participants performed 60 min of cycling exercise at 50% of $\dot{V}O_2$ peak on each of the 2 days preceding each trial and were required to refrain from any additional vigorous exercise. Participants mean daily caloric intake for the 3 days before the first trial was 3260 ± 399.5 kcal, which comprised an average consumption of 497 ± 77.7, 118.4 ± 20.3, and 91.61 ± 13.0 g of carbohydrate, protein, and fat, respectively. Participants were instructed to duplicate this diet before their remaining two trials; therefore, dietary analysis was not performed on food intake after the last two trials.

**Statistical Analysis**

Results were analyzed with two-way repeated measures analyses of variance (ANOVA). After a significant main or interaction effect was obtained, specific mean differences were located with Newman-Keuls post hoc tests. Statistical tests were evaluated at a $p < .05$ level of significance. Values are reported as means ± SE.

**Results**

**Plasma Glucose and Lactate**

Fasting plasma glucose concentrations measured prefeeding were similar among all trials (4.8 ± 0.6, 4.9 ± 0.07, and 5.0 ± 0.12 mmol/L for CON, FIB, and GLU, respectively). After the preexercise feeding a marked increase in plasma glucose concentrations was observed in GLU and FIB 30 min before exercise (GLU = 6.5 ± 0.2 mmol/L, FIB = 6.3 ± 0.1 mmol/L). Plasma glucose values during GLU continued to rise to a peak value of 6.8 ± 0.2 mmol/L at −15 min of the rest phase (see Figure 1). The observed increases in plasma glucose concentrations in GLU and FIB were significantly different from CON ($p < .05$). Although not significant, plasma glucose concentrations in FIB tended to decrease 15 min before exercise.

During exercise, declines in plasma glucose concentrations occurred at 15 min in both GLU and FIB (3.6 ± .3 and 3.7 ± 0.2 mmol/L, respectively) (Figure 1). These plasma glucose concentrations in GLU and FIB were significantly lower than values in CON ($p < .05$). By 30 min of exercise, plasma glucose concentrations for GLU and FIB had risen to approximate fasting levels and were not significantly different among groups for the remainder of the exercise bout.

Plasma lactate concentrations peaked after 15 min of exercise in GLU (4.0 ± 0.6 mmol/L), FIB (3.5 ± 0.6 mmol/L), and CON (4.1 ± 0.9 mmol/L) (see Figure 2).
Figure 1 — Plasma glucose responses to preexercise feedings during rest and exercise. *Significantly different from CON ($p < .05$).

Figure 2 — Effect of preexercise feedings on plasma lactate responses.
However, none of these values were significantly different. Plasma lactate measurements at 30 min of exercise showed a decline in concentration, which continued until exercise completion in all three trials.

**Plasma Insulin Response**

Resting insulin levels were 57.6 ± 7.1, 51.3 ± 11.1, and 58.4 ± 12 pmol/L in CON, FIB, and GLU, respectively. The peak values for plasma insulin concentrations occurred at −15 min in FIB and 0 min in GLU (229.1 ± 28.5 and 244.4 ± 52.9 pmol/L, respectively). These values were significantly greater than the highest plasma insulin concentration for CON (62.4 ± 10.3 pmol/L at −30 min, \( p < .05 \)) (see Figure 3). During the resting phase there were no differences in GLU and FIB plasma insulin concentrations.

A marked decline in plasma insulin concentrations was measured in GLU (244.4 ± 52.9 to 76.0 ± 19 pmol/L) and FIB (210.7 ± 35.2 to 62.8 ± 13.5 pmol/L) from 0 to 30 min during cycling, whereas insulin concentrations remained stable during CON. There were no differences among GLU, FIB, and CON during exercise (see Figure 3).

Although plasma insulin concentrations were generally higher at 60 min in GLU (44.5 ± 10 pmol/L) and FIB (47.4 ± 8.9 pmol/L) compared to CON (16.9 ± 4.3 pmol/L), these values were not significantly different (see Figure 3), apparently due to the large variability in FIB.

![Graph showing plasma insulin concentrations](Image)

**Figure 3** — Effects of preexercise feedings on plasma insulin concentrations during rest and exercise.

*Significantly different from CON (\( p < .05 \)).
**Plasma FFA Response**

There were no significant differences in plasma FFA concentrations among trials during the rest phase (see Figure 4). Immediately preexercise, plasma FFA concentrations were 0.220 ± 0.039, 0.199 ± 0.041, and 0.173 ± 0.056 mmol/L for CON, FIB, and GLU, respectively. At 60 min of exercise, plasma FFA concentrations were significantly lower in GLU (0.206 ± 0.017 mmol/L) compared to CON (0.335 ± 0.045 mmol/L, *p < .05*). Although FFA concentrations were generally lower in FIB (0.232 ± 0.046 mmol/L), this difference did not reach statistical significance. There were no differences in FFA concentrations in GLU compared to FIB during exercise.

**Muscle Glycogen Concentration**

Fasting muscle glycogen concentrations (see Table 2) were greater (*p < .05*) in GLU (449.7 ± 41.5 mmol/kg dry weight) compared to CON and FIB (333.4 ± 17.9 and 363.7 ± 27.2 mmol/kg dry weight, respectively). There was no measurable glycogen synthesis during the 45 min following the feeding in any trial, and muscle glycogen concentration remained higher in GLU compared to CON and FIB immediately preexercise. Since increased concentrations of muscle glycogen may result in increased use of muscle glycogen during exercise (21), these data were examined with an analysis of covariance, with muscle glycogen concentration at the start of exercise as the covariate. Muscle glycogen use was not different in CON (86.0 ± 37.8 mmol/kg dry weight), FIB (106.9 ± 26.1 mmol/kg dry weight), and GLU (138.1 ± 33.2 mmol/kg dry weight).

![Graph](image-url)

**Figure 4** — Plasma FFA concentration changes throughout rest and exercise following preexercise feedings.

*Significantly different from CON (*p < .05*).
Table 2  Muscle Glycogen Concentration (mmol/kg dry weight)

<table>
<thead>
<tr>
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<th>Postexercise</th>
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<tr>
<td>CON</td>
<td>333.4</td>
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<td>FIB</td>
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<td>GLU</td>
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<td>451.2</td>
<td>35.4*</td>
<td>313.0</td>
<td>53.8</td>
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</tbody>
</table>

Note. n = 8.
*Significantly different from FIB and CON (p < .05).

Respiratory Exchange

Respiratory exchange ratio values at 15, 30, and 45 min during GLU (0.94 ± 0.01, 0.93 ± 0.01, and 0.92 ± 0.01, respectively) were significantly greater than CON (0.91 ± 0.02, 0.89 ± 0.01, and 0.87 ± 0.01, respectively, p < .05) (see Figure 5). RER was significantly elevated during FIB at 45 and 60 min (0.90 ± 0.01 and 0.89 ± 0.004, respectively) compared to CON (0.87 ± 0.01 and 0.86 ± 0.01, respectively, p < .05). No significant differences were observed between trials for oxygen consumption (mean = 68% \( \text{VO}_2 \text{peak} \)) throughout the exercise bout.

Ratings of Perceived Exertion

Participants perceived increased difficulty from the beginning to end of exercise. Average RPE values increased from 0 and 60 min of exercise in CON (12.6 ± 0.5 vs. 13.8 ± 0.5), FIB (12.1 ± 0.5 vs. 14.5 ± 0.05), and GLU (12.4 ± 0.5 vs. 14.5 ± 0.4). There were no significant differences in RPE among trials.

Discussion

Rapid declines in the plasma glucose concentration are seen following a preexercise carbohydrate feeding due to the combined effect of insulin-stimulated and contraction-mediated glucose uptake (1, 8, 9). The increased plasma insulin reduces FFA availability (10). It may cause increased reliance on muscle glycogen stores and limit endurance exercise performance (7, 11). Soluble fiber can reduce the glycemic response to an oral glucose feeding (5, 6). Although the moderating effect of soluble-fiber on the glycemic response may improve substrate availability during exercise and enhance exercise performance, some soluble fiber feedings are unpalatable (6, 14). This investigation aimed to examine how a combined carbohydrate and soluble-fiber feeding delivered in a more palatable capsule form would affect the metabolic responses during exercise.

In this study, 14.5 g of soluble fiber delivered in capsule form with a glucose drink did not reduce the glycemic response compared to the glucose-only feeding. Previous research has demonstrated significant attenuation of the postprandial increases in plasma glucose and insulin levels after feeding participants 50 g of carbohydrate combined with 14.5 g of soluble fiber (8). Thus, smaller increases in the
plasma glucose and insulin concentrations in FIB compared to GLU were expected because of the added 14.5 g of soluble fiber to the preexercise carbohydrate feeding.

A blunting of plasma glucose and insulin responses to a carbohydrate feeding that includes fiber is not a universal finding. MacLaren et al. (20) observed no difference in participants’ metabolic responses or endurance performance when soluble fiber was added to either glucose or maltodextrin feedings. However, the soluble fiber concentration (8%) was half that which affects glucose and insulin responses (8). Additionally, the feeding was consumed immediately prior to exercise, thereby bypassing the usual preexercise glucose and insulin responses that soluble fiber is thought to attenuate. Soluble fiber exerts its effects by reducing rates of gastric emptying and absorption (4, 14, 16). In the present study the feedings were administered 45 min before exercise to more closely duplicate an athlete’s behavior prior to competition and to allow for the mixing of gastric contents.

The present results extend the previous work and suggest that not only the timing and dose of fiber ingested but also the mode of administration may significantly affect which soluble fiber reduces insulin and glucose responses to carbohydrate feeding. The ineffectiveness of the soluble fiber among the current participants may be attributed to the use of gelatin capsules for fiber administration. The similar rises in plasma glucose in GLU and FIB at 30 min preexercise suggest similar rates of glucose delivery and absorption in the small intestine. Inadequate mixing of gastric contents prior to emptying into the small intestine may account for the lack of differences in the glycemic response between GLU and FIB. The capsules may have dissolved at a rate slow enough to allow the carbohydrate solution to
empty into the small intestine before combining with the encapsulated guar gum. Ingesting the capsules earlier than the glucose solution may therefore produce the expected modulation of glucose and insulin responses.

Opinions about the effectiveness of preexercise carbohydrate feedings on endurance exercise performance are varied (10, 12, 23). Differences in feeding and performance test methodologies complicate the interpretation of results. Nevertheless some researchers have shown that maintaining alternate fuel sources during exercise reduces muscle glycogen utilization (7, 18). In the current study we hypothesized that the potential increased glucose and FFA availability due to the added soluble fiber to the carbohydrate feeding would provide alternative energy substrates and diminish the reliance on muscle glycogen during exercise. The current data demonstrate that FFA concentrations during FIB were similar to GLU. Furthermore, significant elevations in RER values during exercise in GLU and FIB compared to CON confirmed an increased reliance on carbohydrate during both treatments. Consequently, there were no statistically significant differences among the postexercise concentrations of muscle glycogen among GLU, FIB, or CON. These findings are consistent with fiber having no effect on preexercise glucose and insulin responses.

In summary, the glycemic and metabolic responses to GLU and FIB were similar. The attempt to improve preexercise feeding palatability by encapsulating the guar gum may have resulted in ineffective mixing of the soluble fiber and carbohydrate in the stomach and eliminated any delayed glucose absorption by the small intestine. Consequently, adding soluble fiber did not increase FFA availability or spare muscle glycogen. Therefore, encapsulated guar gum does not moderate the glycemic effect of an oral glucose feeding or improve substrate availability during exercise.

References


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