Low Carbohydrate Diets and Performance

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Abstract

Athletes are continually searching for means to optimize their performance. Within the past 20 years, athletes and scientists have reported and/or observed that consuming a carbohydrate restricted diet may improve performance. The original theories explaining the purported benefits centered on the fact that fat oxidation increases, thereby "sparing" muscle glycogen. More recent concepts that explain the plausibility of the ergogenicity of low carbohydrate, or high fat, diets on exercise performance pertain to an effect similar to altitude training. We and others have observed that, while fat oxidation may be increased, the ability to maintain high intensity exercise (e.g., above the lactate threshold) seems to be compromised or at least indifferent compared to when more carbohydrate was consumed. That said, clinical studies clearly demonstrate that ad-libitum low carbohydrate diets elicit greater decreases in body weight and fat than energy equivalent low fat diets, especially over a short duration. Thus, while low carbohydrate and high fat diets appear detrimental or indifferent relative to performance, they may be a faster means to achieve a more competitive body composition.

Introduction

Low carbohydrate higher fat diets, such as the Atkins® Diet, resurfaced during the last decade as more and more individuals searched for means to decrease body weight at a time when overweight and obesity were viewed as increasing problems in the United States. The attractiveness of this particular diet strategy stems from the relatively rapid decrease in body weight seen during the first few days and weeks when carbohydrate intake is severely diminished, while fat and protein intake are increased. A commonly touted "metabolic advantage" of low carbohydrate diets (LCD) over traditional diets suggest that more weight may potentially be lost when matched calorie-for-calorie with other diets higher in carbohydrate content, due in part to the higher thermogenic cost of protein that makes up a larger percentage of many LCDs [1].

Sedentary, overweight individuals are a common group of individuals that utilized the LCD to achieve desirable health outcomes commonly associated with reductions in body weight and body fat. Consequently, this group is also the most frequently reported in the scientific literature regarding outcomes determining the impact LCDs have on health. Much of the available research seems to suggest improvements in most metabolic health parameters after consumption of a short-term LCD (< 6 months) in both normolipidemic and hyperlipidemic individuals. Decreases in fasting serum triglyceride levels [2-5] have been reported in conjunction with consuming a LCD, as well as increases in HDL cholesterol (HDL-C) levels [5,6], as HDL-C has been shown to increase when dietary carbohydrate is replaced by saturated, monounsaturated, or polyunsaturated fat in the diet [7]. Previous studies also suggest improvements in insulin sensitivity as serum glucose and insulin levels decrease after consuming a low-carbohydrate diet [7,8].

While LCDs are more frequently consumed by the average weight-conscious consumer, some athletes may opt for that dietary pattern to potential enhance endurance performance and/or to rapidly affect body composition. Data are contradictory regarding the performance effects, with most suggesting a lack of improvement [9], but the weight loss results are fairly supportive [10]. This review will discuss the potential health risks of low carbohydrate and high fat diets and the effect of this dietary practice on aspects of athletic performance.

Potential Health Risks

Despite the reported benefits, some have warned of potential negative health consequences associated with consuming a diet low in carbohydrate and higher in fat and protein. Protein rich foods, particularly animal based protein foods, often contain higher levels of saturated fat and cholesterol that may adversely affect LDL cholesterol levels and increase the risk for cardiovascular disease; although, research demonstrates that lipid-lipoprotein levels improve when carbohydrate intake is decreased [6,11,12]. LCDs tend to be low in dietary fiber and may increase the risk of constipation, irritable bowel, diverticulitis, and other intestinal issues. Other concerns associated with LCDs include potential metabolic strain on liver and kidney function (i.e. kidney stones) and potential electrolyte or pH imbalances; although, recent evidence does not support the latter issues [13]. Low carbohydrate diets may lack required vitamins/minerals and essential fatty acids, but that risk can be decreased by supplementing these nutrients. The majority of high fat and LCD research has focused on short-term (< one year) metabolic adaptations, as such, the long-term benefits and/or potential consequences are still poorly understood. Moreover, severe carbohydrate restriction is only recommended for a short period of time and carbohydrate-containing foods are usually added back into these diets (e.g., Atkins® and South Beach®).

Exercise Performance

Aside from health outcomes, LCDs have recently found their way into the athletic arena and have warranted attention from a few investigators as a potential mechanism to improve endurance performance. It has been a subject of recent debate as to what type of diet is best for an athletic population, and one of the recent approaches in the scientific community has been to examine the effects of LCDs, more commonly referred to as high fat diets, on performance parameters in athletes. This approach has primarily focused on endurance athletes, such as competitive cyclists and distance runners. It is a common perception among athletes that a diet low in carbohydrate and high in fat will negatively affect exercise performance. Proponents of LCDs suggest that this dietary practice provides large amounts of lipid as substrate for ATP synthesis, thus potentially decreasing the reliance on the bodies limited muscle glycogen stores and ultimately delaying muscle glycogen breakdown during exercise.

It is generally assumed that a carbohydrate intake of 7-10g/kg/d [14] is necessary for endurance athletes to restore muscle and liver glycogen stores to ensure sufficient glucose availability for skeletal muscle contraction during endurance type aerobic exercise [15]. Consumption of a high carbohydrate diet has been shown in earlier studies to increase carbohydrate oxidation and muscle glycogenolysis during exercise [16]. Consuming large amounts of carbohydrate may provide adequate substrate to fuel daily training and competition needs, and potentially increases the relatively low amount of carbohydrate stored in the body as glycogen.

Carbohydrate and fat are the primary substrates for skeletal muscle metabolism during rest and exercise. Their contribution to total oxidative metabolism is dependant on a variety of factors, including exercise intensity, exercise duration, diet, and other factors such as training status [17]. Low carbohydrate diets result in metabolic and hormonal adaptations that may improve fat oxidation and promote glycogen sparing in exercising skeletal muscle. Similar to endurance training adaptations, there is a shift towards a greater reliance on fat oxidation for fuel at rest and during exercise on a LCD, which may be due to a combination of increased oxidative enzymes, increased mitochondrial density, greater storage and utilization of intramuscular triglyceride, and enhanced muscular uptake of plasma free fatty acids [18-21]. In addition, LCDss have been shown to increase resting human skeletal muscle pyruvate dehydrogenase (PDH) kinase activity and decrease the amount of active PDH [22], which in turn decreases carbohydrate oxidation. These combined mechanisms would lead to a reduction in muscle glycogenolysis and carbohydrate oxidation and contribute to greater utilization of free fatty acids during exercise.

Havemann and colleagues [23] reported respiratory exchange ratio (RER) values after adaptation to a low carbohydrate, higher fat diet. Eight cyclists ingested either a LCD for seven days followed by a high carbohydrate diet on day eight or a high carbohydrate diet alone for eight days. During exercise, the RER values at rest and during exercise were decreased on the LCD and the corresponding blood data demonstrated increased plasma free fatty acid levels when compared to ingestion of a higher carbohydrate diet for 8 days [23]. These results represent specific examples demonstrating increased fat utilization at rest and during exercise with adaptation to a LCD, even when carbohydrate intake is restored.

In examining the effects of a LCD on exercise performance, a few animal studies have demonstrated that increased availability of fatty acids delays the development of exhaustion in rats subjected to prolonged exercise [24,25]. This has led investigators to examine differing amounts of carbohydrate intake on human performance outcomes. One study, in which competitive cyclists were confined to a metabolic ward and provided eucaloric LCD for 4 weeks designed for weight maintenance (83% fat, 15% protein, and <3% carbohydrate) and supplemented with additional key minerals (1g/d K+, 3 g/d Na+, 600mg Ca+, 300mg Ma+, and a multivitamin) showed no loss of VO_{2max} or endurance exercise capacity (time to exhaustion at 60-70% VO_{2max}) when compared to baseline assessments despite diminished pre-exercise muscle glycogen content [26]. Lambert et al. [27] demonstrated that two weeks of adaptation to a high fat (67%) low carbohydrate (7%) diet in 5 endurance trained male cyclists nearly doubled exercise time to exhaustion at ~60% VO_{2max} when compared to a low fat (12%) high carbohydrate (74%) diet, while muscle power during supra-maximal exercise (30 second Wingate test) and high intensity cycling exercise to exhaustion at ~90% VO_{2max} were not impaired after the LCD despite low pre-exercise glycogen levels.

Pitsiladis and Maughan [28] examined the effects of more moderate changes in dietary carbohydrate in trained male cyclists and experienced tri-athletes. Subjects in this study consumed an iso-energetic diet that consisted of either 70% carbohydrate or 40% carbohydrate and exercised to exhaustion at either 90% VO_{2max} (n = 7 cyclists) or 80 % VO_{2max} (n = 5 tri-athletes). The results of this study showed no differences in cycling exercise times to exhaustion and no differences in RPE, heart rate, or oxygen uptake between conditions. Despite the performance enhancement found in a few studies, it has also been demonstrated by some that

LCDs have no effect on exercise performance in either trained or untrained individuals [9,29-31].

Low carbohydrate diets generally lead to greater total energy deficits than traditional or habitual diets, and thus may affect diet adherence and exercise performance. However, Horvath and colleagues [32] have demonstrated that trained male and female runners may consume fewer overall calories on a low fat diet (16% total energy) and have reduced endurance performance when compared to medium (31%) and high fat (44%) diets when allowed to eat ad libitum. Also, Muoio et al. [33] suggest that restriction of dietary fat may be detrimental to endurance performance as these investigators found that treadmill running time to exhaustion in 6 trained males was greatest after a diet higher in fat (38%) versus two diets higher in carbohydrate (61% and 73%).

Low carbohydrate/high fat diets may lead to greater utilization of fat as fuel during exercise, thereby leading to a glycogen "sparing" effect and potentially improving endurance exercise capacity. The low amount of glycogen stored in the human body, which is approximately 300-400 grams in skeletal muscle and 70-100 grams in the liver [34], poses a limitation in the ability to maintain a high power output during prolonged endurance exercise. It has been argued that a consequence of a LCD may be a decline in pre-exercise muscle glycogen content especially in untrained individuals, which may defeat the purpose of creating the glycogen sparing effect in the first place. However, Lambert et al [27] demonstrated enhanced endurance capacity in endurance-trained individuals on a LCD even in the face of diminished pre-exercise glycogen levels. The metabolic adaptations associated with a short term LCD combined with an already enhanced oxidative system, including an up-regulation of mitochondrial oxidative enzymes and increased mitochondrial density, suggests endurance athletes may still be able to perform similar amounts of physical work on a LCD even in the face of potentially more difficult perceived effort.

The available research on the effects of a LCD on endurance performance is still limited and the results equivocal, and there is little data regarding the effects on high intensity exercise performance. The research that has been done to date has focused mainly on time-to-exhaustion exercise trials, with a few studies utilizing time trial performance as a primary outcome. Few studies have performed a cross-over study design where all subjects received each dietary treatment. Furthermore, most studies have used a pre-post testing design and have not controlled for deviations in daily training.

Daily Training

What remains relatively unknown is the effect high fat diets have on daily training; the vast majority of research has utilized a pre-post study design. The athletes are tested before beginning the diet modification and then tested again at the end of the diet. If high fat diets lower glycogen and hinder performance based on a pre-post testing design, how certain is it that the observed differences are not due to reductions in training volume. For example, if someone does less work on a daily basis while following a high fat diet, then that individual would likely have a reduced performance effort due to a decreased training stimulus. Therefore, differences in performance may be due to chronic changes in substrate utilization and not necessarily acute changes during the final testing session. It is imperative that studies that utilize a pre-post testing design insure that work and training are similar between diet groups; otherwise, it is difficult to know account for differences in training volume.

Since most studies have used time to fatigue or time trial methods to test performance, little is understood regarding how these diets affect day to day training. As most training bouts neither continue to the point of fatigue nor are completed at maximal effort, it would be useful to know how these diets alter daily exercise, if at all. Since most training sessions occur at intensities less than what occurs during competition, the negative effects previously observed may not occur when training.

We recently reported [35] a case study of a professional triathlete consuming a grain-based diet and a LCD, each lasting two weeks with a wash-out period between the diets. The athlete was not able to perform the same training volume while on the carbohydrate restricted diet compared to what he was able to complete on the grain-based diet. There are several limitations with a design of this nature (e.g., biased towards preferred diet, history and training effect, etc.), however, this case report does provide evidence that fluctuations in daily training may influence performance outcomes in addition to or separate from the diet intervention. Thus, research designs need to incorporate control mechanisms, such as supervising the training sessions, to insure that any performance differences are due to the diet and not training volume, which is often unsupervised. Albeit, the change in training volume was affected by the diet it is just difficult to tease out how much each contributes performance.

Weight Loss

Weight loss and body composition are issues that have received little research attention regarding this diet strategy in the athletic arena. Many athletes gain fat weight during the off-season and have to decrease the gained body fat to attain an optimal level for in-season performance. Based on the available literature, it appears that a LCD may offer an athlete a faster means of attaining the desired body composition.

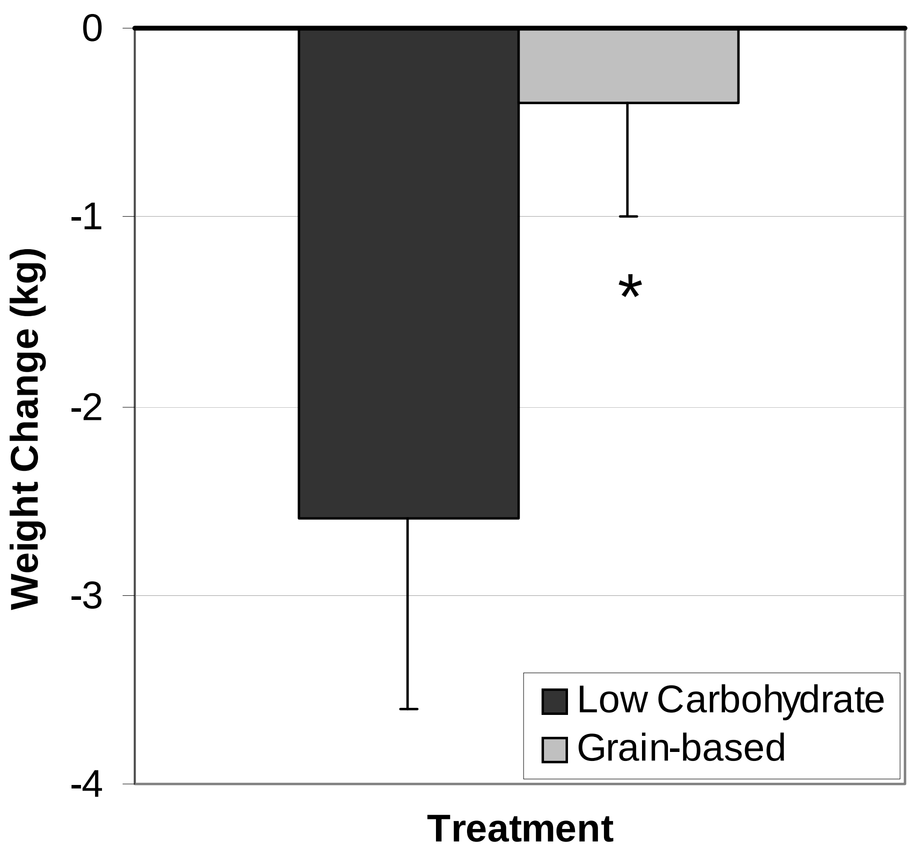
While the athletic and exercise literature has almost exclusively investigated the short-term performance change following a LCD with less regard to body composition, the health-related literature has numerous studies pertaining to the body composition and weight effects of this diet strategy. One limitation regarding this aspect of LCDs is the issue of controlling for weight stability.

When attempting to reduce body weight quickly, it appears that higher fat, LCDs may offer the better means of accomplishing that goal (Fig. 1, unpublished). Athletes followed Phase one of the Atkins® diet or a grain-based diet (focus on whole-grains with limited refined carbohydrate and desserts) for two weeks. [au: PLEASE CHECK THE FOLLOWING FOR ACCURACY] The Atkins® diet contained 56% fat and 13% carbohydrate and the grain-based diet contained 28% fat and 56% carbohydrate (unpublished). There was significant ($p<0.05$) weight reduction following the LCD phase however, others observed that only increasing fat content alone did not reduce body weight in a group of cyclists [36]. Furthermore, during our study,both body weight and lean mass decreased to a greater extent with the higher fat diet . Thus, it may not be advantageous to merely reduce body weight by following a LCD if preservation of lean mass is desired.

Conclusions

It is evident that higher carbohydrate intake tends to elicit fewer perturbations in athletic performance compared to low carbohydrate intake. Many report that restricting carbohydrate intake elicits improvements in oxidative mechanisms, especially fat oxidation. However, any performance benefits of this approach have not been demonstrated consistently (9). Weight loss is one area where LCDs might be of benefit compared to higher carbohydrate. Research consistently demonstrates that LCDs elicit faster weight loss than low fat diets however, it remains to be fully understood if the more rapid weight loss improves athletic performance.

Figure 1 – Weight loss following a 2-week high fat diet (phase one of Atkins Diet®) or grain-based diet (focused on whole-grains and restricted fried foods and desserts) in athletes (n=7) – the athletes consumed both diets, via a cross-over design, with a wash-out period between diets; *=significantly ($p<0.05$) different from high LCD.


0
-1
-2
-3
-4
Weight Change (kg)
*
Low Carbohydrate
Grain-based
Treatment

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