Effect of Variable Carbohydrate Intake on Exercise Performance in Female Endurance Cyclists

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This study measured the effect of variable carbohydrate intake on time to exhaustion, variations in heart rate (HR), respiratory exchange ratio (RER), and rating of perceived exertion (RPE) in female endurance cyclists during an exercise trial. Subjects were 11 eumenorrheic women with maximal oxygen consumption (VO$_{2\text{max}}$) 60.1 ± 5.1 ml/kg who habitually cycled at least 100 miles per week. In a crossover design, each woman was randomly assigned to an eucaloric diet providing 8, 5, or 3 g of CHO/kg of body weight. Subjects cycled at least 100 miles while adhering to the diet for 6 days. The exercise trial was performed on the 7th day, consisting of a 60 min cycle at 70% VO$_{2\text{max}}$, followed by an increase in intensity to 90% VO$_{2\text{max}}$ until that intensity could no longer be maintained. Results indicated no difference in mean time to exhaustion, heart rate, or RPE. RER increased over time-elapsed ($F = 40.4, p < .001$) and across diets ($F = 6.1, p = .015$). Conclusions: Female endurance cyclists did not experience a difference in time to exhaustion, HR, or RPE with different levels of CHO intake during an endurance trial. RER varied with diet at submaximal intensities. Further research is needed to determine the optimal level of CHO intake for this population.

Key Words: nutrition, substrate utilization, women, diet, carbohydrate

Inadequate availability of carbohydrate from blood glucose and glycogen stores is known to limit endurance exercise performance at intensities of 65–80% VO$_{2\text{max}}$. However, the effect of dietary carbohydrate on muscle glycogen stores and exercise performance has been studied primarily in male athletes. While few studies are available on female athletes, they suggest that nutritional requirements might be different for women than for men. Gender differences in substrate utilization suggest a reduced reliance on carbohydrate and protein in exercising women, and a greater reliance on fat (14, 22). Also, glycogen loading, the practice of maximizing muscle stores with a high carbohydrate intake, has been shown to be less effective in
women than in men (23). It appears, therefore, that the level of carbohydrate intake required to optimize physical performance may be different for men and women.

The American College of Sports Medicine, the American Dietetic Association, and the Canadian Dietetic Association have recently issued a joint position paper on nutrition for athletic performance (1). They recommend that athletes consume 6–10 g of carbohydrate per kg body weight daily. They note that a specific recommendation should be based on factors including weight and gender of the athlete. However, the position paper does not define how to determine precise recommendations, and there is little research available to guide the sports nutritionist in determining the optimal carbohydrate intake for female endurance athletes.

Complicating this issue is the observation that nutritional adequacy is a concern for female athletes. A number of studies have shown that women athletes consume fewer calories than their predicted requirements (12, 25, 28). These women may consume inadequate protein and very little fat. A recommendation to maximize carbohydrate intake could exacerbate this problem as women focus on this nutrient and inadvertently exclude others. For example, a 55-kg woman attempting to consume 10 g of carbohydrate per kg body weight would have to consume about 550 g a day, or about 2200 kcal from carbohydrate alone, leaving little room for the protein and fat required in the diet. It therefore appears logical to recommend a lower level of carbohydrate intake for women. Research to determine the effect this would have on athletic performance, however, is lacking.

The purpose of this study was to determine the effect of various levels of carbohydrate intake on endurance exercise performance. We hypothesized that women endurance cyclists consuming a diet providing 5 g of carbohydrate per kg body weight would perform comparably to women endurance cyclists consuming an isocaloric diet consisting of 8 g of carbohydrate per kg body weight. We further hypothesized that athletes consuming 3 g of carbohydrate per kg body weight would experience a higher rating of perceived exertion than those consuming an isocaloric diet with a higher level of carbohydrate (5 g and 8 g per kg) and that time to exhaustion would be lower.

**Methodology**

**Subjects**

Subjects were recruited through cycling club Web sites and word of mouth in the New York metropolitan area. Initial criteria were for women of 20–45 years of age who cycled a minimum of 100 miles per week and were eumenorrheic. Descriptive data are presented in Table 1. Respondents were interviewed over the telephone to ascertain their willingness to adhere to the study protocol and to come to the laboratory four times for testing. Eumenorrhea was determined by self-report. A 3-day food record was requested for analysis and to determine food preferences. The food record was analyzed using a computerized nutrient analysis program (Food Processor, v. 7.30 Esha Research, Salem, OR, USA).

Each volunteer who met the initial inclusion criteria was fully informed of all testing procedures and signed written informed consent for participation. The protocol was approved by Teacher’s College, Columbia University and St. Luke’s Roosevelt Hospital Center Institutional Review Boards.
Baseline Data

Body weight was measured on a calibrated balance scale (Detecto Medics, Detecto, Brooklyn, NY, USA). VO$_{2\text{max}}$ was determined to confirm training status using a FITCO metabolic cart (FITCO, Farmingdale, NY, USA) that was calibrated prior to each test using calibration gases of a known concentration. Barometric pressure, relative humidity, and room temperature were recorded to correct metabolic measurements to STPD. Subjects were attached to an electrocardiogram with a V$_5$ lead configuration (Marquette Max 2000, Milwaukee, WI, USA) for heart rate monitoring at rest and during exercise. A continuous graded exercise protocol on a cycle ergometer (Bodyguard 990, Olgaerd, Norway) was used. The protocol followed established criteria to elicit the highest oxygen consumption, with subjects cycling in 2-min increments of 25–40 W (3). Maximal oxygen consumption was confirmed by a plateau in VO$_2$ along with an RQ > 1.2 and an increase in VE without further increase in VO$_2$.

To confirm that all subjects would be exercising below their ventilatory threshold (VT) at 70% VO$_{2\text{max}}$, VT was estimated by plotting expiratory ventilation (VE/VO$_2$ against VE/VCO$_2$).

Estimation of Caloric Requirements

As an excess or deficiency of calories might affect substrate utilization, caloric requirements for each subject were determined using measurement of resting metabolic rate and estimates of the caloric cost of activity using a published table (11).

Resting Metabolic Rate. Resting metabolic rate was obtained using indirect calorimetry. Subjects reported to the laboratory after a 12-h fast and 24 h after exercise. Subjects were tested either in an energy metabolism chamber using a ventilated hood apparatus or with a mouthpiece and nose clips based on availability of the chamber. The reliability and validity between these two methods has been established (18).
Those tested in the chamber rested quietly on a bed in the supine position with a large plastic hood placed comfortably over the head. The hood was connected to an air sampling device, which made measurements of \( \text{CO}_2 \) and \( \text{O}_2 \) in expired air for 18 min after the data stabilized. Values were corrected for temperature, barometric pressure, and humidity. The remaining subjects rested in the supine position in a darkened room with a rubber mouthpiece placed in the mouth and nose clips attached to ensure that all breathing took place through the mouthpiece. A FITCO metabolic cart (FITCO, Farmingdale, NY, USA) was used and calibrated prior to each test using calibration gases. Metabolic measurements were made using open-circuit spirometry for 18 min after the data stabilized. Fractional expiration of \( \text{CO}_2 \) and \( \text{O}_2 \) and expiratory ventilation (VE) was measured. Respiratory exchange ratio (RER) was calculated (RER = \( \frac{\text{VCO}_2}{\text{VO}_2} \)).

Caloric expenditure was estimated using the Weir equation (27):

\[
\text{kcal/min} = \left[ \frac{(1.1 \times \text{RER}) + 3.9}{\text{VO}_2 \text{ (L/min)}} \right]
\]

Resting energy expenditure (REE) was calculated as follows:

\[
\text{kcal/min} \times 1440 \text{ min/d} = \text{REE}
\]

**Diet**

Diets were calculated to provide 100% of total estimated energy requirements. Protein was calculated to provide 1.5 g/kg body weight to ensure nitrogen balance. Carbohydrates were calculated to provide 8 g/kg body weight (HiCHO), 5 g/kg body weight (ModCHO), or 3 g/kg body weight (LoCHO). The remaining kilocalories were provided as fat. All diets were isocaloric and contained the same amount of protein. Each diet was individualized in accordance with the subject’s food preferences as obtained from a 3-day food record.

We chose 8 g CHO/kg BW as our high CHO level, as that is the maximum level of carbohydrate achievable within our subject’s energy and other nutrient requirements.

**Body Composition**

Muscle mass, fat mass, and lean body mass were evaluated, since glycogen is stored in muscle. Dual-energy x-ray absorptiometry (DEXA; Lunar DPX, software v. 3.1) was selected as a method that would provide a multi-compartmental model of body composition. The validity and reliability of this method in estimating body composition in adults who vary in gender, race, athletic status, body size, musculoskeletal development, and body fatness has been established (15).

**Procedures**

The study protocol was a double-blind, cross-over design. Subjects were randomly assigned to diet 1, 2, or 3, which corresponded to HiCHO, ModCHO, and LoCHO. A volunteer who was not involved with the performance testing did the randomization. The diets were carefully reviewed with each subject. Menus were provided, with lists of foods and portion sizes to be consumed daily. The importance of accurate measuring, consumption, and recording of foods was emphasized. To ensure double-blindness, the volunteer provided each subject with a sports drink.
that contributed to the variability of carbohydrate in the diet. HiCHO received Gatorlode, a high carbohydrate supplement (20% carbohydrate). ModCHO received Gatorade, a 6% carbohydrate drink, and LoCHO received an artificially sweetened placebo. All sports drinks were provided by The Gatorade Company (Barrington, IL, USA).

Testing was conducted during the mid-follicular phase of the menstrual cycle. Subjects were instructed to adhere to the diet for 6 days prior to the testing date while cycling a predetermined distance of at least 100 miles per week on their own bike at their normal training pace. They could elect to exercise more than the minimum, but they were asked to notify the researchers of this so that energy expenditure could be calculated and energy intake adjusted accordingly. Exercise was required to be consistent between all three test periods.

On day 7, subjects consumed a standardized breakfast (8 oz. Gatorpro, a 360-cal drink containing carbohydrate, protein, and fat) 3 to 4 h before coming to the laboratory. No other food or beverage other than water was permitted, and subjects were asked to not exercise prior to coming to the laboratory.

All testing occurred in an environmentally controlled laboratory. Temperature was maintained between 20°C and 24°C with 79–84% relative humidity for all three trials.

To ensure adequate hydration, urine-specific gravity was measured prior to the performance trial. If urine-specific gravity measured above 1.02, subjects were instructed to drink at least 8 oz. of water prior to initiating the exercise test. This occurred on two occasions.

Subjects were weighed on a calibrated Detecto Medic scale (Detecto, Brooklyn, NY, USA) to within 0.1 kg. They were attached to an electrocardiograph with a V5 lead configuration for monitoring heart rate at rest and during exercise.

Oxygen and carbon dioxide analyzers were calibrated before each test. The subject sat on the cycle ergometer and adjusted the seat for comfort. A mouthpiece was inserted and held in place with headgear, and a nose clip was attached. A fan was directed towards the subject to keep her cool. After a short warm-up on the cycle ergometer, the workload was increased to that calculated to elicit an oxygen consumption of 70% VO2max. The intensity was confirmed by the computer readout of VO2, and the workload and/or pace was adjusted as necessary. Once VO2 readings were stabilized, the mouthpiece was removed. Heart rate was monitored continuously, and rating of perceived exertion (RPE) was determined every 15 min. The mouthpiece was reinserted and nose clip reattached at 30 min. Oxygen consumption data were obtained to confirm intensity (VO2) and to determine RER. Adjustments in intensity were made as necessary. Water was given continuously throughout the trial when the mouthpiece was removed. Subjects were encouraged to consume a full liter of water during the first hour of cycling.

At 56 min, the mouthpiece was reinserted, nose clip reattached, and exercise intensity was confirmed. At 60 min the intensity was increased to 90% VO2max. Oxygen consumption, RER, heart rate, and RPE were monitored while subjects cycled until fatigue. Verbal encouragement was provided. Fatigue was defined as the point at which cycling could not be maintained above 60 rpm and VO2 dropped. Time to exhaustion (TTE) was recorded. The workload was then lowered, the mouthpiece and nose clip removed, and subjects recovered at their own pace. Water was supplied immediately.
There was approximately a 3-week washout between trials. At the initiation of the next menstrual cycle, the subject was randomly reassigned to the next diet. The exercise protocol remained identical to the previous trial.

The above procedure was repeated until each subject had been assigned to each of the three diets.

**Statistical Analysis**

All analyses were conducted using SPSS v. 7.5 software on an IBM Pentium-based computer. Group results are presented as mean ± standard deviation. Differences in time to exhaustion (TTE) across diets were examined with a singly repeated measures analysis of variance. Doubly repeated analyses of variance were used to test differences in RPE, RER, and HR across the three diets and across time during each endurance trial. Analyses were run using measures taken at 30 min, 60 min, and 61 min and also using measures taken at 30 min, 60 min, and end of trial as there were differences between subjects in total length of trial. As there were no appreciable differences between the two approaches, only results of the former are reported.

A repeated measures one-way MANOVA was used to evaluate a possible correlation between muscle mass and effect of diet on time to exhaustion. As those with the greatest muscle mass were the tallest, the model was re-tested for the following interactions: Diet Group × Muscle, and Diet Group × Height. These interactions were tested simultaneously to determine whether the effect of diet on TTE depended on muscle and height independent of each other.

Eleven subjects completed all protocols; however, data was incomplete for 3 of the subjects. Data from the 8 remaining subjects was used for analysis.

**Results**

**Energy Requirements**

Resting metabolic rate was 1414 ± 215 kcal, and total energy expenditure was 2473 ± 295 kcal.

**Analysis of Food Records**

Three-day food records collected at the time of subject recruitment were analyzed using Food Processor software (v. 7.4, Esha Research, Salem, OR, USA). Average habitual intake was 2386 ± 669 kcal with 54% of kcal from carbohydrate, 16% of kcal from protein, and 29% of kilocalories from fat. Estimated energy intake closely approximated measured energy requirements.

**Compliance**

Dietary analysis revealed that subjects consumed 92% of kcal prescribed. Most, however, were unable to consume adequate CHO on the HiCHO diet. Mean compliance on the high CHO diet was 0.84 ± 0.07 (n = 6), 1.04 ± 0.07 on the moderate CHO diet (n = 6), and 1.02 ± 0.09 on the low CHO diet (n = 4). Compliance data were not available for all 8 subjects, as incomplete data were handed in by some subjects.
Mean resting RER increased with the CHO content of the diet, indicating greater CHO oxidation (See Figure 1). As evidence of energy balance, subjects were weighed prior to each performance trial. The mean change in weight over the duration of the study was $-0.44 \pm 1.5$ kg. The greatest change in weight occurred in 1 subject who started the study after competing in a double Ironman triathlon. She lost 3.5 kg over the duration of the study.

**Body Composition**

Subjects weighed $58.2 \pm 7.4$ kg with $22 \pm 5\%$ body fat. Lean body mass was $45.2 \pm 5.9$ kg with $22.4 \pm 2.8$ kg muscle mass. Bone mineral density was $1.15 \pm 0.05$ gm/cm$^2$ (see Table 1).

There was no diet effect on the correlation between kilogram of muscle and time to exhaustion ($r = 0.30, p = .48$ for LoCHO; $r = -0.11, p = .79$ for ModCHO; $r = -0.13, p = .76$ for HiCHO). The exclusion of height did not change the results.

Percent body fat was inversely correlated with VO$_{2\text{max}}$ ($r = -0.85, p = .008$) and ventilatory threshold ($r = -0.48, p = .23$), although the latter was not significant.

**Exercise Performance**

**Time to Exhaustion.** The differences between times to exhaustion on the three diets were not statistically significant ($F = 1.5, p = .255$) and widely variable. In only 2 of the 8 subjects did TTE decline consistently across diets of decreasing carbohydrate intake (see Figure 2).
Hemodynamic, Metabolic, and Psychomotor Parameters

Heart Rate. There was no increase in heart rate during submaximal exercise as evidenced by 30- and 60-min heart rates ($F = 0.37, p = .57$). With the increase in exercise intensity, heart-rate increased over time-elapsed ($F = 36.4, p < .001$). Effect of diet on heart rate was not statistically significant ($F = 0.6, p = .531$), nor was the Diet $\times$ Time interaction ($F = 0.6, p = .682$; see Figure 3).

Rating of Perceived Exertion (RPE). RPE increased over time elapsed ($F = 41.7, p = .001$) but not across diet ($F = .514, p = .609$). Within diets, significance was observed during submaximal exercise ($F = 14.4, p = .007$). The interaction term was not significant ($F = 1.6, p = .213$; see Figure 4).

Figure 2 — Effect of diet on time to exhaustion expressed as mean $\pm$ SD. Open bar = low carbohydrate diet; horizontal lines = moderate carbohydrate diet; vertical lines = high carbohydrate diet. Differences were not significant.

Figure 3 — Effect of diet on heart rate expressed as mean $\pm$ SD. Open bar = low carbohydrate diet; horizontal lines = moderate carbohydrate diet; vertical lines = high carbohydrate diet. Steady-state exercise represented by 30 min and 60 min. High intensity exercise represented by 61 min. Differences were not significant.
Respiratory Exchange Ratio (RER). RER increased over time elapsed \((F = 40.4, p < .001)\) and across diets \((F = 6.1, p = .015)\). Within diets, there was no statistical difference during submaximal exercise \((F = 1.16, p = .32)\). The specific contrast of diets 1 and 2 versus diet 3 approached statistical significance \((F = 5.6, p = .056)\). The Diet \(\times\) Time interaction was not significant \((F = 0.6, p = .682; \text{see Figure 5})\).

**Discussion**

The main finding of this study was that, as hypothesized, there were no performance differences in female cyclists who completed a trial to exhaustion after 1 week on a diet supplying 8 g of CHO/kg body weight (HiCHO) versus 5 g of CHO/kg body weight (ModCHO). Surprisingly, there were also no significant changes in performance after 1 week on a diet supplying 3 g of CHO/kg body weight (LoCHO).

Our study, in agreement with others (9, 10, 19, 21, 26), did not demonstrate a diet effect on heart rate. In agreement with some (10, 19), we also did not find a diet effect on RPE. We surmise that glycogen stores were adequate for the 1 h cycle at 70% \(\text{VO}_{2\text{max}}\), allowing the trial to continue without distress. In one study that did report a statistical significance in RPE (9), the difference observed was not physiologically meaningful (13.1 ± 0.4 on HiCHO vs. 13.2 ± 0.4 on LoCHO).

The most robust statistically significant result of the present study was a diet effect on RER. This indicates that as the CHO content of the diet increased, subjects oxidized more CHO during exercise at submaximal levels. These differences disappeared once the workload was increased so that subjects were exercising at or above anaerobic threshold. This is in agreement with a number of other studies (9, 13, 26).
We found only one previous paper specifically designed to study the effect of variable levels on CHO intake on exercise performance in women (13). Those investigators found no difference in performance of 7 cyclists consuming 6.4 versus 4.3 g of CHO per kg body weight for 1 week prior to a performance trial. A significant decrease in performance was observed in those cyclists consuming 1.2 g of CHO/kg body weight. That study, however, had a number of design problems. Diets were self-selected, protein intake varied, and there was no washout period between trials. Furthermore, phase of menstrual cycle was not controlled for, and the exercise trial to exhaustion was conducted at 80% VO$_{2\text{max}}$. It is possible that this level of intensity was above the subject’s anaerobic threshold, which would affect results by increasing the reliance on carbohydrate.

Much of the work that has been done in the emerging area of gender differences in metabolism has been criticized for failing to control for numerous factors, including age, training level of the subjects, exercise intensity, diet, menstrual status, and phase of the menstrual cycle. While not comparing genders, our study used a crossover design to control for subject characteristics, controlled exercise intensity, prescribed a diet, ensured that all subjects were eumenorrheic, and that the performance trial occurred during the follicular phase of the cycle. Furthermore, all subjects were considered highly trained as they were only included upon demonstration of a VO$_{2\text{max}}$ of 50 ml/min/kg or greater.

One disadvantage of our design, however, was that the study occurred over a span of time during which training patterns varied. Subjects were recruited in the
spring when training levels were high due to the increase in daylight hours and impending competitions. Over the summer, training levels probably peaked, and many subjects were involved in competitive events such as Ironman distance triathlons and long distance bike races. Most of the performance trials took place over August, September, and October, with a few trailing into November, December, and January. As the competitive season passed and daylight hours diminished, training hours dwindled as well. Subjects were required to maintain the same training during the week as they were on the protocol but for the balance of the month were free to bike any or no distance. It is possible that VO$_{2\text{max}}$ declined from the point when it was tested in late spring. While we did not retest the subjects for VO$_{2\text{max}}$, the cross-over design of the study was felt to control for any differences that might have occurred due to variations in fitness level.

It is also possible that the test we used, a performance trial to exhaustion, was not sensitive enough to detect a difference in performance. We chose this test, as we were modeling our study after the work of others (13, 19, 26). However, others have suggested that a time trial in which subjects are required to cycle a given distance in the fastest time is a more sensitive test. One group found a within-cyclist coefficient of variation of 1.7% after three 100-km time trials (16). In fact, in explaining their inability to detect a significant difference in performance, Sherman and co-authors did suggest that their test, also a trial to exhaustion, may have been insufficiently sensitive (19).

As others have asked (6, 20), the survey data beg the question of whether women are obtaining inadequate dietary CHO or whether current recommendations are inappropriate. The 3-day food log submitted by our subjects prior to beginning the study indicated that these women were routinely consuming 54% of their kilocalories from CHO, or 5.5 g/kg body weight.

The literature demonstrating an improvement in athletic performance with a very high carbohydrate intake (8–10 g CHO/kg BW) among males is itself less than convincing. While most studies show a decline in muscle glycogen stores with a lower CHO intake, they have failed to demonstrate an improvement in athletic performance, the parameter of greatest concern to the athlete (5, 9, 10, 19, 21).

The questionable benefits of a diet very high in carbohydrate has particular significance when advising female athletes, given the generally accepted impression that their diets are often deficient in energy and a number of nutrients, including protein, iron, zinc, and calcium. The reported average energy intake of female athletes is 2200 kcal (28). A diet including 500 g from CHO per day would provide 2000 kcal from this nutrient alone, leaving little room for protein and fat kilocalories, and the micronutrients that are consumed with them.

It is interesting to note that analysis of the test food records revealed that subjects’ actual CHO intake on ModCHO and LoCHO was very close to the prescription, while on HiCHO subjects consumed only an average of 83% of the prescribed amount of CHO, reducing their diet to 6.5 g of CHO per kg body weight rather than the 8 g/kg of body weight prescribed. This could be taken as further evidence that the high CHO diet is unrealistic for women. Also of interest, the 2 subjects who dropped out of the study due to a reported intolerance to the diet were on HiCHO at the time. O’Keefe and colleagues (13) also found that subjects had difficulty achieving the high carbohydrate diet, consuming 72% of kcal from CHO instead of the 75% prescribed.
In addressing the issue of an appropriate CHO recommendation for female athletes, one must consider whether the answer lies in specifying CHO as a percent of total kilocalories, as an absolute amount of CHO, or as a weight-based CHO requirement (g/kg body weight). Expressed as a percent of total kilocalories, our subjects consumed 63–85% CHO on the HiCHO diet, 43–52% CHO on ModCHO, and 27–32% on LoCHO. Absolute CHO ranged from 368–560 g on diet 1, 230–350 g on diet 2, and 140–210 g on diet 3.

There is also the real possibility, suggested by Hawley, that we need to differentiate between the training diet and the pre-competition diet (6). It is possible that during the months of training, dietary carbohydrate is less critical than it is in the days before an event. Most diet and exercise performance studies have been 7 days in duration or less. Perhaps it is an error to extrapolate the results of these studies to conclude that the optimal training diet should be very high in carbohydrate.

One possible rationale for a lower carbohydrate for female athletes than male is the lower amount of muscle mass per kilogram body weight. While muscle glycogen concentration does not vary between genders, according to Behnke’s model, the reference woman has one third less muscle mass than the reference man (20.4 kg vs. 31.3 kg; 11). This would seem to infer that women store one third less glycogen in their muscle. We therefore theorized that, as glycogen is stored largely in the muscle, those athletes with greater muscle mass would benefit from more CHO. To our surprise there was a lack of correlation between muscle mass and a diet effect on time to exhaustion. It is possible that the failure to detect a correlation is the result of a type 2 error or due to the narrow range of muscle mass in this population. The statistical analysis, however, seems definitive.

Most studies reported differences in RER as a main effect with variations in dietary CHO and between genders (8, 13, 22, 26). The mechanism for greater fat oxidation in female endurance-trained athletes remains speculative. It has been suggested that women are more sensitive to the lipolytic action of catecholamines (8). Another possibility is that women are utilizing intramuscular triglycerides at a greater rate than men (22). While adipose stores are virtually unlimited, intramuscular fat stores are not. Storage of this substrate is increased with endurance training, as is oxidative capacity. It has been reported that this effect is greater in women than in men (24). If, in fact, women rely more on intramuscular triglycerides as an energy source during long-distance events, the need to consume adequate dietary fat may be a critical issue. A diet very high in CHO makes this difficult to accomplish while maintaining calorie balance.

More work is needed before an optimal level of dietary CHO can be recommended to female athletes with any degree of certainty. This study provides evidence that the level will be lower than the optimal level recommended for male athletes. Research is also needed to determine whether there is a maximum intake of CHO beyond which glycogen levels and exercise performance will not benefit. This has been suggested to be 500–550 g in men and would probably be lower in women.

Unfortunately, most of the reported literature appears weak due to insufficient power related to small sample size. The recent Walker study (26), for example, reports that “women cycled longer at \( \approx 80–82\% \text{ VO}_{\text{max}} \) after the high carbohydrate diet (115:31 ± 10:47 min:s) compared with the medium carbohydrate diet (106:35 ± 8:36 min:s)” (p. 2153). The authors do not report a significance level, however, which suggests that perhaps this result was not statistically significant. (Their study
had only 6 subjects.) In our study, mean time to exhaustion was lower on the LoCHO diet, although the results did not reach statistical significance, illustrating the need for larger studies. Subject recruitment is difficult due to the inclusion requirements and the demanding nature of the protocol. With a crossover design, subjects were required to adhere to a strict dietary protocol, often for several weeks, and to return to the laboratory for testing numerous times. Larger studies could perhaps be accomplished by cooperation among institutions, in effect creating multi-center studies, which would improve subject numbers and statistical power. Also, while respiratory exchange data taken at rest prior to the exercise trial provided evidence of dietary compliance, the provision of food in a controlled environment would provide for greater control.

It should be noted that the diets used in this study were specifically planned to provide adequate protein and were well balanced. In reality, few athletes consume a diet planned by registered dietitians or nutritionists, making it more difficult for the athletes to achieve an adequate intake of protein and minerals while striving to increase their intake of carbohydrate-rich foods. A diet that does not include a variety of foods from all food groups may result in suboptimal athletic performance due to deficiencies in a variety of minerals, including iron, zinc, and calcium.

In conclusion, the explosion in female participation in endurance and ultra-endurance events such as marathon-distance road races, long distance cycling events, and triathlons increases the need for nutritional recommendations derived on research specific to this population rather than extrapolated from male data.

Ours is the first dietary study of female athletes to control for menstrual status, phase of menstrual cycle, age, training level of subjects, and exercise intensity. This study adds to the body of literature to suggest that female endurance athletes are best served by a recommendation for dietary CHO intake which is less than that recommended for male endurance athletes. The specific level for optimal health and performance should be determined by future research.

References


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