CASE STUDY

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Endurance Training on Low-Carbohydrate and Grain-Based Diets: A Case Study

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Purpose: To illustrate the effects of low-carbohydrate (LC) and grain-based (GB) diets on body composition, biomarkers, athletic training, and performance in an elite triathlete. ***Methods:*** The athlete followed 2 dietary interventions for 14 d while maintaining a prescheduled training program. Pre- and postintervention measurements for each diet included plasma and serum samples, resting energy expenditure, body composition, and a performance bike ride. ***Results:*** Compared with the GB diet, the LC diet elicited more disruptions to training and unfavorable subjective experiences. Total cholesterol, HDL cholesterol, LDL cholesterol, ratings of perceived exertion, and heart rate were elevated in the LC diet. Blood insulin, resting lactate, postexercise lactate, and C-reactive protein were lowest in the LC diet. ***Conclusion:*** The LC diet resulted in both favorable and unfavorable outcomes. The primary observation was a disruption to scheduled training on the LC diet. Researchers should consider how the potential mediating effect of disruptions to training could influence pretest–posttest designs.

Key Words: high-fat, exercise, performance, triathlon, triathlete

Interest in macronutrient intake and exercise performance has increased with the current obesity epidemic (29). Several investigations have tested the effects of differing amounts of carbohydrate and fat intake on human-performance outcomes (3, 13, 18, 20, 21, 25, 26, 31). It is also evident that low-carbohydrate (LC) diets are capable of decreasing body weight and increasing insulin sensitivity (30, 32); however, the effects of lower carbohydrate intake (commensurate with higher intakes of fat and protein) on exercise performance are equivocal (9). Furthermore, there is a paucity of research examining the effects of these LC diets on daily exercise regimens and training for athletic competition. There are limited data to indicate whether the performance differences observed in studies from before and after dietary interventions are a result of the actual dietary intervention alone or of perturbations in exercise regimens (volume, frequency, intensity, and combinations thereof).

Endurance athletes have explored various avenues to improve sustained performance both by reducing body weight (6) and by increasing the contribution of fatty

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acids as a fuel source, and LC diets seem to facilitate both processes. Preferentially tapping into an athlete's relatively ample fat stores might prolong the capacity to utilize the more limited glycogen stores when increased power output is desired. For example, acute elevations in serum free fatty acids, via a heparin injection, elicit a marked increase in free-fatty-acid oxidation and a concomitant sparing of muscle glycogen (22), thus potentially allowing for prolonged endurance capacity. Likewise, chronic intake of a high-fat, LC diet might attenuate the adaptations that favor carbohydrate oxidation and ultimately enhance the capacity to oxidize more fat during exercise (20). Moderately LC diets such as the 40/30/30, or "Zone," diet are also purported to benefit elite endurance athletes (7). More recent research has characterized adaptations from high-fat, LC diets in terms of "glycogen impairment" rather than glycogen sparing (7, 11) because of observations of the down-regulation of carbohydrate metabolism coupled with compromised ability to perform high-intensity exercise.

A presumed deleterious consequence of an LC diet is decreased preexercise muscle-glycogen content (20, 24). A few studies, however, have shown significant improvements in exercise performance with higher fat diets (13, 20, 21, 26). This increased ability to utilize more fatty acids for fuel has been attributed to increased oxidative enzymes (16), increased mitochondrial density (16), greater storage and utilization of intramuscular triglyceride (28), and enhanced muscle uptake of plasma free fatty acids (12).

Although evidence (27) indicates that dietary intake has effects on exercise performance (positively or negatively), one critical aspect that has been neglected in most, if not all, studies is a report of the effects on daily training. That is, pre–post performance testing is a typical outcome measure, and it is not evident whether the dietary intervention only affected the assessed athletic performance or also affected daily exercise regimen in the process. Furthermore, with longer interventions, the exercise regimen itself might have a strong influence on the performance outcome. Thus, the observed changes from pretest to posttest could be confounded by dietary effects on the continuing exercise regimen itself. With these factors in mind, the purpose of this case study was to illustrate the daily exercise regimen and performance tests, along with biomarkers of health, for 2 dietary interventions, an LC diet and a grain-based (GB) diet, in an elite triathlete.

Method

The subject of this project was a 34-year-old man who had been consistently involved in endurance-based athletic training and competition since age 15. After an intercollegiate career of middle-distance and distance running, he took up the sport of triathlon and became a national-class elite competitor in swim-bike-run events. The athlete was self-coached during the preceding 2 y and reported generally good adherence to a preplanned training program designed for short-course triathlons. Short-course triathlons are competitions having a range of distances that take top competitors between 50 min and 2 h to complete. These include the "sprint" distance of a 750-m swim, 20K bike ride, and 5K run; "international" distance of 1.5K swim, 40K bike ride, and 10K run; and various other distances tailored to individual race venues. The athlete employed periodized training methods in an annual training plan, and this was evident in his training logs. His typical combined training volumes for swimming, biking, running, and resistance training totaled 10–16 h/wk over the past few years.

Daily Training Logs

Before enrollment in this study, the athlete outlined a specific training plan of his intended workouts, without regard to dietary alteration. During the study, he maintained a detailed exercise log. All workouts were recorded daily, including interval splits, perceived exertion, and other subjective reactions to the training. These data were handwritten by the athlete in a training log. The athlete provided informed consent as part of a larger dietary-intervention study approved by the institutional review board at Kansas State University. This case study was conceived after the athlete had completed the trials in the dietary-intervention study, making post hoc interpretation a necessity but also tempering potential bias in subjective report of daily training.

Exercise Testing

Before any dietary intervention, the subject performed an initial fitness test (VO_{2max}), which was used to establish the exercise intensity of his subsequent trials. All exercise testing was performed on an electronically braked cycle ergometer that was individually adjusted for the subject (Cardgirus Medical, v 1.2, Guipúzcoa, Spain). A 1-way mouthpiece was used to direct expired gases to a pneumotachometer and the oxygen and carbon-dioxide analyzers (TrueOne, ParvoMedics, Provo, UT). After at least 30 min, the gas analyzers and flowmeter were calibrated immediately before testing using gases of known concentration (16% O_2 and 4% CO_2) and a 3-L syringe, respectively. A ramp protocol was used, in which the initial work rate was 100 W and the work rate increased 1 W every 2 s (30 W/min) thereafter until the subject could not maintain a minimal cadence of 60 revolutions/min. The final work rate was used to calculate the work rate for the subsequent exercise-performance efforts (75% of W_{max}).

Dietary Interventions

After the VO_{2max} test, the athlete was randomly assigned to start the study with the LC diet. For both LC and GB diets, the athlete was provided the portions of the food he was to consume for the diet that he was assigned to follow. For the LC diet, he was provided 0.8 g of protein/kg body weight per day. The following food items were provided using a 5-d rotating menu: eggs, peanuts, beef jerky, cheddar-cheese cubes, mozzarella string cheese, canned tuna, and canned ham. For the remainder of the LC diet the athlete was provided a list of acceptable food items (including nonstarchy vegetables, meat, fish, poultry, eggs, nuts, and any Atkins-approved product) and unacceptable food items (including fruit, bread, pasta, rice, potatoes, or other potent sources of carbohydrate). The LC diet was based on the 2-wk induction phase of the Atkins diet. The athlete kept a food record of everything he ingested during the last 7 d of each dietary intervention, as well as 3 d during the ad libitum period between interventions.

For the GB diet, the athlete was provided GB food products equivalent in calories to the foods provided in the LC diet. The foods provided for the GB diet included whole-wheat tortillas, whole-wheat bread, cheese pizza, long-grain-rice soup, canned beef ravioli, whole-grain waffles, oatmeal, and whole-grain breakfast bars. The GB diet was based on the U.S. Department of Agriculture food-guide pyramid, with the primary exception of restricting refined-flour pastries (doughnuts, cakes, cookies, etc.), oil-fried foods (such as fried chicken, French-fried potatoes, potato and corn chips, etc.), and hard and soft candies.

For both of the 14-d dietary conditions, the athlete visited the laboratory Monday through Friday to receive his food and have his body weight measured. He received food for the weekend on each Friday. Between the 2 controlled diets, the athlete consumed his normal diet, free of any imposed restrictions. This ad libitum period lasted approximately 5 wk.

Blood and Urine Analysis

After each dietary condition, the subject's urine was collected for a ketosis test using standard keto strips. Before and after each 14-d dietary condition, the athlete visited the laboratory after an overnight fast. First, he rested supine in bed for 40 min to measure his resting metabolic rate, heart rate, and respiratory-exchange ratio via indirect calorimetry (TrueOne, ParvoMedics, Provo, UT). After the metabolism test, body composition was assessed via dual-energy X-ray absorptiometry (GE-Lunar Prodigy v 5.6, General Electric, Milwaukee, WI). A fasting blood sample was then collected for the assessment of glucose (YSI 2300, Yellow Springs, OH), insulin (Alpco Diagnostics, Salem, NH), total cholesterol (Wako Chemicals, Richmond, VA), high-density lipoprotein cholesterol (HDL-C; Wako Chemicals, Richmond, VA), triglyceride (Wako Chemicals), and C-reactive protein (R&D Systems, Minneapolis, MN). Low-density lipoprotein cholesterol was calculated from the total-cholesterol, HDL-C, and triglyceride levels (10).

Exercise Performance

The subject warmed up on the cycle ergometer to prepare for the 5-km effort. The intensity of the exercise was set at 75% of W_{max}. During the ride, the following parameters were measured: rating of perceived exertion (RPE) (4), power output, heart rate (HR) via radiotelemetry, and oxygen uptake (VO_2). After the exercise, another blood sample was collected to measure postexercise plasma glucose and blood lactate levels.

Observations

Dietary

The relative contributions of fat, carbohydrate, and protein in each diet are displayed in Figure 1 and Table 1. Carbohydrates composed 21.5%, fat 54.7%, and protein 23.5% of the average 3736 kcal consumed during the final 7 d of the LC diet. The GB diet contained the following macronutrient composition: 58.7% carbohydrates, 28.3% fat, and 12.1% protein. Compared with the LC diet, the macronutrient intake during the GB diet was more representative of the athlete's self-selected diet, which consisted of 68.9% carbohydrate calories, 19.1% fat calories, and 12% protein calories. The average energy intake during the GB diet (3949 kcal/d; Table 1) was higher than during the LC diet (3736 kcal/d). Both LC and GB energy intakes were lower than the unrestricted ad libitum energy intake (4659 kcal/d). Based on his food logs, the athlete reported excellent adherence during each dietary intervention.

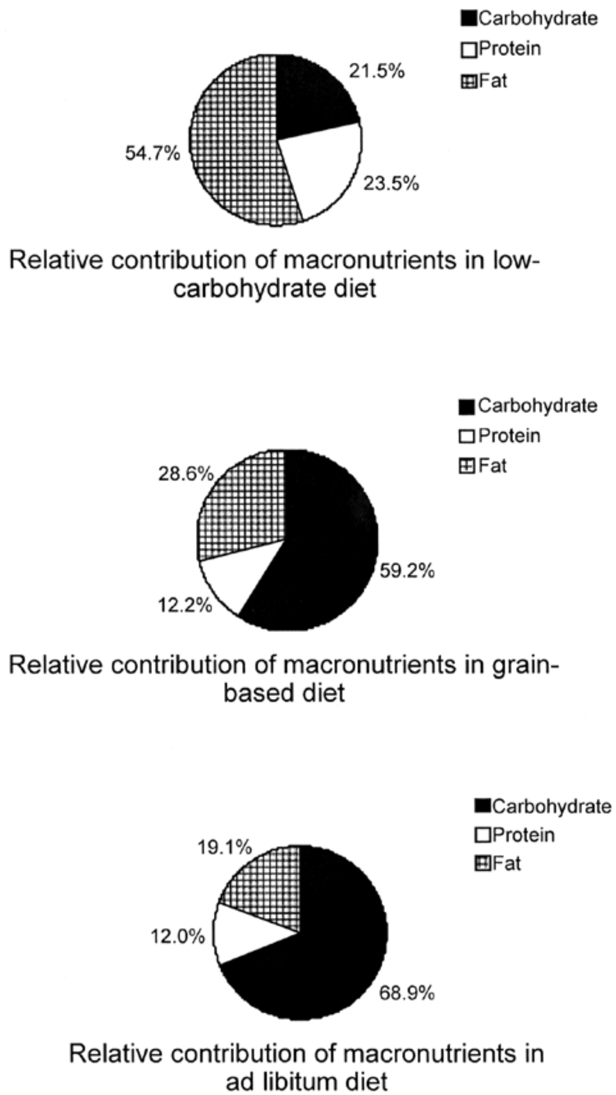

Figure 1 — A comparison of fat, carbohydrate, and protein in the 3 dietary conditions.

Table 1 Summary of Relative Contribution of Macronutrients in 3 Dietary Conditions

	Diet		
	Low carbohydrate	Grain based	Ad libitum
Percentage carbohydrate	21.5	58.7	68.9
Carbohydrates (g/d)	208	603	822
Percentage fat	54.7	28.3	19.1
Fat (g/d)	235	129	102
Percentage protein	23.5	12.1	12.0
Protein (g/d)	227	125	143
Total energy (kcal/d)	3736	3949	4659

Anthropometric Measures

The athlete lost weight on the LC diet (pre = 78.8 kg, post = 75.6 kg; Table 2). Similarly, his body-fat percentage, fat mass, and fat-free mass all decreased on the LC diet. All these variables were lower at posttest on the LC diet than at pretest or at either testing time for the GB diet.

Metabolic Measures

Table 2 summarizes the metabolic data for each diet. Resting energy expenditure increased from about 1515 kcal/d at pretest to about 1,585 kcal/d at posttest during the LC diet, while resting HR remained relatively stable. The athlete's resting energy expenditure increased to a lesser extent during the GB diet, from 1510 kcal/d at pretest to about 1552 kcal/d at posttest. Resting HR was slightly lower at pretest before the GB diet. Overall, resting energy expenditure and HR were highest at the end of the LC diet and lowest at the end of the ad libitum condition (GB pretest).

Performance Measures

Table 3 summarizes the performance data for the end of each dietary condition. With VO_2 and power output relatively constant throughout tests, the exercise HR and RPE scores were higher during the posttest after the LC diet.

Biomarkers

Tables 2 and 3 display the blood values before and after each diet. The subject's total cholesterol, HDL-C, and LDL-C increased from pretest to posttest in the LC condition, and these values were higher than either pretest or posttest for the GB diet condition. Triglycerides, resting glucose, postexercise lactate, and insulin decreased from pretest to posttest in the LC condition, and these values were lower than at either pretest (ad libitum posttest) or posttest for the GB condition. C-reactive-protein values before and after the GB diet were higher than before and after the LC diet. Based on testing of the urine samples, the LC diet induced mild ketosis and the GB diet did not.

Table 2 Summary of Pretest-to-Posttest Anthropometric, Metabolic, and Biomarker Data for the Low-Carbohydrate (LC) and Grain-Based (GB) Conditions

Variable	LC pretest	LC posttest	GB pretest[a]	GB posttest
Anthropometric measures				
weight (kg)	78.8	75.6	77.1	77.7
% body fat	8.0	6.4	7.6	7.5
fat mass (kg)	6.0	4.7	5.7	5.6
fat-free mass (kg)	68.9	67.9	69.5	69.7
Metabolic measures				
HR_{Rest} (beats/min)	47.3	47.8	45.6	47.0
resting energy expenditure (kcal/d)	1514.8	1584.8	1510.0	1551.8
Biomarkers				
total cholesterol	152	178	163	160
HDL	43	60	53	53
LDL	84	98	89	83
triglycerides	126	96	104	118

[a]Also ad libitum posttest.

Table 3 Summary of Performance-Ride Data for Each Dietary Condition

	Diet		
Variable	Low carbohydrate	Ad libitum[a]	Grain based
HR (beats/min)	185	178	180
VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	67.3	70.8	67.8
VO_2 (L/min)	5.10	5.48	5.28
Work rate (W)	325.1	324.7	323.7
Rating of perceived exertion	17.2	15.0	14.8
$Glucose_{Fast}$ (mmol)	4.28	4.79	4.85
$Glucose_{Postex}$ (mmol)	6.32	6.91	6.23
Resting lactate (mmol)	0.86	1.10	1.27
Postexercise lactate (mmol)	8.69	12.05	11.05
Insulin	0.9	1.3	1.9
C-reactive protein	2.2	2.6	2.9

[a]Immediately before grain-based diet.

Daily Training and Subjective Daily Experiences

The athlete reported fewer problems associated with his training on the GB diet. He reported cutting 2 workouts short while on the GB diet because of lethargy, fatigue, and muscle soreness. Training-log commentary on other subjective experiences of training and eating during the GB diet was similar to that for the ad libitum dietary period.

While training on the LC diet, the athlete experienced and reported the following atypical feelings and symptoms, which he described in his training log.

Frequent Experiences. After the third day of the LC diet, lethargy and fatigue were mentioned nearly every day in the training log. When monitored or measured by the athlete during training, HR and/or speed for a given RPE was lower than normal. Conversely, perceived exertion for a given speed or heart rate was higher than normal. The athlete reported frequent cravings for sweets, which he attempted to satisfy via artificially sweetened soft drinks and other artificially sweetened foods. He also reported frequent nighttime urination, which interrupted sleep on most nights, and persistent muscle soreness, even after days of reduced training volume and intensity. The athlete frequently reported worries about compromising his health, especially concerning lack of fiber and excess protein, saturated fat, and cholesterol consumption. Similarly, he noted the psychological difficulty of adhering to the LC diet when faced with frequently unsatisfactory workouts, feelings of physical depletion postworkout, cupboards and refrigerator full of his typical foods, and when grocery shopping or eating at restaurants.

Less Frequent Experiences. Poor mood and grumpiness were reported on 4 days. Constipation was reported on 3 days, and night sweats were reported 3 times. The athlete reported feelings of inhibited recovery and muscle weakness on 4 occasions. Finally, he recorded feeling a decreased ability to concentrate and what he reported as persistent "foggy thinking" on 2 days.

Adherence to Training Plan

Table 4 shows the training volumes and intensity of workouts during both diets and during the ad libitum period of training. The athlete recorded 6 instances of cutting his planned workout short during the LC diet, compared with 2 instances for the GB diet and 1 for the ad libitum diet. He recorded 5 instances of purposefully reducing the training intensity from a planned high-intensity workout during the LC period of training, compared with zero instances of intensity reduction on the GB diet and 1 in the ad libitum condition.

Discussion

Because this research is a case study of observations from a clinical study, there were no statistical analyses performed. All quantitative data herein are offered solely as demonstrative observations of how LC and GB diets affected this endurance athlete compared with his usual ad libitum high-carbohydrate diet. The observations of this case study indicate that it was possible, although not without difficulty, for this elite endurance athlete to adhere to a LC diet and to lose weight while following a

Table 4 Daily Training Mode, Duration, and Intensity for Each Dietary Condition[a]

	Diet		
Day	**Low carbohydrate**	**Grain based**	**Ad libitum**
1	Bike, 60 min, high Run, 14 min, low	Bike,150 min, high Run, 22 min, low	Bike, 30 min, low Other, 25 min, low Run, 25 min, low
2	Run, 74 min, low Swim, 16 min, low	Run, 48 min, high Bike,120 min, low	Bike, 45 min, low Swim, 55 min, high
3	Bike, 30 min, low Swim, 60 min, low	Run, 87 min, low Swim, 15 min, low	Bike, 30 min, low Run, 60 min, high
4	Bike, 30 min, low Swim, 60 min, low[b]	Swim, 60 min, low Bike, 30 min, low Other, 20 min, low	Bike, 30 min, low Swim, 60 min, low
5	Run, 45 min, low[b] Bike, 0 min[c] (30 min)	Swim, 56 min, high Run, 21 min, low	Swim, 50 min, low Bike, 150 min, high
6	Bike, 30 min, low Swim, 16 min, low[c] (40 min)	Run, 67 min, high	Bike, 60 min, low Other, 20 min, low
7	Bike, 30 min, low Other, 30 min, high	Bike, 30 min, low Swim, 48 min, low Other, 20 min, high	Run, 90 min, low Swim, 0 min[c] (15 min)
8	Bike, 90 min, low[b] Run, 14 min, low[c] (14 min)	Bike, 180 min, high Run, 27 min, low	Run, 29 min, low Bike, 30 min, low
9	R, 75 min, low Swim, 0 min[c] (16 min)	Run, 14 min, low	Bike, 30 min, low Swim, 60 min, high Other, 30 min, high

(continued)

typical training program designed to optimize performance. It appears, however, that high-intensity training and performance were negatively affected during the 2 wk of LC diet. On the LC diet, the athlete experienced psychosomatic symptoms, feelings of lethargy, and untoward physiological outcomes during the standardized 5-km cycling performance. This performance ride was designed to represent both higher intensity training and a typical intensity experienced during competition. Furthermore, the athlete's daily training program during the LC diet was negatively affected compared with the GB and ad libitum diets—workouts were cut short more frequently or were reduced in intensity from what was originally planned. These observations are akin to research on runners with varying levels of carbohydrate in

Table 4 *(continued)*

Day	Diet Low carbohydrate	 Grain based	 Ad libitum
10	Bike, 30 min, low Run, 30 min, low Swim, 55 min, low	Run, 66 min, low[c] (20 min) Swim, 0 min[c] (55 min)	Run, 60 min, low[b] Bike, 30 min, low
11	Bike, 45 min, low Swim, 50 min, low[b]	Run, 42 min, low Bike, 115 min, low Other, 25 min, high	Bike, 30 min, low Swim, 64 min, low
12	Swim, 15 min, low[c] (35 min) Bike, 30 min, low Other, 20 min, low	Off	Swim, 50 min, low Bike, 170 min, high Run, 13 min, low
13	Bike,40 min, low Run, 51 min, high Other, 30 min, low	Bike, 30 min, low Swim, 57 min, low	Run, 15 min, low Bike, 40 min, low Run, 54 min, high
14	Bike, 130 min, low[d] (20 min) Other, 15 min, low	Bike, 30 min, low Swim, 45 min, high	Bike, 36 min, low Run, 60 min, low Swim, 20 min, low
Total	1215 min = 20:15 out of planned ~23:20, 3/8 high-intensity workouts.	1425 min = 23:45 out of planned ~25 h, 8/8 high-intensity workouts.	1551 min = 25:51 out of planned ~25 h, 7/8 high-intensity workouts.

[a]Other indicates resistance training or other cross-training; swimming low intensity = 1:18–1:30 per 100-yd average pace of workout; swimming high intensity < 1:18 per 100-yd average pace of workout; bicycling low intensity = heart rate below 160 for entire ride (approximately 22 miles/h); bicycling high intensity = heart rate above 160 for at least 5 min of ride; running low intensity = heart rate below 160 for entire run (approximately 6:30/mile); running high intensity = heart rate above 160 for at least 5 min of run.
[b]Intensity lowered from planned high-intensity workout.
[c]Workout cut short (by time in minutes).
[d]Intensity lowered and workout cut short (by time in minutes).

their diet during intense training (1). Because none of the dietary conditions came with restrictions on total energy intake, the LC diet could theoretically meet the carbohydrate requirements needed to support heavy training, provided the athlete ate enough food.

One issue illustrated by this case study is how much influence alterations in the daily exercise regimen could have had on the subsequent postintervention performance test. This study might serve as a preliminary call for future dietary interventions examining exercise-performance outcomes to track daily training. Such tracking might ensure that similar work is being performed from trial to trial. If study volunteers are basing training intensity and work rate on RPE or HR, they might not be completing similar amounts of work, which ultimately might elicit diet-independent myocellular adaptations. Over time, this could detrimentally affect postintervention assessments and confound study results.

In accordance with previous work by Jarvis et al. (15), our athlete decreased body mass and showed decreased athletic performance after an LC diet. The results of the present study extend the work of Jarvis et al. (15)—the observations of this athlete were compared with another dietary condition, whereas the Jarvis et al. study compared performance after an energy-deficit diet only with an ad libitum diet. Lambert et al. (19) indicated that it should not be surprising to observe a decrement in exercise performance with short-term exposure to an LC, high-fat diet. Erlenbusch et al. (9) suggested that LC dietary changes less than a week in length might demonstrate decreased glycogen status but no evident metabolic effects. Previous studies have demonstrated positive metabolic adaptations to high-fat diets in 2 wk or less (17, 19). Given the equivocal outcomes observed in the literature and further supported in this case study, carbohydrate restriction (<25%) by athletes attempting to lose weight or increase endurance performance should be undertaken with caution, if at all.

Regarding body-composition changes, the subject of this study unintentionally lost body fat, weight, and some fat-free mass during the LC condition as his percentage body fat decreased from 8% to 6.4%. It is noteworthy that these data indicate that the athlete lost 1 kg of fat-free mass during the LC diet, despite higher protein intake. This loss might have been from reduced cell size as a result of glycogen depletion, lower levels of body water (hydration status was not monitored in this study), actual muscle-tissue loss, or artifact in the dual-X-ray-absorptiometry analysis. Despite no volitional restrictions on protein, fat, or total volume of food in the LC diet, the athlete consumed far fewer calories than during a period of ad libitum eating. The discrepancy in energy intake (~900 kcal/d), however, probably does not fully account for the amount of weight lost. It is likely that a good portion of the weight lost on the LC diet was from loss of body water, especially that bound to muscle glycogen (2).

The HR (averaged over 20 min) and RPE values seem to indicate that the GB diet and ad libitum diet were superior to the LC diet with regard to cycling performance at a higher intensity. For this athlete, a 5-km ride at an HR around 180 beats/min is less taxing than his actual competitive event, and methodologies employing a longer high-intensity cycling test in this study might have revealed a greater dietary effect on the physiological parameters. Training-log information also supports these testing data, in that training speeds were generally slower at any given HR or RPE on the LC diet. What is not known from the present data is whether such an observed difference is from the dietary intake per se or whether training might serve as a mediator in such a relationship between diet and postintervention performance. Furthermore, it is unknown whether a short-term decrement in performance might be replaced with a "rebound" ergogenic effect, should the athlete return to a carbohydrate-replete diet. Although some evidence (18) suggests this possibility, this athlete reported experiencing more of a gradual return to normalcy than an ergogenic rebound (data not shown). Recent literature (7, 11) seems to suggest no endurance-performance benefit from low-carbohydrate, high-fat diets, despite an increase in fat utilization.

In terms of health, the American Heart Association and American Dietetic Association have called for caution regarding LC diets, because of potential risks such as bone-mineral loss, hyperlipidemia, and fatigue (23). Although the values for this athlete were still in the "normal" range, total cholesterol and LDL-C both increased during the LC diet. These findings are in opposition to some promoters of low-carbohydrate lifestyles, in that LC diets are purported not only to reduce weight but also to improve health—including blood lipid profiles. It may be that overweight or obese individuals (those most likely to adopt a low-carbohydrate lifestyle) experience improvements in lipoproteins because they tend to have high lipoprotein levels when beginning a lifestyle modification. Certain health-related aspects did improve in our athlete on the LC diet, including decreased triglyceride and insulin and increased HDL-C levels. The last of these likely increased to transport and offset rising LDL. The outcomes observed here were in line with the review by Onega (23). Finally, although it was not directly measured in the present study, insulin sensitivity most likely did improve on the LC diet, as evidenced by the lower insulin, blood glucose, and triglyceride levels.

The present case study has a number of limitations. First, because it is a case study of a single elite endurance athlete, external validity is minimal. Second, it is not known whether the dietary manipulation itself or the specific characteristics of each diet actually caused apparent differences observed at the end of each diet. Radical departures from the typical diet might result in effects such as those observed in the present study, regardless of macronutrient content. Third, there might be an order effect at work, because the LC diet preceded the GB diet and because the cardiorespiratory fitness of the athlete improved over the 7-wk intervention period. It is conceivable that training on the LC diet stimulated changes in substrate metabolism for this athlete, because others have reported enhanced fat oxidation after higher fat diets (19). Fourth, the dietary data were self-reported, so errors, omissions, or other forms of bias must be considered. Finally, neither the researchers nor the subject was blind to the condition, which could influence such variables as perceived exertion, subjective daily experiences, and training volumes and intensity.

Future research should assess health and fitness outcomes along with the ability of the "fitness exerciser" to adhere to an exercise routine under varying dietary conditions. Many questions remain unanswered regarding the effects of weight-loss diets on athletic performance and health in both the short term and the long term. As illustrated by the triathlete in the present study, there was an incompatibility between LC eating and high-intensity training. Therefore, a practical question for athletes and fitness exercisers might be whether dietary restriction is necessary in efforts to improve fitness, health, or body composition.

With relevant literature and this study's observations and limitations in mind, and given the high number of fitness exercisers currently attempting to lose weight, what should be recommended with regard to a diet supportive of health and an exercise routine? On one hand, an LC diet has hereby been shown to allow weight loss even for a lean athlete consuming 3700 kcal/d in training. On the other hand, mood, daily athletic training, and HR and RPE during higher intensity exercise seem to be negatively affected while on such a diet. Blood lipids may or may not be a concern, depending on the individual's current health status or lipoprotein-lipid profile. Insulin sensitivity improved on the LC diet, which has been reported by others (3), but insulin sensitivity also improves via exercise alone (14). Thus, we might be left with the fence-sitting position typified by Bravata et al. (5) that there is insufficient evidence at this time to make definitive recommendations for or against LC diets. Alternatively, we could argue along the lines of Onega (23) that LC diets are associated with potential health risks and poor athletic performance. Because there is currently little evidence to support the use of LC or high-fat diets by athletes, and the long-term health effects of such diets are unknown (9, 16), there appears to be no compelling argument for athletes or perhaps even serious exercisers to employ such diets.

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