LOW-CARBOHYDRATE KETOGENIC DIET FOR WEIGHT MANAGEMENT

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INTRODUCTION

The concept of a low-carbohydrate diet (LCD) is not new (e.g., the *Atkins Diet Revolution* was first published in 1972), however, there has been a surge of public interest over the last decade in carbohydrate-restricting diets. One particular type of LCD, the ketogenic diet (KD), has shown promise for its purported ability to aid in weight management. Achieving and maintaining significant weight loss over the long-term remains a very elusive endeavor. Low-carbohydrate diets (LCD) have demonstrated promise in this regard and may hold certain advantages over traditional calorie-restricted dietary strategies.

The KD stands in stark contrast to current macronutrient recommendations for both health promotion, as well as enhancement of athletic performance (7,21). The KD is characterized by a macronutrient distribution ratio consisting of approximately 70 – 80% fat, 10 – 20% protein and <5% carbohydrate (CHO), with daily CHO intake limited to ≤50 grams. Two of the most prominent and vocal researchers of the KD, Jeff Volek, PhD and Stephen Phinney, MD, PhD, in their book *The Art and Science of Low Carbohydrate Performance*, recommend protein consumption of 0.6 – 1.0 grams per lb of lean body mass, a figure which almost perfectly matches the commonly recommended protein intake for athletes (i.e., 1.2 – 2.0 g/kg bodyweight) (21,26). With CHO intake radically restricted and protein within the commonly recommended range, fat becomes the primary macronutrient target for manipulation.

CARBOHYDRATE METABOLISM

The importance of dietary CHO is so well ingrained that the concept is taken for granted. In fact, basic macronutrient guidelines are predicated upon the idea that the central nervous system (CNS) requires a minimum of ~130 grams (~520 kcal) per day to function properly (i.e., to maintain optimal cognitive function). As a result, the minimum recommended daily intake of CHO reflects this idea (7). Similarly, most contemporary texts on sports nutrition emphasize the outsized role of CHO in optimizing both athletic performance and recovery (9). Frequently referred to as the "master fuel," recommendations range from 3 – 12 grams per kilogram of bodyweight, per day. As an example, the recommended daily intake for a 180-lb athlete would be 246 – 982 grams, with a caloric equivalent of 984 – 3,928 calories. In marked contrast, the KD would recommend a maximum of just 50 grams (~ 200 calories) per day for the same individual.

As ingested CHO is broken down by the stomach and absorbed through the small intestine, rising blood sugar creates a feedback loop which results in secretion of insulin. The primary role of insulin is to "dispose" of excess blood sugar by signaling tissues to "uptake" more glucose from the circulating supply. In this manner insulin serves a prominent role in glucose regulation. This concept also provides the basis for the glycemic index, a concept which attempts to quantify the impact CHO foods have on blood sugar response. For example, foods rich in simple CHO (i.e., "sugars"), which are absorbed quickly, trigger a rapid rise in blood sugar (and subsequently insulin response), whereas foods rich in complex CHO, such as fiber-rich legumes, exert a relatively blunted response on blood glucose.

When dietary CHO is of sufficient quantity the body has the ability to store small amounts for later use. Stored CHO is referred to as glycogen. Body reserves of glycogen, however, are limited, with relatively small amounts stored in the liver and skeletal muscle. As CHO is the "go to" energy source for the CNS, as well as an important energy source for other tissues, the body must maintain a stable supply of circulating blood glucose. While this is a complex process, the liver is primarily responsible for either breaking down stored glycogen or manufacturing small amounts of glucose in a process known as gluconeogenesis. In this manner the liver is able to maintain circulating blood glucose levels under most conditions. If the liver is unable to supply a sufficient amount of glucose, blood sugar levels will fall and result in hypoglycemia, a condition characterized by hunger, fatigue, headache, nausea and impairments in cognitive ability. In sporting terms hypoglycemia is referred to as "bonking" or "hitting the wall" and significantly affects athletic performance. Therefore, it is easy to understand the perceived need for dietary CHO; in the absence of sufficient blood glucose, physiological function is rapidly compromised.

While CHO is almost universally regarded as necessary for both health and athletic performance, many studies have called into question the absolute necessity of dietary CHO. As early as 1930 there was evidence demonstrating the efficacy of long-term CHO restriction (14). In an audacious attempt to demonstrate proof-of-concept, arctic explorers Dr. Viljalmur Stefansson and K. Anderson, agreed to participate in a study that involved one year of eating a diet that consisted solely of "meat." The diet, which consisted of beef, pork, lamb, and chicken, also included significant portions of animal fat, as well as organ meat. This dietary regimen yielded a macronutrient distribution of approximately 81% fat, 18% protein and 1% CHO, over the course of 375 days. The subjects experienced a modest reduction in weight, which occurred during the first week; there were no restrictions on food portions, subjects ate to satisfy appetite. Interestingly, the researchers noted no vitamin deficiencies, no significant change in mental alertness or physical impairment, or any other deficit attributed to eating a high fat, all-meat diet.

WHAT IS KETOSIS?

Fat is an important energy source; however, it plays a secondary role as an energy substrate, particularly during exercise that exceeds moderate intensity. For example, one of the fundamental concepts of bioenergetics illustrates this point through the axiom "fat burns in a carbohydrate flame;" clearly emphasizing the important role of CHO in energy metabolism. In the absence of adequate CHO availability, as might occur during starvation, near the end of a long endurance event or CHO-restricting diet, the body must turn to an alternate source to maintain energy for all tissues. Under normal dietary conditions there is a steady supply of glucose which the body readily uses as a primary fuel.

In the absence of CHO, however, the body must shift to fat as the primary energy source. In this case, the body catabolizes stored triglycerides, which exist in abundance in even the leanest individual. In effect, the KD provokes a physiological stimulus, i.e., CHO restriction, that mimics starvation. Due to the limited ability to store or produce CHO during periods of starvation, the body thus switches to ketogenesis, the production of ketone bodies as a primary fuel source (3).

Ketogenesis results in the production of ketone bodies, a product of fatty acid catabolism performed primarily by the liver, in the absence of adequate CHO availability. Three primary ketone bodies are produced; acetone, acetoacetate and β-hydroxybutyrate. Even though trace amounts of ketones are always present in the blood, it is only during periods of inadequate CHO availability that significant ketone production will occur. This accumulation of ketone bodies in the blood is commonly referred to as ketosis.

The goal of the KD is to sufficiently deprive the body of CHO to achieve physiological or "nutritional ketosis," a metabolic state which is characterized by blood ketone levels between 0.5 and 3.0 mmol/L (26). This "switch over" point, however, is not seamless and may take up to several weeks for individuals to become "keto adapted" (18). Supporting this idea is a significant amount evidence indicating that a "keto adapted" body has little reliance on glucose for CNS function (8,14,16) or as a source of energy for exercise (17,18,25,27).

KD FOR WEIGHT MANAGEMENT

Weight loss is a common target for disease management, as well as health promotion. The prevalence of obesity remains high among U.S. adults (36.5%) (5), as well as children and adolescents (17%) (6). Importantly, obesity is a significant contributor to increased morbidity and mortality, as well as being a primary driver of increasing medical expenses (4). Despite much effort and cost, there has been little success on this front and obesity remains a public health crisis.

Given the lackluster success of commonly prescribed diets for the majority of individuals it is not surprising that there is interest in alternative strategies. Anecdotal evidence regarding KD abounds on the internet, with reports of "miraculous" weight loss commonplace. The reality of KD, however, may be less impressive.

Several studies have investigated the potential of LCD or KD on weight loss. For example, Brinkworth et al. (2) compared one year of low-fat (LF) vs. LCD diet in adults with abdominal obesity. Subjects were randomly assigned and diets were isocaloric, with moderate energy restriction. Both groups realized significant weight loss, however, there was no significant difference between groups, suggesting that a LCD was equally effective as a LF diet.

Moreover, two recent meta-analyses sought to investigate the effect of LCD on weight loss and cardiovascular disease risk. Sackner-Bernstein et al. (19) compared LCD to LF, among overweight and obese men and women. The authors found a significantly greater effect of weight loss in the LCD vs. the LF diets (-8.2 kg vs. -5.9 kg). The impact of diet on cardiovascular risk factors was split, with LCD resulting in significantly greater improvements in HDL cholesterol and triglycerides, while the LF resulted in significantly greater improvements in LDL and total cholesterol. From this the authors concluded that LCD were a viable alternative to LF diets and recommended "dietary recommendations for weight loss should be revisited to consider this additional evidence of the benefits of [low] CHO diets." A significant limitation of this meta-analysis, however, was the authors' definition of low-carbohydrate as a daily CHO consumption less than 120 grams. This value, while well below the standard recommendation of daily CHO consumption, still far exceeds the strict recommendation of KD (≤50 g/day), therefore the results of this meta-analysis must be approached with caution.

Supporting these results, Naude et al. (15) found a similar outcome in obese adults with and without type 2 diabetes. This meta-analysis of 19 randomized, controlled trials compared dietary interventions using standard CHO recommendation (i.e., 45 – 65%), low-carbohydrate/high protein (LCHP) and low-carbohydrate/high fat (this group, although not specifically stated, met the criteria for KD). Results demonstrated significant weight loss among all groups in the short-term (3 – 6 months) and long-term (1 – 2 years), with no significant difference among dietary interventions. The authors concluded that weight loss interventions using CHO restriction are equally effective as isocaloric diets of standard CHO recommendation.

Most recently, Wilson et al. (27) investigated the effect of a 10-week KD on strength, body composition, blood lipids and hormonal response in resistance trained males, while following a periodized resistance training program. The investigation included a 2-week dietary adaptation period, and a control group, which followed a more traditional macronutrient ratio consisting of 55% CHO, 25% fat and 20% protein (WD). The 10-week dietary intervention was followed by a 1-week CHO re-introduction for the KD group. Average caloric consumption across the 11-week intervention was similar between groups. Blood lipids remained constant and were not significantly different between groups. The KD group did, however, elicit a significant increase in blood triglycerides during week 11, with the re-introduction of CHO. Total testosterone was significantly increased in the KD group, compared to WD, however, free testosterone was not significantly different between groups. While both groups saw increases in lean body mass, the KD group realized gains significantly greater than the WD group. Similarly, the KD group experienced significantly greater decreases in fat mass during the 10-week CHO restriction period. There were no significant differences in measures of strength or power between groups. From this, the authors concluded that the KD favorably impacted body composition, with no negative impact on blood lipids or muscular strength and power.

Providing additional support Paoli et al. (17) examined the effect of a modified KD diet (~55% fat, 41% protein, and 4.5% CHO) on performance and body composition in gymnasts. In a crossover design, researchers compared independent 30-day dietary regimens consisting of "normal diet" (WD; 46.8% CHO, 38.5% fat, and 14.7% protein) and modified KD in nine elite male gymnasts. There were no significant changes from pre to post during either dietary intervention for measures of physical performance, indicating the absence of significant dietary CHO did not negatively impact physical ability. The post-KD measurements, however, saw a significant decrease in fat mass (pre: 5.3; post: 3.4 kg), as well as a concomitant decrease in body fat percentage (pre: 7.6%; post: 5.0%). Moreover, there was a significant increase in lean body mass percentage (pre: 92.4%; post: 95.0%). In this 30-day modified KD elite male gymnasts, eating an ad libitum diet, improved body composition via both loss of bodyfat, as well as increasing lean mass.

Taken together, these results demonstrate a positive effect of LCD/KD on body composition. While KD may not be superior to other dietary strategies aimed at weight reduction, the evidence does suggest that it may be equally effective. Nevertheless, the International Society of Sports Nutritionists, in their Position Stand on the effects of diets on body composition, suggest the KD holds little benefit over higher CHO diets, with one notable exception; KD may enhance appetite control (1).

POSSIBLE MECHANISM OF ACTION

Nutritional ketosis has been proposed as a mechanism through which hunger may be suppressed. A recent meta-analysis investigated the impact of diet on appetite and shed some light on this possible phenomenon (11). The meta-analysis included 12 studies which investigated the effect of either a very low energy diet (VLED: defined as <800 calories per day) or ketogenic low-carbohydrate diet (KLCD: defined as CHO consumption of <10% of energy or <50 g/day, but ad libitum consumption of total energy, protein and fat). Interventions ranged from 4 – 12 weeks and weight loss was from 5.0 to 12.5 kg. In all studies nutritional ketosis was confirmed in VLED and KLCD via circulating levels of β-hydroxybutyrate. Interestingly, both groups reported decreases in appetite. The results of this meta-analysis are noteworthy in two regards. The VLED groups were clearly and significantly hypocaloric, suggesting a state in which hunger should be increased, not decreased. Similarly, the KLCD groups experienced simultaneous reductions in weight and appetite, while eating an ad libitum diet. The results of this meta-analysis provide support for the theory that nutritional ketosis may exert an appetite suppressing effect.

CAUTIONS AND POTENTIAL SIDE EFFECTS

Although the KD has shown promise as an alternative dietary strategy for weight management, it should be approached with caution. Acutely, the KD causes physiological changes which may manifest as the "keto flu," a set of symptoms which commonly includes headache, nausea, gastrointestinal upset and fatigue. A recent study by Urbain et al. (22) illustrates this point, as they state, "Consistent with other studies, our subjects complained about headache, gastrointestinal symptoms, and general weakness mainly during the 1-week metabolic adaptation phase to a KD." While these symptoms typically resolve within the first one to two weeks, this may present an unpleasant barrier for many individuals to overcome.

Over the long-term the KD poses possible risks as well, although the evidence remains unclear on this topic. Consumption of a high fat diet, particularly saturated fat, is associated with increased cardiovascular risk (23) and consumption of saturated fat has been shown to acutely induce insulin resistance and raise blood triglyceride levels (12). Nevertheless, many KD studies have documented improvements in markers of cardiovascular risk, including improvements in vascular function (24) reduction in inflammatory markers (10), and other markers of cardiovascular health (13,20). Methodological issues, such as clear definitions of dietary interventions, may play a significant role in obscuring the underlying principles, however, it is clear that more targeted research is warranted.

CONCLUSION

Diet is the most important lifestyle factor for weight loss. In order to effect significant loss of weight it is necessary to create a consistent caloric deficit. This has the rather obvious side effect of leaving individuals feeling hungry and as though they are in a constant state of deprivation. Dieting is based upon this basic concept, which is the most likely reason why dieting is very likely to fail in the long-term. The ketogenic diet, while controversial and a highly polarizing subject, has demonstrated promise as an alternative dietary strategy for weight management. The KD may hold an advantage over traditional calorie-restricted diets, in that nutritional ketosis may enhance appetite control, and subsequently improve dietary adherence and long-term success. Nevertheless, the KD should be approached with caution, as there are both short- and long-term potential negative side effects. More research into this unique dietary strategy is warranted to fully investigate all potentially positive and negative aspects.

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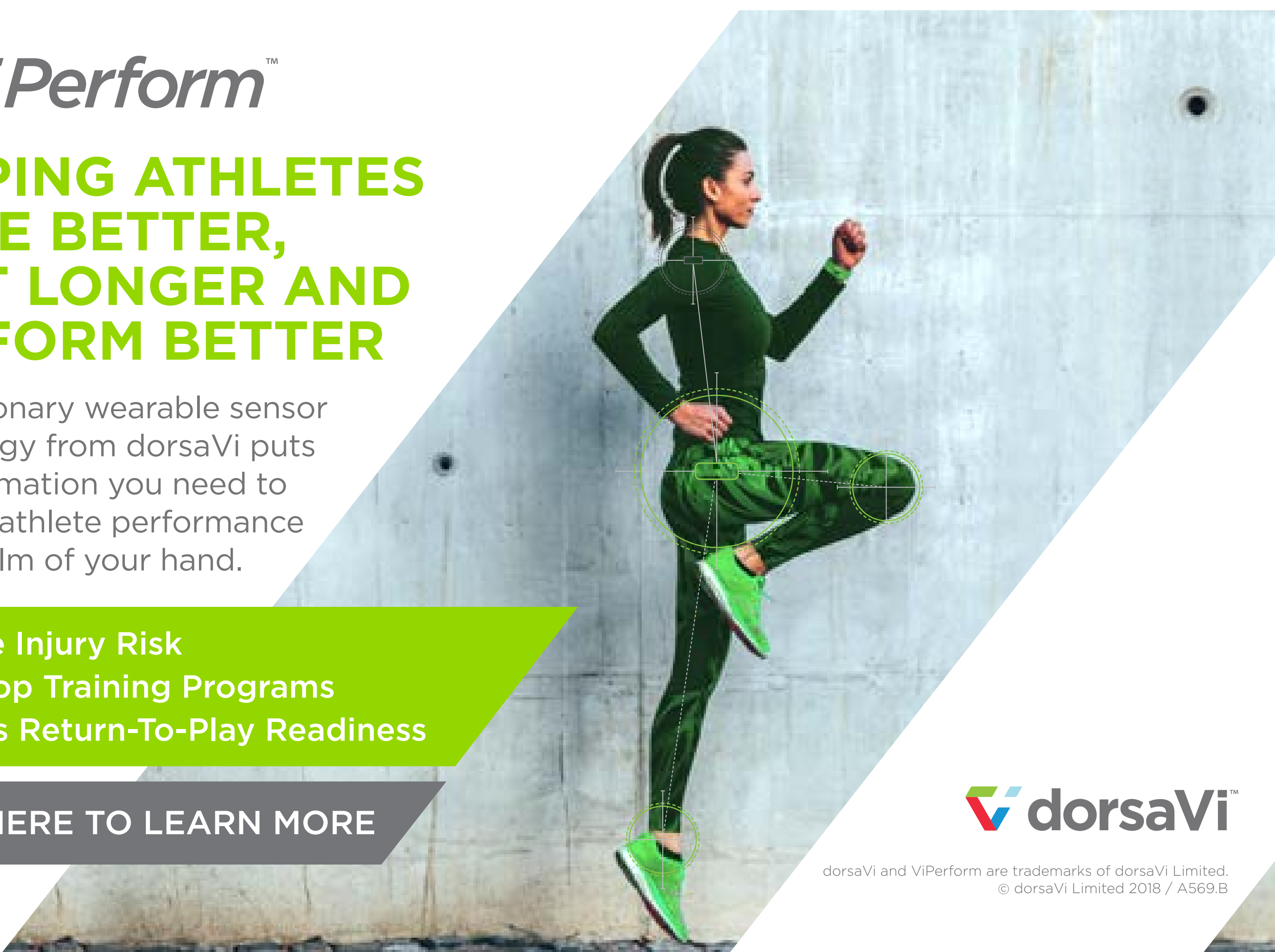

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