Carbohydrates, performance and weight loss low the way to go or the way to bonk?

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Carbohydrates, Performance & Weight Loss
Is Low the Way to Go or the Way to Bonk?

KEYWORDS: *exercise; diet; low-carbohydrate; endurance; sports; marathon*

ABSTRACT:

Despite their popularity, meta-analyses demonstrate that low-carbohydrate diets are no more effective for weight loss than low-fat or balanced diets. Carbohydrates are essential for high-intensity exercise because the maximum rate of energy production is substantially higher for carbohydrates compared to fats. Low-carbohydrate diets reduce tolerance for very high-intensity exercise. Training under low-carbohydrate conditions may enhance skeletal muscle adaptations, but no study has shown that this type of training results in superior endurance performance. The fact that world's best marathoners consume relatively high carbohydrate diets is testament to the superiority of carbohydrates as a fuel for competitive endurance sports.

INTRODUCTION

Low-carbohydrate diets have been prescribed for weight loss and, more recently, been advocated for athletes to enhance endurance performance (1). Popularity of low-carbohydrate diets was high in the 1960s and early 1970s, after which interest in carbohydrate restriction waned. In late 1990s there was a resurgence of interest in low-carbohydrate dieting, and diets advocating restriction of carbohydrates have remained popular ever since. Despite the popularity of low-carbohydrate diets over the years, only during the past 15 years or so has research on low-carbohydrate diets provided sufficient data to evaluate the efficacy of carbohydrate-restrictive diets for weight loss and health.

In endurance sports, reaching a point in the race where an athlete can no longer maintain the desired pace is referred to as "bonking." The precipitous decline in performance associated with the bonk has been largely attributed to depletion of carbohydrate stores in skeletal muscle and liver, and possibly to reductions in blood glucose concentration. Indeed, carbohydrate is the fuel of choice for endurance athletes, with scientific support dating back to the classic carbohydrate loading studies in the 1960s (2). This seminal research demonstrated increased exercise time to exhaustion associated with high initial muscle glycogen concentrations after consumption of a high-carbohydrate diet (2). However, some exercise scientists have questioned the traditional high-carbohydrate approach for endurance exercise (1,3). But is a low-carbohydrate diet for endurance sports the way to go, or the way to bonk?

The purpose of this review is to examine the published data on the efficacy low-carbohydrate diets for weight loss and health, and to determine whether there is sufficient evidence to support a low-carbohydrate approach for endurance athletes.

WEIGHT CONTROL: IT'S THE CALORIES, NOT THE CARBS

Meta-analyses of randomized controlled trials have produced inconsistent results, but generally demonstrate that there is no advantage to low-carbohydrate diets for weight loss. In favor of low-carbohydrate diets, a 2013 systematic review and meta-analysis of 13 studies involving 1,577 participants with 12 months or more of follow-up concluded that very-low-carbohydrate ketogenic diets produced significantly more weight loss (weighted mean difference (WMD) = 0.91 kg) compared to low-fat diets (4). By contrast, two more recent meta-analyses demonstrated no benefit of carbohydrate-restricted diets for weight loss (5,6). In a 2014 meta-analysis of 48 randomized trials that included 7,286 individuals, there was no difference in weight loss when comparing low-carbohydrate and low-fat diets (5). At 12 months, for example, the difference in weight loss between the two diets was only 0.02 kg. Another 2014 meta-analysis of 19 randomized controlled trials with 3,209 participants revealed no significant difference in weight loss when comparing low-carbohydrate diets with isoenergetic balanced diets for durations up to 2 years (6). Because the more recent studies were larger and included considerably more participants, the current state of the science indicates that there is no advantage of a low-carbohydrate diet for weight loss.

Large-scale epidemiological studies of men and women indicate an inverse association with carbohydrate intake and body mass index (7). This suggests that habitual diets high in carbohydrates are not associated with excess body weight, and, in fact, appear to be associated with better weight control. In support of observations from cohort studies is a meta-analysis of randomized controlled trials that demonstrated that lower total fat intake leads to modest but sustained reductions in body weight (8).

LOW-CARBOHYDRATE DIETS AND HEALTH: SOME POSSIBLE BENEFITS, BUT ALSO SOME CONCERNS

Whether low-carbohydrate diets are healthier than low-fat diets is unclear, as evidenced by inconsistent findings of several meta-analyses. One meta-analysis (4) reported that very-low-carbohydrate ketogenic diets were more effective than low-fat diets for reducing serum triglycerides (WMD = -0.18 mmol/l) and diastolic blood pressure (WMD = -1.43 mmHg), and increasing HDL cholesterol (WMD = 0.09 mmol/l). But very-low carbohydrate ketogenic diets also elevated LDL-cholesterol (WMD = 0.12 mmol/l) (4). Another meta-analysis concluded that a low-carbohydrate diet might be preferred in the management of prediabetes and type 2 diabetes (9). By contrast, a meta-analysis which included randomized controlled trials enrolling overweight and obese adults, with and without type 2 diabetes, concluded that there is no difference in changes in cardiovascular risk factors up to 2 years when comparing low-carbohydrate and isoenergetically balanced diets (6). Furthermore, another meta-analysis demonstrated that low-carbohydrate diets impaired vascular endothelial function when compared to low-fat diets (10). A 2013 systematic review and meta-analysis of observational studies reported that low-carbohydrate diets were associated with significantly higher risk of all-cause mortality (11). Thus the long-term health consequences of low-carbohydrate diets are a concern and require additional research that should include longer follow-up and outcome measures that extend byond traditional cardiovascular disease risk markers.

CARBOHYDRATES ARE ESSENTIAL FOR HIGH-INTENSITY EXERCISE

On a mixed diet, fat and carbohydrate contribute approximately equally to the energy production at rest. This fuel mix can be affected by the macronutrient composition of the diet. During exercise the percentage of total energy production that is derived from carbohydrate increases as exercise intensity increases, until carbohydrate contributes essentially 100% of the total energy production at maximum exercise intensities (12). Although total body fat stores far exceed those of carbohydrate, which are primarily restricted to muscle and liver glycogen, carbohydrate is the dominant fuel for any sport demanding exercise at very high intensities.

The reason that carbohydrate is essential for high-intensity exercise is that the maximal rate of energy production from carbohydrate is much higher than that of fat (12). The maximal rate of fat oxidation varies considerably among individuals, ranging from 2 to 10 kcal/min (13). Fat oxidation in trained cyclists adapted to a ketogenic diet has been reported to be higher, ranging between 11 and 17 kcal/min while exercising at 62-64% of maximum oxygen uptake (VO_2max) (1,14). However, maximum carbohydrate oxidation is much higher, and can easily reach 25-30 kcal/min in well-trained endurance athletes who have VO_2max's of at least 5-6 liters/min (carbohydrate provides 5 kcal/liter O_2 consumed) (See Figure 1). Energy production at or near VO_2max can only be supplied by carbohydrates. Peak fat oxidation occurs at exercise intensities of approximately 45-65% of VO_2max (13,14). Most endurance sport competitions require intensities much higher, approaching 100% of VO_2max. Therefore, energy requirements for competitive endurance sporting events cannot be met via fat oxidation alone.

It has been argued that adaptation to a low-carbohydrate does not compromise endurance exercise performance (1,14). The seminal study frequently cited to support this claim examined exercise responses in five well trained cyclists before and after 4 weeks of consuming a low-carbohydrate, ketogenic diet (14). Although the group mean exercise to exhaustion at 62-64% of VO_2max was not different when comparing the low-carbohydrate diet (151 ± 25 min) to the baseline, high-carbohydrate diet (147 ± 13 min), there was considerable variability among the cyclists. Two cyclists improved their endurance performance on the low-carbohydrate diet by 30 min and 84 min, while two cyclists performed worse on the low-carbohydrate diet, by 48 min and 51 min. One of the cyclists had similar endurance times for the two exercise bouts (178 min vs. 181 min). Aside from the fact that this study was limited by a very small sample size, it also highlights the marked individual variability in response to a carbohydrate-restricted diet. It is also important to note that the two cyclists who had the greatest increases in fat oxidation after adapting to the low-carbohydrate diet were the two cyclists who actually performed worse on the low-carbohydrate diet. This undermines the hypothesis that increased fat oxidation after adaptation to carbohydrate restriction is the reason for maintenance of submaximal endurance performance capacity.

Another significant limitation of this study is that virtually all competitive endurance sports are performed at intensities well above 62-64% of VO_2max, which require carbohydrate as the dominant fuel (12). For example, more than 80% of the total energy production during a marathon race will come from carbohydrate sources, primarily skeletal muscle glycogen (15). Classic studies demonstrated that carbohydrate loading significantly increased muscle glycogen levels, and that exercise time to exhaustion at relatively high intensities was highly correlated with initial muscle glycogen concentrations (2). Carbohydrates are the preferred fuel during high-intensity exercise, and are absolutely essential for exercise at maximal, or near-maximal intensities. Low-carbohydrate diets, on the other hand, adversely affect exercise performance (2,16-19). This is particularly true at maximum aerobic intensities, as a recent study illustrates (19). After consuming a low-carbohydrate diet for 4 weeks, off-road cyclists experienced a 6%increase in VO_2max (59.4 ml/kg/min vs. 56.0 ml/kg/min) due in part to a significant loss of body weight (1.9 kg). This finding, by itself, could be interpreted as a favorable adaptation. However, the maximum workload achieved during an incremental exercise test was reduced while on the carbohydrate-restricted diet. Thus despite an increase in VO_2max, tolerance for very high-intensity exercise was impaired (19).

The reduced exercise tolerance on a low-carbohydrate diet, particularly one that is high in protein, may be due to the greater acid load resulting from the high protein intake (17). An increased acid load decreases blood buffering capacity, which is essential during high-intensity exercise when muscle and blood lactate concentrations are at their highest (17). In 11 healthy men, exercise time to exhaustion on a cycle ergometer at a power output associated with VO_2max was 36% lower (3 min 41 sec vs. 5 min, 45 sec) after consuming a low-carbohydrate, high-protein diet (10.1% carbohydrate, 64.5% fat, and 25.3% protein) compared to a high-carbohydrate diet (65.5% carbohydrate, 24.7% fat, 9.4% protein) (17). The exercise time while consuming the low-carbohydrate, high-protein diet was also lower than the exercise time on the control diet (5 min, 8 sec), that consisted of 46.2% carbohydrate, 39.4% fat, and 14.1% protein. Protein intakes greater than approximately 2 g/kg/day are likely to increase acid load to a level that would adversely affect high-intensity exercise performance (17).

Finally, it must be noted that the best distance runners in the world consume high-carbohydrate diets that are relatively low in fat and protein. Of the top 100 marathon times ever recorded for men, 95 are by Kenyans or Ethiopians (20). Of the top 100 marathon times ever recorded for women, 64 are by Kenyans or Ethiopians (21). The diets of the Kenyan distance runners contain 76.5% carbohydrate and only 13.4% fat and 10.1% protein (22). Similarly, the diets of Ethiopian distance runners contain 64.3% carbohydrate, 23.3% fat and 12.5 protein (23). This does not prove that high-carbohydrate diets are the reason for their distance running superiority, but it does demonstrate that their marathon success is certainly not compromised by a high-carbohydrate, low-fat diet.

"TRAIN LOW – RACE HIGH": TRAINING ON A LOW-CARBOHYDRATE DIET, RACING ON A HIGH-CARBOHYDRATE DIET

Although a low-carbohydrate diet has been shown to reduce exercise performance at very high intensities, it may be possible enhance an athlete's endurance performance by incorporating both low- and high-carbohydrate diets as part of training and racing strategy. Recent published data suggests that endurance athletes may be able to enhance their performance potential by training under conditions of low carbohydrate availability (i.e., "train low"), but race under conditions of high carbohydrate availability (i.e., "race high") (24-26). The rationale is based on studies that show that exercise training under conditions of reduced muscle glycogen may increase the activities of several mitochondrial enzymes that could, in turn, lead to improved endurance performance (24-26).

Despite greater skeletal muscle adaptations documented with "train low" strategies, it should be noted that there is no evidence that these adaptations alone result in improved endurance performance. As stated above, tolerance for very high-intensity exercise is reduced on a low-carbohydrate diet, and high-training intensities are an essential component of the training schedules of endurance athletes. In a case-study of one experienced male triathlete, two weeks of training on a low-carbohydrate diet resulted in reduced tolerance for high-intensity training (27). Compared to two weeks of training on a high-carbohydrate, grain-based diet, the low-carb diet was also associated with increased reports of lethargy and fatigue in the triathlete's training diary, interrupted sleep, persistent muscle soreness and psychological difficulties (27). Training on a carbohydrate-restricted diet may also increase susceptibility to illness and infection, since carbohydrates play a significant role in offsetting exercise-induced immunosuppression (28). A low-carbohydrate diet may also increase protein breakdown (29), which could lead to skeletal muscle loss (24). In contrast, a high-carbohydrate diet has been shown to allow for greater exercise tolerance and work performed under "train high" conditions (24-26). Thus it may benefit the athlete to include some training sessions under conditions of low carbohydrate availability and some training sessions under conditions of high carbohydrate availability.

PRACTICAL APPLICATIONS

There are some strategies that may be used to optimize potential benefits of a “train low” strategy without negatively impacting training (24). For example, an athlete can train under fasting conditions, perhaps either in the morning before eating, or by having two training sessions per day, with the second one occurring without replenishment of carbohydrates after the first training session. The athlete can also make sure that the training sessions under low-carbohydrate conditions are not intense. Ingestion of 20-25 grams of protein before, during and/or right after a “train low” exercise session may minimize chances of muscle protein loss (24). Finally, the training schedule should include sessions of training “high” that simulate a competition fueling schedule (30).

CARBOHYDRATE REQUIREMENTS FOR EXERCISE AND RECOVERY

Daily dietary carbohydrate intake requirements vary depending on the training intensities and durations. For daily light-to-moderate-intensity exercise sessions that last no more than 1 h, 3-5 g of carbohydrate per kg body weight should be sufficient, while higher-intensity exercise training accumulating between 1 and 5 h of exercise per day may require carbohydrate intakes of 6-12 g/kg/day (24-26). On the day of competition, for races lasting longer than 1 h, carbohydrate intake of 1-4 g/kg within 1-4 h prior to the start of the race is suggested. For races lasting less than 1 h, no carbohydrate intake is necessary in the few hours prior to the race. For endurance races lasting between 1 and 1.5 h, suggested carbohydrate intake is 30-60 g/h, and this may be increased to 90 g/h for events lasting several hours (24-25). Intake recommendations during the race are not based on body weight because the carbohydrate oxidation rate of exogenously supplied carbohydrate is not correlated with body weight (26).

CONCLUSIONS

Recent meta-analyses indicate that low-carbohydrate diets are no more effective for weight loss compared to low-fat or balanced diets. Carbohydrates are essential for high-intensity exercise because the maximum rate of energy production is substantially higher for carbohydrates compared to fats. This is true for competitive events lasting from a few min up to several hours (2,15-19,22-27). Carbohydrate intake is essential for optimal muscle glycogen storage, and muscle glycogen is essential for high-intensity exercise. Low-carbohydrate diets may require a reduction in exercise intensity, which may adversely affect performance in training and in competition. Training under low-carbohydrate conditions may enhance skeletal muscle adaptations, but no study to date has shown that this type of training results in superior endurance performance. The fact that world’s best marathoners consume relatively high carbohydrate diets is testament to the superiority of carbohydrates as a fuel for competitive endurance sports.

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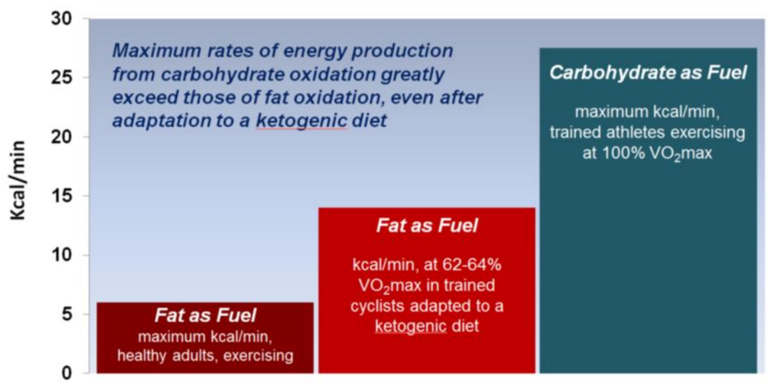
FIGURE 1



Rates of energy production, in kcal/min, from fat and carbohydrate during exercise. Left: data from ref. 13 represents the mid-point of the range of maximum fat oxidation during exercise for 300 healthy men and women. Middle: data from ref. 14 represents the group average for 5 trained cyclists. Right: data from ref. 12 assumes maximum O_2 uptake of ~5-6 L/min for trained endurance athletes.