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A low-carbohydrate ketogenic diet combined with six weeks of crossfit training improves body composition and performance

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A Low-Carbohydrate Ketogenic Diet Combined with 6 Weeks of CrossFit Training

Improves Body Composition and Performance

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Abstract

A low-carbohydrate ketogenic diet (LCKD) is a popular approach to weight and fat loss. CrossFit is a high-intensity power training (HIPT) type exercise for all levels of age and fitness that has gained recognition as one of the fasting growing sports in America. No previous research has been found which examines body composition changes or performance in individuals consuming a LCKD and participating in CrossFit training. **PURPOSE**: The purpose of this research was to examine the effects of a 6-week LCKD and CrossFit program on body composition and performance. **METHODS:** Twenty-seven non-elite CrossFit subjects (mean ± SD age = 34.58 ± 9.26 years) were randomly assigned to a LCKD (males, n = 3; females, n = 9) or control (CON) (males, n = 2; females, n = 13) group. LCKD was instructed to consume an ad libitum diet and restrict carbohydrate intake to less than 50 grams per day (<10% of total energy) and CON maintained usual dietary intake. Diet adherence was evaluated through weekly urinary ketone measurements, dietary compliance checklists, and bimonthly Food Intake Records. All subjects participated in four CrossFit training sessions per week during the 6 weeks. Training compliance was monitored through mandatory check-in procedures at the CrossFit gym. Body composition was measured by dual x-ray absorptiometry and performance testing was measured by benchmark CrossFit protocols. **RESULTS:** Compared to the CON group, the LCKD group significantly decreased weight (0.18 ± 1.30, -3.45 ± 2.18 kg), BMI (0.07 ± 0.43, -1.13 ± 0.70 kg/m^2), percent body fat (%BF) (0.01 ± 1.21, -2.60 ± 2.14 %), and fat mass (FM) (0.06 ± 1.12, -2.83 ± 1.77 kg), respectively. There was no significant difference in lean body mass (LBM) change between or within groups. We found no significant difference in total performance time change between the CON group and the LCKD group; however, both groups significantly decreased total performance time (CON: -41.20 ± 43.17 sec.; LCKD: -55.08 ± 44.29 sec.). Additionally, there were no significant differences in vertical jump and standing long jump change between or within groups. For both groups, the overall change in vertical jump was significant (2.31 ± 4.55 cm) but the change in standing long jump was not. Carbohydrate intake was significantly lower (11.4 ± 5.6%, 40.06 ± 6.81%) and fat intake was significantly higher (62.88 ± 4.19%, 38.38 ± 4.18%) in LCKD at weeks 2, 4, and 6 compared to CON, respectively. There was no statistical difference in total kilocalories or protein intake between or within groups throughout the study. **CONCLUSION:** A LCKD combined with 6 weeks of CrossFit training can lead to significant decreases in %BF, FM, weight, and BMI while maintaining LBM. Additionally, significant improvements in total performance time and power can be achieved. **PRACTICAL APPLICATION:** With the overwhelming increase in obesity and metabolic disease throughout the United States many Americans are searching for the most effective diet and exercise program which promotes fat loss and increases overall quality of life. This study provides valuable insight into the use of a LCKD combined with CrossFit training for 6 weeks to improve body composition and performance outcomes.

Chapter I

Introduction

The prevalence of obesity has increased throughout the United States with one in three Americans categorized as obese (40). Fewer than a quarter of Americans who attempt to lose weight actually follow current recommendations of increasing exercise and reducing caloric intake (46). Those who attempt losing weight through regular aerobic training by using a treadmill or elliptical often get bored and lose motivation very quickly, leading to decreased exercise adherence (28). An exercise program that has grown in popularity over the past few years as an alternative to traditional endurance and resistance training is known as CrossFit (2, 7, 28).

CrossFit was introduced in 2001 by its founder Greg Glassman and is considered "one of the fastest growing sports in America" with over 13,000 gyms worldwide (16, 28). CrossFit is a high-intensity power training (HIPT) type exercise that consists of a combination of gymnastics, plyometrics, functional movements, anaerobic intervals, weightlifting, sprinting, and Olympic lifting (11, 34, 35). These constantly varied exercises, which are combined into the "Workout of the Day" (WOD) (11), allow for training in all three human energy systems: the creatine phosphate (CP) system, anaerobic glycolysis, and oxidative phosphorylation (2) and can be adapted for all levels of age and fitness (8).

The majority of CrossFit participants include men and women ranging from 19-60 years old looking to improve all aspects of health and fitness with a desire to lose weight and increase performance (11). A popular approach to weight loss that has gained recognition in recent years is the low-carbohydrate ketogenic diet (LCKD). This diet is classified by a decrease in carbohydrates with a subsequent increase in proportions of dietary fat and protein (27). The reduction in carbohydrates, usually below 50 grams per day, allows a shift from glucose to fat-based metabolism (20) which produces water-soluble ketone bodies known as acetoacetate (AcAC), 3-β-hydroxybutyrate (3HB) and acetone (36). Ketone body formation, also known as ketogenesis (17), has been shown to aid in the treatment of several diseases such as refractory pediatric epilepsy, cardiovascular disease, Type 2 diabetes, and obesity (27, 36). In addition, ketogenic diets are recognized as one of the more effective treatments for improvements in body weight, body composition, fasting serum lipid levels, and diet tolerability, especially when compared to low-fat diets (21, 33, 42, 44, 46).

Although there are many benefits to following a LCKD, there has been much controversy surrounding its relationship to exercise performance. While there is a paucity of literature, some studies have reported favorable outcomes in body weight and body fat reductions when following a LCKD and adhering to either an endurance or resistance type training protocol (3, 14, 25, 32, 47). To date, there have been no published investigations found supporting changes in body composition or performance in response to a HIPT type exercise program such as CrossFit, while adhering to a LCKD. The purpose of this study is to determine if consuming a six-week LCKD and participating in a CrossFit training regimen yields significant improvements in body composition while maintaining performance. Specifically, we hypothesized that a LCKD would be a successful fat loss and weight loss strategy for CrossFit participants while maintaining or improving performance. Our second hypothesis was that those participating in CrossFit training while adhering to their usual dietary intakes will show significant increases in performance with minimal decreases in body mass or body fat content.

Review of Literature

CrossFit History

CrossFit was introduced on the Internet in 2001 by its founder Greg Glassman (16) and has since grown to include over 13,000 gyms across the world while gaining a ten-year sponsorship with Reebok (11). CrossFit is "a core strength and conditioning program that aims to prepare athletes for any physical contingency" (10) and is responsible for a substantial number of people incorporating exercise into their everyday lifestyle (29). CrossFit defines fitness as the ability to do real work movements of any type, whether that be cardio, strength, or power, for any specified amount of time: short, middle, or long duration (34). In addition, CrossFit incorporates a competitive element into each workout that helps to encourage members to strive beyond their initial goals and expectations. This has led CrossFit to be described as the "Sport of Fitness" and qualified members can participate in the popular annual CrossFit Games (11). Although criticism has arisen about the lack of individualism as well as possible injury risk that accompanies CrossFit programs, no substantial research has been found to support these claims (10, 11, 22).

CrossFit Training

CrossFit is considered a high-intensity power training (HIPT) or high-intensity functional training (HIFT) type exercise. HIPT and HIFT differ slightly from the well known high-intensity interval training (HIIT). HIIT is a popular way to improve aerobic fitness through short, intense bouts of exercise that requires a minimal time commitment.

HIPT and HIFT are very similar to HIIT although they lack a prescribed rest period. In addition, HIPT and HIFT aim at sustaining high power outputs through periods of combining aerobic and resistance exercises with the main focus on multiple joint movements (13, 35).

CrossFit defines its view of fitness based on three guiding standards that include: general physical skills, performance of athletic tasks, and use of the human energy systems (8). The ten general physical skills or fitness domains include cardiovascular and respiratory endurance, stamina, strength, flexibility, power, speed, coordination, agility, balance, and accuracy. CrossFit prides itself in developing workouts to enhance individual's competency in all ten of these areas (28). CrossFit athletes achieve these skills through high-intensity workouts that combine cardiovascular conditioning, weightlifting, and body-weight exercises (34).

Another goal of CrossFit is to strive to keep training regimens consistently broad and varied in order to enhance performance of all athletic tasks (8). This includes incorporating body weight exercises, gymnastics, Olympic style weightlifting, running, and rowing into what is known as the "Workout of the Day" (WOD) (11). The emphasis of each WOD centers on implementing compound or functional movements into shorter high-intensity cardiovascular sessions (7) that can be scaled for a variety of strengths and fitness levels (2).

Each WOD session requires training in all three human energy systems: the creatine phosphate (CP) system, anaerobic glycolysis, and oxidative phosphorylation (2). The CP system and anaerobic glycolysis favor the use of energy from substrates in the absence of oxygen. The CP system provides an immediate source of energy for explosive bouts of exercise lasting up to 20 seconds while anaerobic glycolysis is used upon depletion of the CP stores during short-term, high-intensity exercises lasting up to three minutes (31). Such activities include 100- meter sprints, powerlifting, plyometrics, and gymnastics (2). The oxidative phosphorylation pathway, also known as the aerobic system, requires oxygen to metabolize substrates and involves low to moderate power output. Aerobic activities that last in excess of several minutes include distance running, rowing, and cycling (7, 8). Although each system differs in its percent contribution to energy production at a given time period, all three pathways overlap to provide energy to working muscles during physical activity (2).

Benefits of CrossFit

CrossFit exercises are designed to stress each metabolic system by combining various exercise movements, intensities, resistance, repetitions, sets, and rest periods to maximize training benefits (2). Although CrossFit does not follow the specific 7-step process for resistance training laid out by the National Strength and Conditioning Association (NSCA) (29), research has shown that HIPT can yield both anaerobic and aerobic improvements (35, 48). A study that investigated the effect of a 10-week, CrossFit-based HIPT program on body composition and VO2max in 43 healthy subjects, revealed a substantial improvement in maximal aerobic capacity and a significant decrease in percent body fat in men and women of all levels of fitness (35). A similar study examined the potential improvements in sports performance and body composition in 21 recreationally active adults participating in a four-week moderate to high intensity, short-duration CrossFit training program. Although no substantial changes in body composition occurred, there were significant improvements in the one-mile run test, muscle strength, muscle endurance, and agility performance (2).

Because of CrossFit's diverse variety of exercises and performance training benefits, it has been adopted as the main strength and conditioning protocol for several police academies, tactical operations teams, and military units (2). For example, a six-week study examined the effects of a CrossFit training program on 150 mid-grade officers in the Armed Forces. The program consisted of a minimum of four one-hour training sessions per week that included a variety of aerobic, gymnastics, and weight lifting exercises. All subjects experienced increases in overall work capacity and showed significant improvements in specific areas of assessment including the deadlift, shoulder press, and pushup tests (23).

In addition, a review of literature was carried out to assess the potential benefit of alternative fitness training programs that are used in the Air Force. Such training programs included nontraditional methods of heavy leg resistance training, CrossFit training, kettle bell training, and agility training. The focus of this review was to assess the potential for these programs to better prepare airmen to meet or exceed Air Force fitness standards as well as train them for military missions and rapid deployment. Findings indicate that although nontraditional forms of training elicited various benefits to overall performance, further research is warranted to investigate the specific reasoning of these benefits (22).

Injury Risk of CrossFit Training

Although CrossFit emphasizes the benefits of "constantly varied" exercises, criticism has arisen with regard to lack of individualization of the WODs as well as safety concerns for the high intensity and competitive nature of these workouts (11). Although the literature is scarce, there have been two studies conducted to assess the injury risk during a CrossFit type workout. The first study assessed injury incidence in US Army Brigade combat soldiers participating in either a CrossFit program or Advanced Tactical Athlete Conditioning (ATAC) program. The ATAC program consisted of high-intensity aquatic exercises, tactical agility circuits, combat core conditioning, and interval speed training. Results demonstrated that soldiers participating in the CrossFit or ATAC programs showed similar injury rates compared to soldiers not participating in these programs (10). In the other, a cross sectional observational study, injury rates with CrossFit training were no different than those reported in sports such as Olympic weight-lifting, power-lifting, and general fitness training (11). In addition, the injury risk for CrossFit was actually lower in comparison to competitive contact sports such as rugby. To date, no significant injury rates have been determined with participation in a CrossFit program.

CrossFit Population

Contrary to the criticism of injury risk that has developed for CrossFit over the past years, it has become popular for the "average Joe" looking to get in shape and improve his or her health. A recent randomized control study examined the effects of HIFT as compared to moderate-intensity aerobic and resistance training (ART) on exercise initiation, adherence, and enjoyment (13). Twenty-three participants were stratified by median age and BMI and then randomized to 8-week sessions of either HIFT or ART training. Results found that HIFT participants taking part in CrossFit classes spent significantly less time exercising per week than the ART group and were able to maintain exercise enjoyment and adherence compared to the ART participants; (13) therefore, CrossFit sessions may be time-efficient and practical for those looking to increase overall quality of life through body composition improvements and physical activity levels.

According to its creators, "the CrossFit program was developed to enhance an individual's competency at all physical tasks" (7). CrossFit has become a popular exercise regimen for all levels of age and fitness. CrossFit participants include children, elite athletes, adults of all ages and body types, and even elderly individuals. CrossFit emphasizes that performing functional movements with intensity will benefit everyone and can be adapted to all ages and ability levels (8). CrossFit Kids was developed to provide a broad, general, and inclusive exercise program for young children (1) and incorporates workouts that are scaled down to appropriate youth levels while still maintaining high intensity, functional fitness (34). Many professional and elite athletes such as cyclists, surfers, skiers, tennis players, and triathletes also participate in CrossFit to advance their personal fitness levels (7). Each individual CrossFit community strives to inspire, motivate, encourage, and strengthen its members (9). This idea is supported by a study taken from the Journal of Strength and Conditioning Research that revealed a positive correlation between the perceived motivational climate of CrossFit and its effect on goal orientations of CrossFit members (28).

The majority of CrossFit participants include men and women generally ranging from 19-60 years old (11) looking to improve all aspects of health and fitness. CrossFit welcomes people of all ages and body types while stating that it has "tested its methods on sedentary, overweight, pathological, and the elderly, and found that these special populations met the same successes as other stable athletes" (7). In addition to promoting physical fitness improvements, CrossFit encourages its members to seek out nutritious food options that will help to further support their individual goals as well as foster a healthy lifestyle (7, 35). A popular diet that has evolved over the past years to improve body composition and overall health and fitness levels is the ketogenic diet, which focuses predominantly on the use of fat as the main fuel source (27).

Ketogenic Diet History

A ketogenic diet is generally classified by a reduction in carbohydrates with a subsequent increase in proportions of dietary fat and protein (27). In recent years, a substantial amount of evidence has accumulated in the literature supporting the use of a low-carbohydrate ketogenic diet (LCKD) as a therapeutic tool to treat refractory pediatric epilepsy, cardiovascular disease, Type 2 diabetes, obesity, and much more (27, 36). The origin of the ketogenic diet dates back to 1878 when the earliest documented evidence of physical stamina during a ketogenic diet was observed in the Schwatka expedition. This expedition was carried out by Frederick Schwatka and two Inuit families who successfully travelled 3000 nautical miles on foot over a period of 13 months while consuming the "Inuit" diet made up of about 80% fat, 15% protein, and less than 5% carbohydrate (40). This journey, along with many published observations from other explorers such as Vilhjalmur Stefansson who participated in a similar expedition, illustrates that humans can function sufficiently on a hunter/gatherer type diet that consists mainly of fat and protein while lacking dietary carbohydrate (30, 41).

Ketogenic Metabolism

Ketosis is a fasting, metabolic-adapted state that occurs in humans when carbohydrate intake is restricted and dietary fat intake is increased. A typical low-carbohydrate ketogenic diet (LCKD) consists of a maximum of 50 grams of carbohydrates per day (36). The amount of carbohydrate ingested to induce ketosis is to some extent based on the individual person and some can maintain a ketotic state by ingesting as high as 90 grams of carbohydrate per day; however, the typical amount of carbohydrate intake associated with ketosis is less than 50 grams per day, which has been shown to induce serum and urinary ketones leading to weight loss and body composition improvements (46). In addition, protein consumption must not exceed fat intake during a LCKD due to the additional glucose which can be produced from an excess of protein ingestion via processes such as gluconeogenesis (36). On a LCKD, glucose is replaced by free fatty acids as the primary source of energy due to a shift from glucose to fat-based metabolism (20).

Several hormonal changes occur on a LCKD with the most prominent including a reduction in the circulating levels of insulin, due to decreased blood glucose levels, with a subsequent increase in circulating glucagon (17). These changes cause the body to break down stored fuels such as liver glycogen into glucose, proteins into amino acids, and triglycerides in fat cells into free fatty acids (FFA) and glycerol, which are then released into the blood stream and used for energy (20). If liver glycogen is depleted without regeneration and the rate of mobilization of fatty acids from adipose tissues is accelerated, ketone body formation, or ketogenesis occurs (17).

Ketogenesis results from high levels of circulating FFA which cause the liver to take up these fatty acids at a rate that exceeds its ability to oxidize acetyl CoA. This results in the liver converting acetyl CoA into the water-soluble ketone bodies acetoacetate (AcAC), 3-β-hydroxybutyrate (3HB), and acetone (36). The liver cannot utilize ketone bodies because it lacks the enzyme succinyl CoA synthase; therefore, these ketone bodies are transported to peripheral tissues where they can be converted back to acetyl CoA and utilized in the TCA cycle for energy (4). Because FFA cannot pass the blood-brain barrier and the central nervous system (CNS) cannot use fat as an energy source (27), the oxidation of ketone bodies is an important fuel source for the brain and allows for the sparing of blood glucose (17). Furthermore, because of the metabolic effects of ketosis, in particular the high chemical potential of 3HB which allows for an increase in ATP hydrolysis, ketone bodies are able to produce more energy compared with glucose (27).

The levels of acetoacetate and 3HB in the blood of a person following a normal diet generally range from 0.2 to 0.5 mmol/L; whereas, someone following a LCKD can produce up to 7 or 8 mmol/L allowing for the sufficient use of ketone bodies for energy (27, 36). By comparison, ketone levels that reach higher than 25 mmol/L are characterized by a pathological state known as ketoacidosis. This metabolic, non-adaptive state is often confused with that of dietary or physiological ketosis seen in a LCKD. Uncontrolled ketoacidosis occurs in Type I diabetics when there is a combination of insulin deficiency and lowered blood pH levels that can lead to an overwhelming of the body's buffering capacity, resulting in metabolic acidosis and potentially death (4); however, during a LCKD, the regulated and controlled production of ketone bodies allows blood pH to remain buffered within normal limits making it impossible to reach those levels associated with ketoacidosis and therefore confirming the safety associated with a LCKD (17). In addition, because of the reduced inflammation and other benefits associated with dietary ketosis, it has shown to play an important role in the prevention and treatment of cardiovascular disease, Type 2 diabetes, and metabolic syndrome (40).

Benefits of a Ketogenic Diet

According to recently published research, one in three Americans are obese with a body mass index (BMI) of ≥ 30 kg/m2 while nearly three of four individuals currently have a BMI of 25 kg/m2 or greater (5, 40). Over the past few decades, the average daily energy intake of Americans has increased by about 200 kilocalories with most of this increase coming from dietary carbohydrate with a decline in fat intake. This epidemic may stem from the introduction of low-fat diet trends about thirty years ago (40). In contrast, other weight loss diets have emerged throughout this time, including the popular Atkins Diet which emphasizes a low-carbohydrate approach similar to that of a LCKD (43). Recent literature has compared the effects of a low-fat diet with a low-carbohydrate diet on weight loss, body composition improvements, and overall health benefits.

A randomized, controlled trial was conducted to compare the effects of a low-carbohydrate, ketogenic diet program versus a low-fat, low-cholesterol reduced calorie diet on 120 overweight, hyperlipidemia volunteers. Subjects were randomly assigned to either a low-carbohydrate diet which consisted of less than 20 grams of carbohydrate daily or a low-fat diet consisting of less than 30% of energy from fat and less than 300 mg of cholesterol daily. After 24 weeks, participants in the low-carbohydrate group showed significantly greater improvements in weight loss, fat loss, serum triglyceride levels, and high-density lipoprotein cholesterol levels. In addition, a greater proportion of participants in the low-carbohydrate diet group completed the study in contrast with those in the low-fat diet group. Results from this study illustrate that a low-carbohydrate diet program shows greater improvements in body weight, body composition, fasting serum lipid levels, and diet tolerability when compared to a low-fat diet program (46).

Similar studies assessing the effectiveness of a low fat versus low-carbohydrate diet have been published in the literature (21, 33, 42, 44, 46). A randomized, crossover study compared the effects of an isocaloric, energy-restricted LCKD compared to a low-fat diet on weight loss, body composition, trunk fat mass, and resting energy expenditure (REE) in 28 overweight/obese men and women. Results indicated a distinct advantage of a LCKD over a low-fat diet for weight loss, total fat loss, and trunk fat loss. Although absolute REE decreased with both groups, REE expressed relative to body mass was better maintained on the LCKD (42). Furthermore, a 2006 meta-analysis demonstrated that low-carbohydrate diets without any imposed energy restrictions appear to be more effective compared to low fat energy restricted diets for weight loss (21).

In addition, further research has been conducted to show the effects of a LCKD on appetite suppression, hormone concentration, and long-term weight maintenance. Current literature suggests that when a ketogenic state is reached and maintained, circulating concentrations of appetite-regulating hormones such as leptin, ghrelin, cholecystokinin (CCK), amylin, and peptide YY, are altered (6, 37). Although other factors cannot be ruled out, the alteration of these hormones as a result of ketosis appears to contribute to the success of a LCKD. Many benefits of following a low-carbohydrate ketogenic diet, including successful long-term weight loss and maintenance have been extensively outlined in the literature (6, 14, 19, 24-26, 32, 39, 42). Additionally, the AHA/ACC/TOS Guidelines for the Management of Overweight and Obesity in Adults lists a low-carbohydrate diet as one of the 15 dietary approaches that is effective for weight loss (15). To further understand the practical application of a LCKD in everyday life, it is important to examine the influence it may have on the exercise and performance of active individuals.

Ketogenic Diet and Endurance Performance

Although there are many benefits to following a LCKD, there has been much controversy surrounding its relationship to exercise performance. This controversy stems from the adverse effects that have been associated with following a ketogenic diet. These may include headache, constipation, muscle cramps, diarrhea, general weakness, electrolyte disturbances, dehydration, bad breath, and loss of lean body mass (36). It is important to note, however, that these adverse effects are usually associated with a lack of keto-adaptation (30).

In order to fully adapt and benefit from a LCKD, this type of diet must be sustained for more than just a few weeks (30, 36, 41). For example, one study illustrated that the desire to maintain sustained exercise might be adversely impacted in people following a ketogenic diet for weight loss; (45) however, this study only lasted for a period of 2 weeks, which does not allow enough time to become adequately keto-adapted. In addition to help combat the adverse effects associated with a ketogenic diet, keto-adaptation permits an apparent benefit to exercise by allowing a steady supply of energy to the brain in the form of ketones (41).

While the literature surrounding the effects of a ketogenic diet on performance is not extensive, some studies have assessed the relationship of a ketogenic diet on endurance performance. For example, two studies were conducted to determine the effects of a ketogenic diet on aerobic performance, body composition, and lipid profiles (3, 47). The first study consisted of 19 apparently healthy adults who were randomly assigned to follow either a low-carbohydrate diet or the current USDA guidelines for Americans which include consumption of 45-65% carbohydrates, 10-35% protein, and 20-35% fat (38). All participants were instructed to engage in 30 minutes of brisk walking at 55-65% of their maximal heart rate on three non-consecutive days per week for seven weeks. Results indicate that those following the low-carbohydrate diet showed significant decreases in body mass, fat mass, percentage body fat, blood triglyceride levels, and caloric consumption compared to the USDA guidelines group. In addition, both groups completed all exercise sessions with no adverse effects reported by either group (3). Although the aerobic exercise was not substantial in this study, it is important to note the potential positive effects of combining moderate-intensity walking with a low-carbohydrate diet for the promotion of health to offset the current obesity epidemic.

Another study compared the effects of a long-term ketogenic diet on exercise metabolism and physical performance in eight male off-road cyclists. This crossover design consisted of a three-day testing phase that was preceded by either 4 weeks of a ketogenic diet or a standard Western diet. Performance was measured via a cycloergometer test to determine maximal oxygen uptake (VO_2max) and the level of lactate threshold (LT VO_2) following each diet protocol. Results showed a favorable change in body mass, body composition, and lipid and lipoprotein profiles with a significant increase in relative values of VO_2max and LT VO_2 after the ketogenic diet phase. Furthermore, lower rest and exercise plasma creatine kinase and lactate dehydrogenase activity was observed during the ketogenic diet phase which may contribute to reduced post exercise muscle damage. Therefore, it is suggested that long-term ketogenic diets may be favorable for aerobic endurance athletes based on reduced body mass and fat content as well as decreased post exercise muscle damage (47).

Ketogenic Diet and Resistance Performance

In addition to the effects of a LCKD on endurance performance, there have been few studies addressing its effects on resistance exercise; however, some studies have explored the potential use of a LCKD in sports that include weight class divisions. In one study, Paoli et al investigated the influence of a LCKD versus a standard Western diet (WD) on explosive strength performance in elite artistic gymnasts over a 30-day crossover period with a three-month washout phase (25). Results showed a significant decrease in body weight and fat mass during the LCKD phase with no meaningful differences in strength tests between the two phases. This data suggested that following a LCKD can lead to weight loss and improved body composition without negatively affecting strength and power performance (25).

A similar study investigated the effects of a ketogenic diet on weight loss, body composition, and performance related-physical fitness factors in 20 high school Taekwondo athletes (32). Subjects were randomly assigned to a LCKD group and a non-ketogenic diet (NKD) group for a three-week period. Although all body composition measurements improved over the three-week period, there were no significant differences between groups; however, the LCKD group finished a 2000-meter sprint in less time compared to the NKD group and also reported feeling less fatigue compared to before the diet intervention. In addition, there were no differences in strength tests between the two groups. These results support the use of a LCKD for weight category athletes and suggest the potential for a LCKD in improving aerobic and fatigue resistance capacity (32).

In addition to the use of a LCKD for weight category athletes, one study examined the combination of a LCKD with resistance exercise on 18 untrained overweight women trying to lose weight and reduce body fat. These women were randomly assigned to either a ketogenic diet group or a regular diet group with a combination of 10 weeks of resistance training, two times per week for each group. Results illustrate that the ketogenic diet group lost a significant amount of fat mass with no change in lean body mass (LBM) while the regular diet group gained LBM with no significant change in fat mass (14). Based on these studies, it is clear that when combining a LCKD with resistance exercise, positive body composition outcomes can occur without compromising lean body mass or performance.

With the overwhelming increase in obesity and metabolic disease throughout the United States, many Americans are searching for the best diet and exercise program that promotes fat loss and increases overall quality of life. In addition, CrossFit is a relatively new training method and further research is warranted to determine physiological and performance training benefits. Therefore, the purpose of this study is to examine the effects that a LCKD has on body composition and performance in CrossFit participants ages 18 to 60 years old. It can be hypothesized that a LCKD can be a successful fat loss and weight loss strategy for CrossFit participants while maintaining or improving performance. Limitations of this study include potential for the inability to recruit a large sample size, lack of full adherence to the diet and exercise protocols, lack of control in activity outside of the study, and the short intervention period of six weeks. Despite these limitations we believe this study provides valuable insight into the use of a ketogenic diet combined with CrossFit training to improve body mass and body composition outcomes.

Chapter II: Methodology

Experimental Approach to the Problem

This randomized controlled study investigates the effects of a 6-week low-carbohydrate ketogenic diet (LCKD) on CrossFit members' ages 21-56 years old. Subjects will be randomly assigned to follow either a LCKD or maintain normal dietary intake (CON) while participating in four CrossFit workouts per week for 6 weeks. Body composition using a dual x-ray absorptiometry (DXA) scan and performance testing using benchmark CrossFit testing will be used to assess baseline measurements for all subjects. Diet adherence will be evaluated through urinary ketone measurements, weekly dietary compliance checklists, and Food Intake Records (FIR). Training compliance will be monitored through mandatory check in procedures at the CrossFit gym. After completion of the study, all subjects will be assessed using the same pre-test measurements.

Subjects

Subjects will be male and female members of Rocktown CrossFit & Sports Performance located in Harrisonburg, VA. Inclusion criteria will be the following: between 18 and 60 years old and an active member of CrossFit for at least one month prior to the start of recruitment. Pending IRB approval, subject recruitment will begin in June 2015 and last until August 2015. Subjects will be recruited via the Rocktown CrossFit Facebook page and a message will be posted to all Facebook "friends" outlining the purpose as well as a description of the study. In addition, a recruitment email with the details of the study will be sent via the Rocktown CrossFit website page which is linked to all members' email addresses (Appendix A). Personal recruitment will also take place at the gym throughout this period. Persons interested in participating will be screened to see if they meet the minimum criteria for entrance into the study.

Subjects with current injuries or health conditions that affect CrossFit performance or put them at risk for further injuries such as diagnosis of cardiovascular disease will be excluded from the study. Additionally, subjects taking any performance enhancing supplements (i.e., creatine, HMB, caffeine, protein powder, weight gainer, thermogenics, etc.), will be required to discontinue consumption at least 7 days prior to baseline testing and continue for the remainder of the study.

Procedures

Baseline Testing

Once informed consent is obtained, subjects will be randomly assigned to either the CON or a LCKD intervention group for this 6-week, randomized controlled trial. Data collection during the baseline and post-intervention week will include a CrossFit performance test, a power performance test and clinical and anthropometric data. The CrossFit performance and power tests (Appendix B) will be conducted at the Rocktown CrossFit gym, while the clinical and anthropometric data will be obtained in a private setting in the Health Sciences Human Assessment Lab.

CrossFit Performance Test

The CrossFit performance test will consist of a 500-meter row, 40 body weight squats, 30 abdominal mat sit-ups, 20 hand release pushups, and 10 pull-ups. Subjects will engage in a warm up and dynamic/static stretch before the baseline testing begins and a cool down at the conclusion of testing. Prior to the CrossFit workout, an explosive power test consisting of a vertical jump test and a standing long jump test will be assessed. The

CrossFit workout will be recorded for time (sec.), and the explosive power test will be recorded in inches. A detailed description of the performance tests is provided in Appendix B. Subjects were asked to not train for at least 24 hours prior to testing.

Clinical and Anthropometric Data

Body weight and height measurements will be taken with minimal clothes, no shoes, and measured to the nearest 0.5 kg or 0.5 cm using a calibrated balance scale and stadiometer (Detecto, Webb City, MI). A trained researcher will take these measurements in duplicate and take the average of the two. These measurements will be used to calculate body mass index (kg/m2). Dual x-ray absorptiometry (DXA) scan will be used for the assessment of body composition and include fat mass (FM), lean mass (LBM), and percent body fat (%BF). The DXA assessment will take place using GE Healthcare DXA. Subjects will be asked to lie on their back, positioned on the machine according to protocol. They will be asked to lie completely still, while breathing normally, and closing their eyes while the scan is in progress. The whole body scan will last approximately 6 minutes.

In addition, each subject will be required to submit a 50 ml urine sample to assess baseline ketone levels. Urinary ketones will be tested every week to check compliance and subjects will be instructed to provide a urine sample at the Rocktown CrossFit gym that will be kept in a cooler and then refrigerated and tested within 24 hours. Ketone assessment will be made by a Siemens CLINITEK Status+ Analyzer. The height/weight measurements, DXA scan, and urine assessment will take place in a private setting in the Health Sciences Human Assessment Lab at James Madison University.

Diet Protocol

Subjects will have a mandatory dietary instruction session prior to the beginning of the study that will provide detailed instructions on accurately keeping dietary food intake records (FIR). All subjects will be required to provide a three-day food intake record (two weekdays and one weekend) every two weeks during the study. All food records will be inputted and analyzed using the Nutrition Data System for Research (Minneapolis, MN). Dietary records will be assessed for quality assurance. An example FIR is provided in Appendix C. The CON will maintain its usual dietary intake throughout the study. The LCKD group will be instructed to consume an ad libitum diet while restricting carbohydrate intake to no more than 50 grams per day (<10% of energy) in order to induce and maintain ketosis. The LCKD group will be given a detailed guide on acceptable low-carbohydrate foods as well as a recommended list of nutritious fat and protein rich foods. A list of these foods is provided in Appendix D. In addition, subjects will be given a 6-week low-carbohydrate meal plan but will be advised to use this meal plan as a guide rather than a strict protocol. An example of one week of the 6-week meal plan is provided in Appendix E.

Training Protocol

Each subject will be required to participate in four CrossFit training sessions per week at the Rocktown CrossFit gym. Each workout will be posted on the Rocktown CrossFit website the night before training. Although workouts change daily, they consist of four main components: warm up, dynamic and static stretch, strength, and the "Workout of the Day" (WOD). A three-day Rocktown CrossFit sample workout is provided in Appendix F. After each workout, member's names and respective workout times will be recorded by the CrossFit coach and saved to assure each individual attends four classes per week. Subjects will be prohibited from engaging in any other excessive physical activity during the 6-week study.

Post-Intervention Testing

Data collection procedures will be the same as baseline testing procedures. Results from all tests will be compared to the individual's baseline values.

Statistical Analysis

All statistical analysis will be performed using SPSS version 23 (SPSS, Inc. Chicago, IL, USA). All data are presented as mean ± SD. Significance will be set a priori with an alpha of 0.05. A one-way multivariate analysis of variance (MANOVA) will be performed on all dependent variables in Table 2 for identifying differences between and within groups at baseline. MANOVA is used to look at the relationship between one categorical independent variable and more than one quantitative dependent variable (12).

To examine statistical differences between and within groups, change scores will be computed for each dependent variable (post minus pre-study value) and two one-way MANOVAs will be used to compare body composition and performance variables between the LCKD group and the CON. The independent variable will be the 6-week low-carbohydrate ketogenic diet. For the first MANOVA, the dependent variables will be measures of body composition (body fat %, weight, BMI, lean body mass, and fat mass). For the second MANOVA, the dependent variables will be measures of performance (total performance time) and power (vertical jump and standing long jump). Additionally, Pearson correlation tests will be used to evaluate the relationships between the different dependent variables.

Furthermore, to assess the change in total performance time, vertical jump, and standing long jump from pre to post testing for both groups combined, one sample t-tests will be performed. Additionally, to assess the components of power together from pre to post testing for both groups combined, a multivariate Hoteling T Test will be used since there is a correlation between the power variables. In addition, four separate MANOVAs will be used to examine statistical differences between groups for dietary analysis of total kilocalories, carbohydrate, fat, and protein intake at baseline, week two, week four, and week six of the study.

Chapter III: Manuscript

Abstract

A low-carbohydrate ketogenic diet (LCKD) is a popular approach to weight and fat loss. CrossFit is a high-intensity power training (HIPT) type exercise for all levels of age and fitness that has gained recognition as one of the fasting growing sports in America. No previous research has been found which examines body composition changes or performance in individuals consuming a LCKD and participating in CrossFit training. **PURPOSE**: The purpose of this research was to examine the effects of a 6-week LCKD and CrossFit program on body composition and performance. **METHODS:** Twenty-seven non-elite CrossFit subjects (mean ± SD age = 34.58 ± 9.26 years) were randomly assigned to a LCKD (males, n = 3; females, n = 9) or control (CON) (males, n = 2; females, n = 13) group. LCKD was instructed to consume an ad libitum diet and restrict carbohydrate intake to less than 50 grams per day (<10% of total energy) and CON maintained usual dietary intake. Diet adherence was evaluated through weekly urinary ketone measurements, dietary compliance checklists, and bimonthly Food Intake Records. All subjects participated in four CrossFit training sessions per week during the 6 weeks. Training compliance was monitored through mandatory check-in procedures at the CrossFit gym. Body composition was measured by dual x-ray absorptiometry and performance testing was measured by benchmark CrossFit protocols. **RESULTS:** Compared to the CON group, the LCKD group significantly decreased weight (0.18 ± 1.30, -3.45 ± 2.18 kg), BMI (0.07 ± 0.43, -1.13 ± 0.70 kg/m^2), percent body fat (%BF) (0.01 ± 1.21, -2.60 ± 2.14 %), and fat mass (FM) (0.06 ± 1.12, -2.83 ± 1.77 kg), respectively. There was no significant difference in lean body mass (LBM) change between or within groups. We found no significant difference in total performance time change between the CON group and the LCKD group; however, both groups significantly decreased total performance time (CON: -41.20 ± 43.17 sec.; LCKD: -55.08 ± 44.29 sec.). Additionally, there were no significant differences in vertical jump and standing long jump change between or within groups. For both groups, the overall change in vertical jump was significant (2.31 ± 4.55 cm) but the change in standing long jump was not. Carbohydrate intake was significantly lower (11.4 ± 5.6%, 40.06 ± 6.81%) and fat intake was significantly higher (62.88 ± 4.19%, 38.38 ± 4.18%) in LCKD at weeks 2, 4, and 6 compared to CON, respectively. There was no statistical difference in total kilocalories or protein intake between or within groups throughout the study. **CONCLUSION:** A LCKD combined with 6 weeks of CrossFit training can lead to significant decreases in %BF, FM, weight, and BMI while maintaining LBM. Additionally, significant improvements in total performance time and power can be achieved. **PRACTICAL APPLICATION:** With the overwhelming increase in obesity and metabolic disease throughout the United States many Americans are searching for the most effective diet and exercise program which promotes fat loss and increases overall quality of life. This study provides valuable insight into the use of a LCKD combined with CrossFit training for 6 weeks to improve body composition and performance outcomes.

Introduction

The prevalence of obesity has increased throughout the United States with one in three Americans categorized as obese (30). Fewer than a quarter of Americans who attempt to lose weight actually follow current recommendations of increasing exercise and reducing caloric intake (33). Those who attempt losing weight through regular aerobic training by using a treadmill or elliptical often get bored and lose motivation very quickly, leading to decreased exercise adherence (21). An exercise program that has grown in popularity over the past few years as an alternative to traditional endurance and resistance training is known as CrossFit (1, 5, 21).

CrossFit was introduced in 2001 by its founder Greg Glassman and is considered "one of the fastest growing sports in America" with over 13,000 gyms worldwide (10, 21). CrossFit is a high-intensity power training (HIPT) type exercise that consists of a combination of gymnastics, plyometrics, functional movements, anaerobic intervals, weightlifting, sprinting, and Olympic lifting (7, 26). These constantly varied exercises, which are combined into the "Workout of the Day" (WOD) (7), allow for training in all three human energy systems: the creatine phosphate (CP) system, anaerobic glycolysis, and oxidative phosphorylation (1) and can be adapted for all levels of age and fitness (6).

The majority of CrossFit participants include men and women ranging from 19-60 years old looking to improve all aspects of health and fitness with a desire to lose weight and increase performance (7). A popular approach to weight loss that has gained recognition in recent years is the low-carbohydrate ketogenic diet (LCKD). This diet is classified by a decrease in carbohydrates with a subsequent increase in proportions of dietary fat and protein (19). The reduction in carbohydrates, usually below 50 grams per day, allows a shift from glucose to fat-based metabolism (13) which produces water-soluble ketone bodies known as acetoacetate (AcAC), 3-β-hydroxybutyrate (3HB) and acetone (27). Ketone body formation, also known as ketogenesis (11), has been shown to aid in the treatment of several diseases such as refractory pediatric epilepsy, cardiovascular disease, Type 2 diabetes, and obesity (19, 27). In addition, ketogenic diets are recognized as one of the more effective treatments for improvements in body weight, body composition, fasting serum lipid levels, and diet tolerability, especially when compared to low-fat diets (15, 25, 31-33).

Although there are many benefits to following a LCKD, there has been much controversy surrounding its relationship to exercise performance. While there is a paucity of literature, some studies have reported favorable outcomes in body weight and body fat reductions when following a LCKD and adhering to either an endurance or resistance type training protocol (2, 9, 17, 22, 34). To date, there have been no published investigations supporting changes in body composition or performance in response to a HIPT type exercise program such as CrossFit, while adhering to a LCKD. The purpose of this study is to determine if consuming a six-week LCKD and participating in a CrossFit training regimen yields significant improvements in body composition while maintaining or increasing performance. Specifically, we hypothesized that a LCKD would be a successful fat loss and weight loss strategy for CrossFit participants while maintaining or improving performance. Our second hypothesis was that those participating in CrossFit training while adhering to their usual dietary intakes would show significant increases in performance with minimal decreases in body mass or body fat content.

Methods

Experimental Approach to the Problem

The institutional review board at James Madison University approved the present study and all subjects gave written informed consent prior to participating. This randomized controlled study investigated the effects of a 6-week low-carbohydrate ketogenic diet (LCKD) on CrossFit members' ages 21-56 years old. Subjects were randomly assigned to follow either a LCKD or maintain normal dietary intake (CON) while participating in four CrossFit workouts per week for 6 weeks. Body composition using a dual x-ray absorptiometry (DXA) scan and performance testing using benchmark CrossFit testing was used to assess baseline measurements for all subjects. Diet adherence was evaluated through urinary ketone measurements and biweekly Food Intake Records (FIR). Training compliance was monitored through mandatory check-in procedures at the CrossFit gym. After completion of the study, all subjects were assessed using the same pre-test measurements.

Subjects

Subjects were male and female of all levels of fitness, recruited from and trained at a CrossFit affiliate (Rocktown CrossFit & Sports Performance, Harrisonburg, VA). Inclusion criteria were the following: between 18 and 60 years old and an active member of CrossFit for at least one month prior to the start of recruitment. Subject recruitment began in June 2015 and lasted until August 2015. Subjects were recruited via the Rocktown CrossFit Facebook page, and a message was posted to all Facebook "friends" outlining the purpose as well as a description of the study. In addition, a recruitment email with the details of the study was sent via the Rocktown CrossFit website page which is linked to all members' email addresses. Personal recruitment also took place at the gym throughout this period. Persons interested in participating were screened to see if they met the minimum criteria for entrance into the study. Subjects with current injuries or health conditions that might have affected CrossFit performance or put them at risk for further injuries such as diagnosis of cardiovascular disease were excluded from the study. Additionally, subjects taking any performance enhancing supplements (i.e., creatine, HMB, caffeine, protein powder, weight gainer, thermogenics, etc.), were required to discontinue consumption at least 7 days prior to baseline testing and continue for the remainder of the study.

Procedures

Baseline Testing

Once informed consent was obtained, subjects were randomly assigned to either the CON or a LCKD intervention group for this 6-week, randomized controlled trial. Data collection during the baseline and post-intervention week included a CrossFit performance test, a power performance test and clinical and anthropometric data. The CrossFit performance and power tests were conducted at the Rocktown CrossFit gym, while clinical and anthropometric data were obtained in a private setting in the Health Sciences Human Assessment Lab. (Figure 1)

CrossFit Performance Test

The CrossFit performance test consisted of a 500-meter row, 40 body weight squats, 30 abdominal mat sit-ups, 20 hand release pushups, and 10 pull-ups. Each subject had a single researcher to record time splits and provide encouragement. Subjects engaged in a warm up and dynamic/static stretch before the baseline testing began, and a cool down at the conclusion of testing. Prior to the CrossFit workout, an explosive power test consisting of a vertical jump test and a standing long jump test were assessed. The CrossFit workout was recorded for time (sec.), and the explosive power test was recorded in inches. Subjects were asked to not train for at least 24 hours prior to testing.

Clinical and Anthropometric Data

Body weight and height measurements were taken with minimal clothes, no shoes, and measured to the nearest 0.5 kg or 0.5 cm using a calibrated balance scale and stadiometer (Detecto, Webb City, MI). A trained researcher took these measurements in duplicate and took the average of the two. These measurements were used to calculate body mass index (kg/m2). Dual x-ray absorptiometry (DXA) scan was used for the assessment of body composition and included fat mass (FM), lean mass (LBM), and percent body fat (%BF). The DXA assessment took place using GE Healthcare DXA.

In addition, each subject was required to submit a 50 ml urine sample to assess baseline ketone levels. Urinary ketones were tested every week to check compliance and subjects were instructed to provide a urine sample at the Rocktown CrossFit gym that was kept in a cooler and then refrigerated and tested within 24 hours. Ketone assessment was made by a Siemens CLINITEK Status+ Analyzer. The height/weight measurements, DXA scan, and urine assessment took place in a private setting in the Health Sciences Human Assessment Lab at James Madison University.

Diet Protocol

Subjects had a mandatory dietary instruction session prior to the beginning of the study which provided detailed instructions on accurately keeping dietary food intake records (FIR). All subjects were required to provide a three-day food intake record (two weekdays and one weekend) every two weeks during the study. All food record data were entered and analyzed using the Nutrition Data System for Research (Minneapolis, MN). Dietary records were assessed for quality assurance. The CON maintained its usual dietary intake throughout the study. The LCKD group was instructed to consume an ad libitum diet while restricting carbohydrate intake to no more than 50 grams per day (<10% of energy) in order to induce and maintain ketosis. The LCKD group was given a detailed guide on acceptable low-carbohydrate foods as well as a recommended list of nutritious fat and protein rich foods. In addition, subjects were given a 6-week low-carbohydrate meal plan but were advised to use this meal plan as a guide rather than a strict protocol.

Training Protocol

Each subject was required to participate in four CrossFit training sessions per week at the Rocktown CrossFit gym. Each workout was posted on the Rocktown CrossFit website the night before training. Although workouts changed daily, they generally consisted of four main components: warm up, dynamic and static stretch, strength, and the "Workout of the Day" (WOD) (Table 1). After each workout, member's names and respective workout times were recorded by the CrossFit coach and saved to assure each individual attended four classes per week. Subjects were prohibited from engaging in any other excessive physical activity during the 6-week study.

Post-Intervention Testing

Data collection procedures were the same as baseline testing procedures. To ensure reliability, power measures and performance testing were completed by the same researcher as baseline for each subject. Results from all tests were compared to the individual's baseline values.

Statistical Analysis

All statistical analysis was performed using SPSS version 23 (SPSS, Inc. Chicago, IL, USA). All data are presented as mean ± SD. Significance was set a priori with an alpha of 0.05. A one-way multivariate analysis of variance (MANOVA) was performed on all dependent variables in Table 2 for identifying differences between and within groups at baseline. MANOVA is used to look at the relationship between one categorical independent variable and more than one quantitative dependent variable (8).

To examine statistical differences between and within groups, change scores were computed for each dependent variable (post minus pre-study value) and two one-way MANOVAs were used to compare body composition and performance variables between the LCKD group and the CON. The independent variable was the 6-week low-carbohydrate ketogenic diet. For the first MANOVA, the dependent variables were measures of body composition (body fat %, weight, BMI, lean body mass, and fat mass). Change in BF% and FM was skewed slightly, potentially due to two outliers (one in the CON group and one in the LCKD group); however, when eliminating these two outliers from the model, it improved even more, yielding a smaller p value. We included the two outliers in final analysis. For the second MANOVA, the dependent variables were measures of performance (total performance time) and power (vertical jump and standing long jump). Additionally, Pearson correlation tests were used to evaluate the relationships between the different dependent variables.

Furthermore, to assess the change in total performance time, vertical jump, and standing long jump from pre to post testing for both groups combined, one sample t-tests were performed. Additionally, to assess the components of power together from pre to post testing for both groups combined, a multivariate Hoteling T Test was used since there was a correlation between the power variables. In addition, four separate MANOVAs were used to examine statistical differences between groups for dietary analysis of total kilocalories, carbohydrate, fat, and protein intake at baseline, week two, week four, and week six of the study.

Results

Thirty-one subjects were recruited for the study, and 27 completed baseline and post testing. Of the four subjects that withdrew, three were for family/personal reasons and one withdrew due to injury. Descriptive characteristics of all subjects are presented in Table 2. There were no significant ($P<0.05$) differences between groups for age, body mass, fat mass, lean body mass, BMI, %body fat, performance, or power measures at baseline. Compliance for nutritional intervention and weekly workouts was confirmed through daily workout logs, weekly urinary ketone assessments, and bi-weekly food records.

Body Composition

Changes in body composition after the 6-week intervention are presented in Table 3. The LCKD group significantly decreased weight, BMI, %BF, and FM compared to the CON group. There was no significant difference in LBM change between or within groups. There were no significant changes in any body composition variables in the CON group. In general, for all body composition variables (excluding lean body mass) there was a downward trend in the LCKD group versus the CON group. (Figure 2)

Performance

We found no significant difference in total performance time change between the CON group and the LCKD group; however, both groups significantly decreased total performance time (Table 3). Pearson correlation tests showed a significant correlation ($r = 0.48$; $P < 0.01$) between vertical and standing long jump variables, but no significant correlations between these two variables and total performance time. Additionally, there were no significant differences in vertical jump and standing long jump change between or within groups. For both groups, the overall change in vertical jump was significant (2.31 ± 4.55 cm) but the change in standing long jump was not; however, when looking at vertical jump and standing long jump power together, the change from pre to post testing was significant ($P < 0.042$). As a whole, all subjects participated in an average of 4 days of CrossFit training per week during the 6-week study.

Dietary Intake

Analysis of the food intake records revealed no significant group differences in total kilocalories, carbohydrate, protein, or fat intake at baseline. Carbohydrate intake was significantly lower and fat intake was significantly higher in the LCKD group at weeks 2, 4, and 6 compared to the CON group (Table 4, 5). Mean carbohydrate (%) intake in the LCKD group was 11.4 ± 5.6 compared to 40.06 ± 6.81 in the control group. Mean fat (%) intake in the LCKD group was 62.88 ± 4.19 compared to 38.38 ± 4.18 in the control group. There were no statistical differences in total kilocalories or protein intake between or within groups throughout the study. Additionally, there were no significant changes in dietary macronutrient intake in the CON group from baseline and throughout the study.

All subjects were 100% compliant turning in FIR and submitting weekly urine samples throughout the study. In the LCKD group, 6 subjects tested 100%, four at least 50%, and two less than 50% in ketosis during urine ketone measurements throughout the study. Ketone measurements for the CON group showed that no subjects reached ketosis during the study.

Discussion

The aim of the current study was to examine the effects of a 6-week LCKD and CrossFit training on body composition and performance. The present study revealed that adhering to a LCKD during 6-weeks of CrossFit training results in significant decreases in weight, BMI, %BF, and FM compared with an ad libitum diet while maintaining LBM. Additionally, all subjects significantly improved total CrossFit performance time and overall power. To our knowledge, the present study is the first that has assessed the use of a LCKD combined with CrossFit training to evaluate body composition and performance outcomes.

The use of a LCKD to improve body composition measures has been a topic of interest for many years. There have been numerous studies comparing the weight loss effects of following a LCKD versus a low-fat diet, showing far superior results in the former (15, 25, 31-33). Additionally, a recent meta-analysis showed that subjects had significantly greater long-term reductions in body weight following a LCKD as opposed to a low-fat diet (3). Specifically, Volek et al. found that greater weight and fat loss was achieved with no significant loss of LBM when following a LCKD versus a low-fat diet

(31). Similarly, in the present study, the LCKD group lost an average of 3.5 kg in weight, 2.6% BF, and 2.83 kg of FM while maintaining LBM. Additionally, Moreno et al. compared the effects of following a LCKD versus a standard-low calorie diet in 53 otherwise healthy obese men and women. Similar to the present study, results from Moreno's study concluded that a LCKD diet was significantly more effective in inducing weight loss and fat loss without affecting LBM, compared to a standard low-calorie diet. Moreover, at one-year follow up, 88% of the subjects in the LCKD maintained the weight and fat loss compared to 34.6% of patients in the low-calorie group (12); however, it is worth noting that the present study evaluated normal weight, physical active adults, whereas the two aforementioned studies evaluated otherwise healthy overweight/obese men and women.

There were no statistical differences in total kilocalories or protein intake between or within groups throughout our study; however, while no statistical difference was found, it is important to note that the LCKD group consumed a lower average energy intake (1580.66 ± 283.37) per day compared to the CON group (1746.73 ± 485.45) even when encouraged to eat ad libitum. This small but non significant reduction in energy intake may be due to several factors, including the higher satiety value of protein and fat, effects on appetite-related hormones such as ghrelin, and/or the possible direct appetite-blocking effect of ketone bodies (20, 28, 29). Accordingly, a recent meta-analysis revealed that individuals are significantly less hungry and have a reduced desire to eat when adhering to a LCKD (4).

Individuals in the LCKD group were encouraged and given sample food choices/meal plans to replace carbohydrate intake with high quality proteins and fats.

Additionally, when consuming carbohydrates, they were advised to focus on limiting them to green vegetables, nuts/seeds, and full fat dairy. In accordance with the present study, Paoli and colleagues investigated the effects of a modified ketogenic diet based on green vegetables, olive oil, fish, and other high quality proteins with results showing significant weight and fat loss, reductions in waist circumference, improvements in cardiovascular risk markers, and good overall compliance with diet protocol over a period of 12 months (16, 18).

Several hormonal changes occur on a LCKD with the most prominent including a reduction in the circulating levels of insulin, due to decreased blood glucose levels, with a subsequent increase in circulating glucagon (11). This reduction in insulin levels facilitates the mobilization of FFA from fat stores and it has been proposed that the use of these FFA in combination with ketone bodies spares muscle protein and is thus anti-catabolic (17). The LCKD group in the present study was able to maintain LBM while also increasing performance. These findings are consistent with the aforementioned studies in which LBM was maintained while following a LCKD. Furthermore, Volek et al. examined body composition and hormonal changes in 12 normal, healthy weight men following a 6-week LCKD and found significant decreases in weight, %BF, and FM with a subsequent increase in LBM (29). According to research, LBM is generally conserved during a ketotic state due to the use of ketone bodies and FFA for energy that slows muscle protein catabolism; however, the processes behind this mechanism are not well understood but it is hypothesized that the “sparing effect” of using FFA as an energy source might play a role. Additionally, the relative increase of amino acid uptake in the diet has a distinguished protein synthesis effect via the mTOR signaling pathway, which has also been proposed to be a key reason for the conservation of LBM when following a LCKD (20, 23).

Despite the significant reduction in carbohydrate intake and slight decrease in caloric intake, the LCKD group was able to adhere to CrossFit training at least 4 times per week with no adverse side effects reported. Additionally, there were no significant differences in performance or power outcomes between the LCKD and CON group after 6 weeks of CrossFit training. While the literature surrounding the effects of following a ketogenic diet and adhering to a specific exercise program is not extensive, some studies have shown positive outcomes (2, 9, 17, 24). For example, Jabekk et al. studied the effect of 10 weeks of resistance training in combination with either a regular diet or an ad libitum LCKD in overweight women. Results from their study showed that the LCKD group lost 5.6 ± 2.9 kg of fat mass with no significant change in LBM and the regular diet group gained 1.6 ± 1.8 kg of LBM with no significant change in fat mass (9).

Similar to our study, Sawyer et al. examined the effects of switching from a habitual diet to a LCKD on strength and power performance in 31 trained men and women ages 18 to 30. Results from their study showed a significant decrease in body mass with no decrement in strength and power performance as measured by handgrip dynamometry, vertical jump, 1 rep maximum bench press and back squat, maximum repetition bench press, and a 20 second Wingate anaerobic cycling test (24); however, subjects in their study were assessed after following a LCKD for only 7 days, whereas the subjects in our study adhered to the diet for 6 weeks. Furthermore, a study investigating the influence of a LCKD on explosive strength performance in elite artistic gymnasts showed a significant decrease in body weight and fat mass over a 30-day period with no negative changes in strength and power performance (17).

Over the past few years CrossFit training has become very popular as a community based, competitive exercise program for the average person looking to get in shape and lose weight. CrossFit exercises are designed to stress each metabolic system by combining various exercise movements, intensities, resistance, repetitions, sets, and rest periods in a HIPT type session (1). During the current study, significant improvements in total performance time and power were observed in both groups after 6 weeks of CrossFit training. Although the literature surrounding the benefits of CrossFit is scarce, this study supports existing evidence that HIPT training can yield both anaerobic and aerobic improvements (26, 35).

In accordance with our findings, Beilke et al. demonstrated that a 4-week CrossFit training program significantly improved aerobic capacity, sports performance, and muscle endurance and strength in 21 healthy adults ages 19 to 25 years old (1). Similarly, Smith et al. determined that a 10-week CrossFit-based HIPT program significantly improved maximal aerobic capacity and body composition in individuals of varying fitness levels and gender (26). Furthermore, a recent study showed that 3-months of CrossFit training led to increases in VO_2max, improvements in anaerobic capacity and reduction in % BF in women with increases in LBM in all subjects (14).

Strengths of the present study include the randomized control study design, the 100% compliance of all subjects to attend the prescribed number of CrossFit sessions each week, and the small dropout rate with only one due to a non-severe injury. Limitations of the present study include the lack of control in physical activity outside of the CrossFit training sessions as well as the short intervention period of six weeks; however, the 6-week period is significantly longer compared to previous studies of only 7 days (24) or 4 weeks (1). Additionally, because the same performance test was evaluated during pre and post testing, it is possible that a learning curve may have influenced the results. Furthermore, although all subjects were compliant with turning in their bimonthly 3-day food records, it is hard to assess the complete validity of these records due to the possible measurement error associated with self reported dietary assessment tools.

Practical Application

To our knowledge, no research on the body composition and performance benefits of following a LCKD combined with CrossFit training has been conducted. With the current obesity epidemic stemming our nation, Americans are constantly searching for the most effective diet protocol to induce weight and fat loss. Additionally, the constantly varied and competitive nature of CrossFit training has made it a popular exercise regimen for all levels of age and fitness. Our data suggests that adhering to a LCKD can lead to weight loss and improved body composition outcomes without negatively affecting LBM, strength, or power performance.

Furthermore, these results could be useful for weight category athletes, such as powerlifters, boxers, or wrestlers, seeking to lose a significant amount of body fat without compromising performance. Future research should be directed to the long term physiological adaptations which occur with a LCKD and CrossFit training, as well as the hormonal and psychological changes that may also transpire.

Table 1: Sample CrossFit Workout	
Strength	Back Squats: 1x3@60% 1x3@70% 1x3@75% 1x2@80% 1x2@85% 1x2@80%
WOD	3 Rounds for Time: 500m Row 10 Overhead Squats (Rx: Men -155 lb.) (Rx: Women -105 lb.)
WOD = Workout of the Day Rx = Prescribed weight for workout	

Table 2: Baseline Characteristics of Subjects participating in a 6-week CrossFit Program

	Control (n=16)	LCKD[a] (n=15)	Total (n=31)
Age (yr.)	33.81 ± 9.33	35.40 ± 9.43	34.58 ± 9.26
Height (cm)	167.60 ± 9.82	170.51 ± 9.12	169.01 ± 9.44
Weight (kg)	74.32 ± 14.58	74.79 ± 12.93	74.55 ± 13.58
BMI (kg/m^2)	26.21 ± 2.96	25.60 ± 2.86	25.91 ± 2.88
Body Fat (%)	30.86 ± 7.27	33.45 ± 7.82	32.11 ± 7.53
Lean Mass (kg)	49.17 ± 10.94	47.69 ± 10.26	48.46 ± 10.46
Fat Mass (kg)	22.16 ± 7.18	24.03 ± 6.88	23.06 ± 6.98
Total Performance Time (sec)	401.75 ± 75.12	414.93 ± 73.06	408.13 ± 73.19
Vertical Jump (cm)	43.26 ± 14.73	42.62 ± 11.18	42.93 ± 12.9
Standing Long Jump (cm)	210.97 ± 34.98	209.42 ± 28.65	210.24 ± 31.55

[a] Low Carbohydrate Ketogenic Diet (LCKD)
Values are means ± SD. No between group differences identified.

Table 3. Changes in Body Composition & Performance for Subjects participating in a 6-week CrossFit Program.

	Control (n=15)			LCKD[a] (n=12)		
	Pre	**Post**	**Chg**	**Pre**	**Post**	**Chg**
Body Composition						
Weight (kg)	72.44 ±12.93	72.62 ± 12.95	0.18 ± 1.30	76.63 ± 13.76	73.18 ± 12.51	-3.45 ± 2.18[b]
BMI (kg/m^2)	25.89 ± 2.77	25.97 ± 2.89	0.07 ± 0.43	25.98 ± 2.94	24.86 ± 2.6	-1.13 ± 0.70[b]
% Body Fat (%)	30.85 ± 7.52	30.86 ± 7.72	0.01 ± 1.21	34.0 ± 7.38	31.4 ± 9.12	-2.60 ± 2.14[b]
Fat Mass (kg)	21.59 ± 7.05	21.65 ± 7.30	0.06 ± 1.12	24.9 ± 6.49	22.08 ± 7.26	-2.83 ± 1.77[b]
Lean Mass (kg)	47.87 ± 9.97	47.96 ± 9.96	0.09 ± 0.84	48.64 ± 11.20	48.27 ± 11.04	-0.37 ± 1.27
Performance						
Total Performance (sec.)	404.00 ± 77.20	362.80 ± 43.27	-41.20 ± 43.17[c]	412.00 ± 78.34	356.92 ± 56.91	-55.08 ± 44.29[c]

Values are means ± SD.
[a] Low Carbohydrate Ketogenic Diet (LCKD)
[b] Significant between group difference ($P<0.001$)
[c] Significant within group difference ($P<0.001$)

Table 4: Macronutrient Intake for Subjects participating in a 6-week CrossFit Program.

	Control (n=15)				LCKD[a] (n=12)			
	Pre	**Wk2**	**Wk4**	**Wk6**	**Pre**	**Wk2**	**Wk4**	**Wk6**
Carbohydrate (g)	214.67 ± 101.17	195.77 ± 109.66	172.23 ± 69.79	193.56 ± 102.76	203.45 ± 90.59	37.80 ± 10.13 [c]	41.52 ± 19.15 [c]	53.91 ± 31.15 [c]
Fat(g)	80.81 ± 25.68	78.11 ± 21.11	67.44 ± 20.35	74.87 ± 22.64	88.01 ± 26.84	135.60 ± 25.19 [b]	109.62 ± 36.25 [b]	98.40 ± 27.82 [b]
Protein (g)	81.60 ± 26.76	86.19 ± 25.30	74.90 ± 17.72	80.27 ± 27.60	78.38 ± 16.42	103.84 ± 20.10	83.32 ± 22.15	87.40 ± 23.85
Kilocalories (g)	1834.43 ± 555.60	1835.87 ± 691.91	1600.29 ± 462.70	1804.03 ± 655.75	1891.46 ± 550.94	1786.13 ± 287.37	1485.84 ± 362.04	1470.00 ± 327.74

Values are means ± SD.
[a] Low Carbohydrate Ketogenic Diet (LCKD)
[b] Significant between group difference (P<0.05)
[c] Significant between group difference (P<0.001)

Table 5: Average Bi-weekly Macronutrient Intake for Subjects participating in a 6-week CrossFit Program		
	Control (n=15)	**LCKD[a] (n=12)**
Carb (g)[c]	187.19 ± 68.01	44.42 ± 16.46
Fat (g)[b]	73.47 ± 18.86	114.54 ± 25.23
Protein (g)	80.45 ± 18.61	91.52 ± 17.34
Kilocalorie (g)	1746.73 ± 485.45	1580.66 ± 283.37

Values are means ± SD.
[a] Low Carbohydrate Ketogenic Diet (LCKD)
[b] Significant between group difference (P<0.05)
[c] Significant between group difference (P<0.001)

Figure 1: Flow diagram of the progress through the phases of the CrossFit Study.

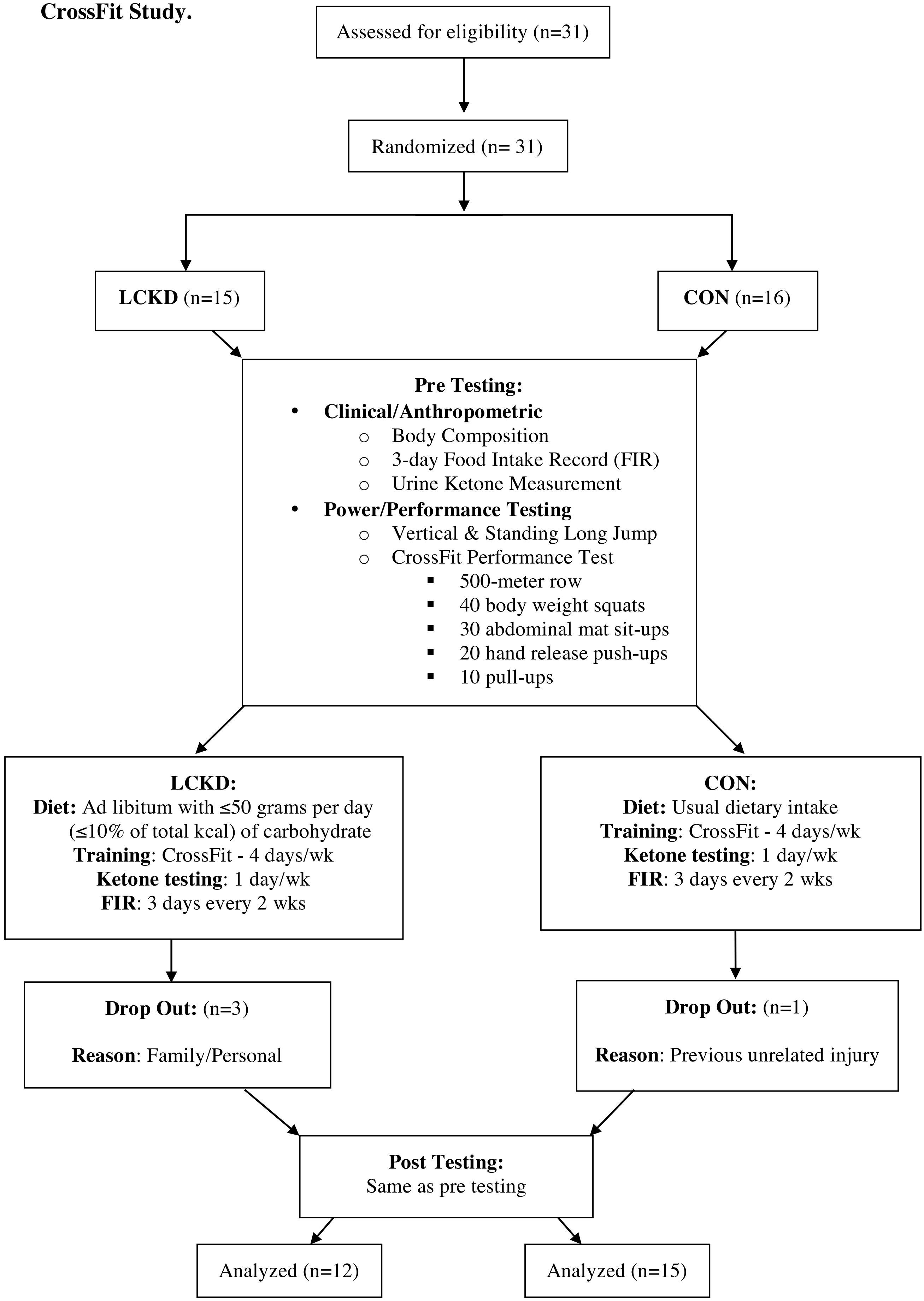
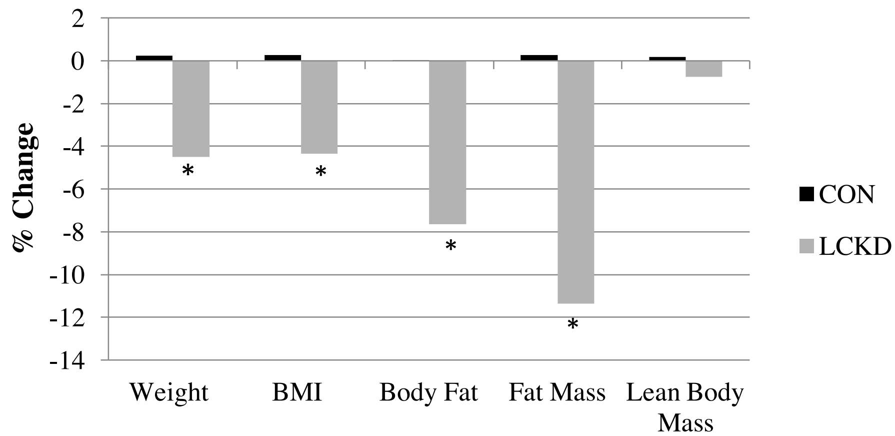


Figure 2: Changes in Body Composition for Subjects participating in a 6-week CrossFit Program



*Significant between group difference (P<0.001)

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Appendix A

Sample Recruitment Letter

Dear members of Rocktown CrossFit & Sports Performance,

Are you ready to lose that stubborn body fat, improve mental focus, and increase your overall health? Do you want FREE nutrition consultation and a personalized diet plan? Do you want FREE body composition analysis and testing?

My name is Rachel Gregory and I am a graduate student at James Madison University in the Health Sciences Department. I am conducting a research study on the effect of a dietary intervention on body composition and performance and am looking for CrossFit members to participate. Details of the study can be found below. If interested in participating, please contact me via email, Facebook message, or telephone.

Contact Information:
Name: Rachel Gregory
Email: gregorrm@dukes.jmu.edu
Phone: 917-848-1192

Who: Rocktown CrossFit members between the ages of 18-45 years who currently engage in CrossFit classes 3-5x a week.

What: Participation includes 6 weeks of FREE nutrition consultation, tests to measure body fat and composition, and a FREE personalized diet plan and dietary analysis.

When: September-October 2015

Thank you,

Rachel Gregory

Appendix B

Performance Testing Protocol

Warm up
- 250-meter row
- 10 body weight squats
- 7 hand release push-ups

Dynamic Stretch (all stretches performed walking 10 yards while alternating legs)
- Knee hugs
- Quad pulls
- Figure 4s
- Inch worms
- Walking Samson hip flexor stretch
- Lateral lunges

Static Stretch
- Quad stretch on wall using ab mat (hold 30 sec. each side)
- Arm on wall, 90-degree stretch (both sides) (2x30 secs.)
- Facing wall, both hands shoulder with apart, bend knees and hold stretch (2x30 sec.)
- Pigeon stretch on ground (30 sec. each leg)

Vertical Jump Test
- This test will be done using a wall mounted vertical jump test apparatus that is located in the Rocktown CrossFit gym. Subjects will stand with their dominant side facing the wall, slightly away from apparatus. While wearing shoes, subjects will perform a vertical jump using both legs and dominant arm. Subjects will have three attempts to hit the highest mark on the apparatus and the best of the three attempts will be recorded.

Standing Long Jump Test
- This test will be performed on the main floor of the Rocktown CrossFit gym. A piece of white tape will be placed across the floor with visible measurements in inches using a standard tape measure. While wearing shoes, subjects will stand at a beginning marker and will be instructed to squat down slightly and perform a standing long jump landing on both feet. The best out of three attempts will be recorded.

CrossFit workout for time (min./sec.)
- 500-meter row
    - The 500-meter row will take place using the standard rowing machines provided at the Rocktown CrossFit gym. Each subject will be seated on the rower with his or her feet strapped into the machine. Subjects will

begin to row for 500 meters and once completed, will immediately transition to body weight squats.

- 40 body weight squats
    - The subjects will be advised to perform the body weight squats with their feet lined up in the same way as if they were going to perform back or front squats (i.e., feet shoulder width apart, toes pointed slightly outward). Subjects will be informed to squat just below parallel while keeping arms and hands locked out directly in front of them.
- 30 ab mat sit-ups
    - The Rocktown CrossFit gym will provide ab mats and subjects will be instructed to perform 30 ab mat sit-ups with their legs in a triangular position and soles of feet touching. Subjects will be informed to perform a complete sit-up making sure to touch hands to ground in between legs each rep.
- 20 hand release pushups
    - Hand release pushups will be performed with hands shoulder with apart, legs together, and toes point toward the floor. Subjects will be informed to completely release hands from floor on each rep while maintaining a straight back on the way up.
- 10 pull-ups
    - Each subject will perform strict overhand grip pull-ups on the rig. No swinging or kipping motions will be allowed. Subjects who cannot perform strict pull-ups will use their respective pull-up band. Pull-up bands are color-coded based on resistance provided by each band. Subjects will have performed pull-ups prior to testing and will already have a preferred band resistance chosen. This same band will be used during post-testing.

Cool Down

- 200-meter row
- 10 body weight squats

All post-test measurements performed in the same exact way as the above pre-test measurements

Appendix C

Sample Food Intake Record

Meal (breakfast, lunch, dinner, snack)	**Time**	**Meal Location (restaurant, home, work, etc.)**	**Name of Food Item or Beverage (provide as much detail as possible, *one food item per line)***	**Amount consumed (cups, tsp., Tbsp., ounces, etc.)**

Appendix D

Recommended Foods

Fats

- Almonds
- Almond butter
- Almond milk, unsweetened
- Almond oil
- Avocado
- Avocado oil
- Beef tallow
- Blue cheese
- Brazil nuts
- Butter (Kerrygold is a high-quality brand)
- Cheese (cheddar, Colby, feta, mozzarella, provolone, ricotta, Swiss, and others)
- Chia seeds
- Chicken fat
- Coconut
- Coconut cream
- Coconut milk, unsweetened
- Coconut oil
- Cream cheese
- Dark chocolate (80 percent or higher)
- Fish oil
- Ghee
- Greek yogurt (full fat: in moderation)
- Heavy whipping cream
- Macadamia nut oil
- Macadamia nuts
- Mayonnaise (no added sugar)
- Olive oil
- Pecans
- Pistachios
- Sour cream
- Sunflower seeds
- Walnuts

Proteins

- Bacon (not turkey bacon)
- Beef jerky (watch out for added sugars)
- Beef ribs
- Beef roast
- Bratwurst
- Chicken (choose darkest cuts, skin on)
- Duck
- Eggs (whole)
- Fish (salmon, bass, carp, flounder, halibut, mackerel, sardines, trout)
- Ground beef (not lean)
- Goose
- Ham
- Hot dog
- Kielbasa
- Pepperoni
- Pheasant
- Pork chops
- Pork ribs
- Pork rinds
- Pork roast
- Quail
- Salami
- Sausage
- Shellfish (scallops, shrimp, crab, meat, mussels, oysters)
- Steak (the fattier the better)
- Tuna
- Turkey (darker pieces are best)
- Veal

Carbohydrates (in moderation)

- Arugula
- Asparagus
- Bok choy
- Broccoli
- Brussel Sprouts
- Cabbage
- Cauliflower
- Celery
- Chicory greens
- Cucumbers
- Eggplant
- Garlic
- Green beans
- Jicama
- Kale
- Leeks
- Lemon
- Lettuce
- Lime
- Mushrooms
- Okra
- Parsley
- Peppers
- Pumpkin
- Radicchio
- Radishes
- Rhubarb
- Scallions
- Shallots
- Snow peas
- Spaghetti squash
- Spinach
- Strawberries
- Summer squash
- Tomatoes
- Watercress
- Wax beans
- Zucchini

Appendix E

1-Week Sample Ketogenic Meal Plan

All recipes can be found at http://www.ibreatheimhungry.com/menu-plans-new

Day 1
Breakfast
4-inch square, Sausage & Spinach Frittata
Coffee with 2 Tbsp. Heavy Cream
Snack
1/2 avocado w/ lite salt and pepper
Lunch
1/2 cup Simple Egg Salad
Romaine Lettuce Leaves (4)
2 slices cooked bacon
Snack
24 raw almonds
Dinner
6 oz. Rotisserie Chicken
3/4-cup Easy Cauliflower Gratin
2 cups chopped romaine lettuce
2 Tbsp. Caesar Salad Dressing (sugar free)
Dessert
2 squares Lindt 90% Chocolate

Day 2
Breakfast
4-inch square, Sausage & Spinach Frittata
Coffee with 2 Tbsp. Heavy Cream
Snack
5 sticks of celery with 2 Tbsp. Almond Butter
Lunch
2 cups chopped romaine lettuce
2 Tbsp. Caesar Salad Dressing (sugar free)
1 cup chopped leftover chicken
Snack
1/2 avocado w/ lite salt and pepper
Dinner
1 Italian sausage link, cooked and sliced
1 cup cooked broccoli
1 Tbsp. butter
2 Tbsp. grated Parmesan cheese
Dessert
2 squares Lindt 90% Chocolate

Day 3
Breakfast
2 Cream Cheese Pancakes
2 pcs cooked bacon
Coffee with 2 Tbsp. Heavy Cream
Snack
2 String Cheese
Lunch
1 Italian sausage link, cooked and sliced
3/4-cup Easy Cauliflower Gratin
Snack
1-cup bone broth
Dinner
1 1/2-cup Chili Spaghetti Squash Casserole
2 cups raw baby spinach
1 Tbsp. ranch dressing (sugar free)
Dessert
2 squares Lindt 90% Chocolate

Day 4
Breakfast
4-inch square, Sausage & Spinach Frittata
Coffee with 2 Tbsp. Heavy Cream
Snack
1/2 avocado w/ lite salt and pepper
Lunch
1 1/2-cup Chili Spaghetti Squash Casserole
Snack
1-cup bone broth
Dinner
1/2 cup "Anti" Pasta Salad
4 Sundried Tomato & Feta Meatballs
2 cups raw baby spinach
1 Tbsp. Italian dressing (sugar free)
Dessert
2 squares Lindt 90% Chocolate (105 calories, 9g fat, 3g net carbs, 3g protein)

Day 5
Breakfast
2 Cream Cheese Pancakes
2 pcs cooked bacon
Coffee with 2 Tbsp. Heavy Cream
Snack
1-cup bone broth
Lunch
1/2 cup "Anti" Pasta Salad

4 Sundried Tomato & Feta Meatballs
Snack
5 sticks of celery with 2 Tbsp. Almond Butter
Dinner
1 cup Cuban Pot Roast (taco salad style)
2 cups chopped romaine lettuce
2 Tbsp. sour cream
1 Tbsp. chopped cilantro (optional)
1/4 cup shredded cheddar cheese
Dessert
2 squares Lindt 90% Chocolate

Day 6
Breakfast
3 eggs (scrambled or fried)
1 tsp. butter
2 pcs cooked bacon
Coffee with 2 Tbsp. Heavy Cream
Snack
24 raw almonds
Lunch
1 cup Cuban Pot Roast (taco salad style)
2 cups chopped romaine lettuce
2 Tbsp. sour cream
1 Tbsp. chopped cilantro (optional)
1/4 cup shredded cheddar cheese
Snack
1-cup bone broth
Dinner
1 1/2-cup Chili Spaghetti Squash Casserole
2 cups raw baby spinach
1 Tbsp. ranch dressing (sugar free)
Dessert
2 squares Lindt 90% Chocolate

Day 7
Breakfast
2 Cream Cheese Pancakes
2 pcs cooked bacon
Coffee with 2 Tbsp. Heavy Cream
Snack
2 String Cheese
Lunch
1/2 cup "Anti" Pasta Salad
4 Sundried Tomato & Feta Meatballs
Snack
1-cup bone broth
Dinner
1 cup Cuban Pot Roast (taco salad style)
2 cups chopped romaine lettuce
2 Tbsp. sour cream
1 Tbsp. chopped cilantro (optional)
1/4 cup shredded cheddar cheese
Dessert
2 squares Lindt 90% Chocolate

Appendix F

3-Day Sample CrossFit Workout

Day 1

Warm up

- 200-meter run
- 10 back squats (empty barbell)
- 5 toes to bar

Dynamic Stretch (all stretches performed alternating legs and walking 10 yards)

- Knee hugs
- Quad pulls
- Figure 4s
- Inch worms
- Cross & touch (both directions)
- Lateral lunges

Static Stretch

- Quad stretch on wall using ab mat (hold 30 sec. each side)
- "Paleo Chair" stretch on wall (hold 1 minute)
- Arm on wall, 90-degree stretch (both sides) (2x30 secs.)
- Facing wall, both hands shoulder with apart, bend knees and hold stretch (2x30 sec.)
- Sleeper stretch on floor (5 sec. hold, 3x each arm)

Strength

- Front Squat 10×3 @ 85%

Workout

- 9-7-5
    - Squat Snatch (power + overhead squat permitted)
    - Barbell Burpees
    - Toes to Bar (Scaled: 2:1 knee tucks)

Day 2

Warm up

- 200-meter row
- 10 power cleans (empty barbell)
- 10 push press (empty barbell)
- 10 body weight squats

Dynamic & Static Stretch (generally the same each day, may vary slightly)

Strength

- 10min to work up to a Heavy Clean & Jerk

-then-

- 3×2 @ 80%

Workout

- 3 Rounds for Time
    - 9 Deadlifts
    - 7 Hang Snatch
    - 5 Overhead Squats

Day 3

Warm up

- 10 calorie row
- 15 box jumps
- 10 hand release push ups
- 5 pull-ups

Dynamic & Static Stretch (generally the same each day; may vary slightly)

Strength

- 5×5-10 Strict Pull-up/Chest2Bar
- 3×10 Dips

For Advanced: with remaining time practice stringing pull-ups to chest to bar together…or chest to bar to muscleups

Workout

For Time

- 50 Calorie Row
- 40 Box Jumps
- 30 Handstand Pushups (Scaled: Kneeling box push-ups)

Appendix G

6-week CrossFit Training Program

Week #1						
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Strength		Front Squats 1x3@60% 1x3@70% 1x3@75% 1x2@80% 1x2@85% 1x2@80% OR 5x100m Sled Push & 3xMax Effort Rope Climbs	6x2 Split Jerks (with a 3 second hold in the split) OR 6x1 Full Snatch (with a 2 second pause at the knee) OR 6x1 Snatch Balance (with a 3 second pause in the bottom)		Back Squats 1x3@60% 1x3@70% 1x3@75% 1x2@80% 1x2@85% 1x2@80%	
WOD	Every 3 minutes for 6 Rounds: 6 Push Jerk (165/115) 12 Box Jumps 200m Run !Cash Out! 6min Tabata Odd-Hollow Hold Even-Side Planks	15-12-9-6-3 Thrusters (95/65) *30 Double Unders (2:1) after each set*	10 min AMRAP: 15 Barbell Burpees 7 Power Snatch (135/95)	For Time: 20 Front Squats (135/95) 20 Strict Handstand Pushups (35lb plates) 20 Toes to Bar (30 knee tucks) 15 KB Swings (2/1.5) 15 Hang Cleans (135/95) 15 Chest to Bar Pull-ups 1 Mile Run 10 Muscle Ups (20 dips) 20 Shoulder to Overhead (135/95) 30 Abmat Situps	3 Rounds: 500m Row 10 Overhead Squats (155/105)	With a Partner: 800m Run 4 Rounds of “DT” (relay style) 1000m Row (one person working at a time) 4 Rounds of “DT” (relay style) 800m Run DT = 12 Deadlifts, 9 Hang Cleans, 6 Shoulder to Overhead (155/105)

Week #2						
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Strength		3 Front Squats + 1 Split Jerk: Heaviest Possible (minimum 5 sets)	Every Minute on the Minute for 10 Minutes: 5 Barbell Burpees + 1 Full Snatch @ +75%		Back Squats 1x3@70% 1x3@75% 1x2@85% 1x2@90% 1x2@80%	
WOD	Hotshots 19: Six rounds for time of: 30 Squats Power cleans, 19 reps 7 Strict Pull-ups Run 400 meters	For Time: 25 Burpee Box Jumps 50 Wall Balls 25 Box Jumps	5 Rounds: 200m Run 40 Double Unders (2:1) 10 Handstand Pushups	15 min AMRAP: 30 Calorie Row 15 Toes to Bar 5 Shoulder to Overhead (185/125)	“Amanda” 9-7-5 Muscle Ups Squat Snatch (135/95)	With a Partner: 300 Double Unders (600 singles) 50 Squat Cleans 1 Mile Run

Week #3						
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Strength	Find a heavy of the following complex…minimum 5 attempts: 1 Hang Snatch + 2 Overhead Squats	Find a 3 Rep Max Front Squat OR 14 Minutes of: 200m Run 2 Rope Climbs			Back Squats 1×5@50%, 1×5@60%, 1×5@65%, 1×5@70%, 1×5@75% OR 6x2 Split Jerks	
WOD	10 Minutes: 1 Power Snatch (135/95) 2 Barbell Burpees *__30 Double Unders each round__*(2:1) -Each round add 1 snatch and 2 burpees…Ex. 1&2, 2&4, 3&6, 4&8, 5&10, etc. Score is total reps of Snatch and Burpees Combined.	8 min AMRAP: 3 handstand push-ups (35lb plates), 3 cleans 6 handstand push-ups,3 cleans 9 handstand push-ups,3 cleans 12 handstand push-ups,6 cleans 15 handstand push-ups,6 cleans 18 handstand push-ups,6 cleans 21 handstand push-ups, 9 cleans Etc., *Adding 3 reps to the handstand push-up each round and 3 reps to the clean every 3 rounds. Men clean 185 lb. Women clean 125 lb.	As Many Pull-ups as Possible in: 20 min Every time you drop from the bar = 400m Run !Cash Out! 9 Minutes Tabata Style L Hold on the Rig Plank Russian Twist	For Time: 1000m Row 20 Alternating Front Rack Lunges (135/95) 40 Alternating Pistols 20 Alternating Front Rack Lunges (135/95) 1000m Row	12!: Push Press (115/75) KB Swings (1.5/1)	In Teams of 3: 42-30-18 Toes to Bar (knee tucks 1:1) Partner Deadlifts Rx:315, Scaled:275 *2 people must hold the deadlift while one person is doing toes to bar…if the bar drops the toes to bar must stop. Rotate as many times as you would like. Once the 42 toes to bar are done 2 people will do the deadlifts, the other person rests. Again, you may rotate as many times as you would like on the deadlift.

Week #4						
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Strength		Front Squats 1×5@50%, 1×5@60%, 1×5@65%, 1×5@70%, 1×5@75%			Find a 3 Rep Max Back Squat	
WOD	6 Rounds: Every 2 minutes complete the following: 100m Run 6 Deadlifts (Athlete Picks the Load) 12 Toes to Bar (1:1 Knee Tucks) -Then- 2-minute rest into 10 minutes to find a max Clean and Jerk	5 Rounds: 18 Wall Balls 6 Power Snatch (135/95)	20 min EMOM: Odd Minute – 12 Burpees Even Minute- 1 Round of Cindy (5 pull-ups, 10 pushups, 15 Squats) !Cashout! 2 Mile Run	20 min AMRAP: 7 Handstand Pushups 14 Thrusters (75/55) 21 Calorie Row 28 Abmat Situps	12 min AMRAP: 5 Power Cleans (155/105) 25 Double Unders (50 Singles)	16 Minutes: 1 Mile Run -then- 3-3-6-6-9-9-12-12-15-15-etc Front Squats (135/95) Barbell Burpees

Week #5						
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Strength	Find a heavy of the following Complex: 1 Squat Clean + 1 Front Squat + 1 Jerk	Gymnastics: 3x10 Handstand Pushups (strict, deficit, paralette, handstand holds, etc.) 3x20 Hollow Rock 3x10 Dips	5x1 Snatch Balance 5x1 Hang Snatch		Find a 1 Rep Max Front Squat	
WOD	3 Rounds for Time: 10 Toes to Bar 10 Shoulder to Overhead (135/95) 400m Run	100 Calorie Row *Every Minute on the Minute 7 KB Swings (1.5/1)	10! Chest to Bar Pull-ups (scaled: regular pull-ups) Front Rack Lunges (135/95)	Athlete of the Month Workout: 100 Double Unders (2:1) 20 wall balls 10 deadlift (225/155) 250 m row 50 push-ups 10 deadlifts 250 m row 50 kb swings (1.5/1) 10 deadlifts 250 m row 50 Abmat sit-ups 10 deadlifts 250 m row 50 air squats 10 deadlifts 250 m row 20 wall balls 100 Double Unders	7 min AMRAP: 5 Muscle Ups (scaled 10 dips) 10 Overhead Squats (135/95)	5 Rounds: 3min on, 1 min off 200m Run 15 Wall Balls Max Burpee Box Jumps with remaining time *score is total box jumps

Week #6						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Strength		Find a 1 Rep Max Snatch			Find a 1 Rep Max Back Squat	
WOD	9-6-3 Power Clean (205/15) Front Squat Shoulder to Overhead *Coaches Note: designed to be heavy. No strength so they can get plenty of warm-up. !Cashout! 1 or 2 Mile Run or Row (NOT for time)	4 Rounds for Time: 50 Double Unders (100 singles) 10 Handstand Pushups 5 Power Snatch (165/115)	18 min AMRAP: 3 Squat Cleans (225/155) 6 Barbell Burpees 400m Run !Partner Cashout! 3x10 Barbell Rollouts 3x20 Hollow Rocks	20 min AMRAP: 10 Toes to Bar (15 Knee Tucks) 15 Wall Ball 20 Calorie Row	8 min AMRAP: 7 Pull-ups 7 Box Jump Overs 7 KB Swings	**The Rocktown Rack Rescue 3.0** With your favorite person: 100 Calorie Row 100 Box Jumps (Scaled-Step Ups) 100 Thrusters (45/35) 100 Kettlebell Swings (1.5/1) 100 Wall balls (20/14) 100 Burpees *Only 1 person may work at a time*

AMRAP = as many rounds as possible; **EMOM** = every minute on the minute; **Double-Unders** = two jump rope passes per jump; **HSPU** = hand stand push-ups; **KB** = kettlebell; Percentages listed as relative to subjects' 1-repetition maximum.

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