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Effects of a low-carbohydrate ketogenic diet on power lifting performance and body composition

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Effects of a Low-Carbohydrate Ketogenic Diet on Power Lifting Performance and Body Composition

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Abstract

The aim of the present study is to investigate whether a low-carbohydrate ketogenic diet (LCKD) is an effective strategy to decrease overall weight and fat mass, and preserve lean body mass (LBM) without compromising performance in trained, power-lifters. This was a six-week randomized controlled trial, with a LCKD intervention group and a normal diet control group (CON). The LCKD group was instructed to consume a diet with less than 7% carbohydrates, 50% fat, and 45% protein. Those in the CON group maintained an ad libitum diet. Both groups completed the same validated training protocol during the intervention. The CON had significant increases ($p < 0.05$) in one-repetition maximums for bench press, back squat, and deadlift, while the LCKD had a significant increase in deadlift ($p = 0.000$), with maintenance of both bench press and back squat performance. There were no changes in body composition measures. The main findings of the current study were that deadlift power increased, and LBM was maintained while consuming a LCKD and following a power-lifting training protocol for six weeks. Because of poor subject compliance, results of this study are inconclusive as to whether a LCKD can be used as an effective strategy for power-lifters whose aim is to lose body weight and fat mass while maintaining performance during a six week power-lifting training regimen.

Chapter 1: Introduction/ Review of Literature

Ketogenic diets have resurfaced in the last decade as a means to combat the rising obesity epidemic. The popularity of the low-carbohydrate diet seems predicated from the rapid weight-loss shown to take place within the first few days or weeks[5]. In addition to the increasing popularity of ketogenic diets for weight-loss among the average weight-conscious consumer, they have recently become a popular trend among competitive athletes as a means of rapid weight loss for performance benefits[5]. Low-carbohydrate ketogenic diets (LCKD) are widely used among sports that are divided into weight class divisions, such as wrestling, boxing, and weight lifting[18,21]. Rapid body weight reduction prior to competition in athletes who compete in specific weight categories can be an appropriate and vital tool for performance success. For example, it is common practice among competitive weight lifters to train at a body mass that is 5-10% higher than their competition weight class, and then try to lose one to two kg before competition to make the weight class at which they want to compete[25]. The power lifter's perceived ideal weight can be achieved through many traditional strategies, most of which can be detrimental to the body and performance. Several of the techniques include using extremely low-calorie diets, dehydration, saunas, or diuretics, all of which can impair health, psychological function, water and electrolyte balance, glycogen storage and decrease lean body mass (LBM), and in the case of diuretics, are sometimes illegal in competition[18]. Severe dehydration and a low-residue diet are the more common strategies used by competitive athletes to drop weight, but have also been shown to decrease max force production, muscular endurance, and power [22,25]. Because of the potential dangers that accompany these rapid weight-loss strategies, there is a call for research in order to find a safe method for competitive weight lifters to decrease weight quickly prior to competition while minimizing power and LBM loss.

Low-carbohydrate ketogenic diets (LCKD)

LCKD are a recurring trend that have increased in popularity within the last ten years. A few diets that are well known include *Atkins Diet, Carbohydrate Addict's Diet, Protein Power Diet, Sugar-Busters! Diet,* and *the South Beach Diet*. All of these diets severely restrict carbohydrates (CHO) to induce ketosis, by limiting glucose availability to tissues. Ketone bodies, such as β-hydroxybutyrate (β-OHB), acetone, and acetoacetate, are by-products of partial oxidation of fatty acids in the liver, used to supply the heart and central nervous system with a high metabolic substrate when glucose is not available. The guiding principle behind a LCKD is the fuel shift from CHO to fat stores. The fuel sources during a LCKD are approximately 70% from fatty acids, 20% from ketone bodies, and only 10% from glucose [30]. Westman et al. states that even if virtually no glucose is consumed, the liver and kidneys can make up to 200g/day of glucose from dietary fat and protein alone [30]. LCKD have been shown to increase resting skeletal muscle pyruvate dehydrogenase kinase activity, and decrease active pyruvate dehydrogenase, attenuating CHO oxidation[19]. This metabolic shift results in a reduction of muscle glycogenolysis and CHO oxidation and an increase in utilization of free fatty acids while training on a LCKD[5,10,19]. Other processes causing the same metabolic reactions include increases in oxidative enzymes, mitochondrial density, storage and utilization of intramuscular triglycerides, and muscular uptake of plasma free fatty acids[5,10,19]. It is common misconception that LCKD are detrimental to anaerobic performance because of low muscle glycogen stores [23,30,31], when in actuality intramuscular triglycerides become a sustainable fuel source during short-burst, heavy resistance training[8,10].

Ketone production is essential to protein conservation [17]. When ketone bodies become the primary source of fuel in the body, instead of glucose, protein breakdown decreases because amino acid conversion for gluconeogenesis slows [17]. One specific ketone body, β-OHB, is quickly gaining attention among researchers. Researchers recently examined the metabolism of leucine during an infusion of β-OHB and found that increased levels of β-OHB decreased the oxidation of leucine [17]. Leucine is a branched chain amino acid (BCAA) that interacts with the insulin-signaling pathway to stimulate the making of endogenous proteins[17]. Those same researchers also concluded that infusions of β-OHB enhanced the incorporation of leucine in skeletal muscle protein[17]. Other researchers have concluded that β-OHB assists in preserving LBM [14,28] and reduces proteolysis during a starvation state[28]. Since a LCKD shows similar metabolic changes as starvation (i.e. production of ketone bodies), it can be assumed that a LCKD in combination with excess production of β-OHB will be, if anything, protective against muscle protein catabolism because of the reduction of leucine oxidation and the increase in incorporation of leucine in skeletal muscle protein[14,17,28]. Past research reveals that there is an inverse association between LBM and a reduction in one repetition maximum (1RM) of bench press [22], meaning that if LBM is decreased, 1RM of bench press will decrease as well; therefore, it is vital to preserve LBM prior to power lifting competition because body composition is directly related to performance.

LCKD and exercise

While LCKDs are commonly used by the average consumer for weight-loss, they are recently finding their way into the athletic arena. LCKDs warrant attention from researchers as a means to maintain performance in the face of weight loss, specifically in those sports divided into weight classes. A common assumption with athletes on a LCKD is that with significant weight loss there is a loss of LBM and fat mass (FM); which would have an adverse effect on performance by decreasing power[5]. A few other reported negative effects of a short-term LCKD include dehydration, electrolyte or pH imbalances, headache, gastrointestinal discomfort, hypoglycemia, elevation of blood uric acid levels, metabolic strain on liver and kidney function, and vitamin deficiency; however, biochemical evidence is inconclusive and indicates that a LCKD will lead to impaired nutritional status [2,5]. Proponents of a LCKD suggest that because large amounts of lipids are available as substrate for ATP synthesis, the reliance on the breakdown of muscle glycogen stores is decreased[5]. Other possible benefits for athletes consuming a LCKD are an increases in satiety and fat loss[11,18,28], which may be attributed to higher protein to carbohydrate ratios[9,12,13,24,27,29]. While these positive effects would greatly benefit competitive power lifters trying to decrease body fat in a short amount of time, research testing specifically the influence of LCKDs on sport performance remains poorly investigated overall.

Authors of current literature have examined resistance training, endurance training, or a mix of the two in combination with a short-term LCKD; however, there is a large gap in research on sport-specific resistance training and LCKD. Competitive power-lifting is a unique sport that is growing in popularity. The overall goal of power lifting is to enhance total power relative to body weight. It is common practice for power lifting athletes to train at a much higher weight class than they intend to compete, in hopes of maintaining the LBM gains from the larger weight class and decreasing only FM prior to competition. Current practices of weight loss used by power lifters, such as extremely low-calorie diets, dehydration, and diuretics, are dangerous and can severely affect training and performance. The strategy of extreme calorie restriction for weight-loss among competitive power lifters is considered detrimental to performance because of their effect on the cardiovascular system[26]. Severe caloric restriction can produce myofibrillar damage, orthostatic hypotension, bradycardia, low QRS voltage, QT-interval prolongation, ventricular arrhythmias, and sudden cardiac death[26]; therefore, the most commonly used strategy is deliberate dehydration, which can be achieved via fluid restriction, acute heat exposure, or diuretics— which are banned in most competition settings[25]. In 2001 Schoffstall, et al. showed that dehydration directly decreased 1RM of bench press performance by 5.6% [22]. Rehydration in combination with rest allowed subjects to almost reach initial 1RM for bench press; however, power lifters in this study only decreased body mass by 1.5% with dehydration. Once hypohydration-induced reductions in body mass reach 3-4%, the athlete's ability to overcome dehydration is significantly impaired[25]. If current power lifters are decreasing body mass by 5-10% prior to competition with dehydration, then rehydration may not be as easily achieved, hindering performance. The mechanisms of dehydration that directly affect performance are not fully defined. It has been speculated that dehydration may impair anaerobic metabolism and lactate efflux from muscle to blood, as well as possibly affecting action potential propagation along motorneurons and calcium release from the sarcoplasmic reticulum[22]. In the same study by Schoffstall, et al. concluded that the percent of LBM reflects how an individual will react to dehydration. The 1RM of a subject with a higher percent LBM will be less affected by dehydration because there is a larger water reservoir in LBM[22]. A greater amount of LBM can also elicit better metabolic functioning[26]. More research is needed to find an effective weight-loss strategy for competitive power lifters that will decrease FM, while maintaining LBM and euhydration.

Many studies have looked at the effects of a LCKD on performance, physical appearance, metabolism, hormonal profiles, and psychological effects. Results are mixed in almost every category examined. Issues among studies begin with the subjective definition of a "low-carbohydrate diet"[30]. Westman et al. describes an individualized "threshold effect" where CHO intake is low enough to produce ketones in the urine [30]. In general, CHO restriction should be less than 50g/day or less than 7% of total kilocalories (kcal) from CHO in order to produce ketones and see true metabolic changes [2,30]. Studies that exceed 50g/day may not bring about any changes, and will therefore lead to insufficient results. Another issue purported by Westman et al. is that LCKDs only restrict one macronutrient [30]; fat and protein intake levels are therefore not consistent among LCKD. A variance of different macronutrient intakes prevents any uniformity of LCKD, particularly regarding total energy intake, and makes it difficult to compare results from LCKD and performance research.

Some reviews point out recurring, universal problems with LCKD and exercise studies, including time allowed for keto-adaptation and protein intake[20,30]. Accurate time allotted for keto-adaptation is individualized, but can take anywhere from 2-4 weeks [30]. When considering training status, adaptation has not shown to occur any faster in a trained individual compared to an untrained individual [20]. Also, CHO restriction must be closely monitored. Intermittent CHO restriction can severely affect adaptation, and has shown a decrease in exercise tolerance [20]. Also affecting study results is protein dosage. The main concern among athletes using a LCKD for weight-loss is preserving LBM and maintaining power performance. Ideal protein intake for athletes is 1.2-1.7g/kg per day[20]. Amounts not meeting the requirements will most likely result in muscle degradation, while intake well above the recommended amounts could possibly lead to suppression of ketogenesis [20]. Competitive weightlifters consume on average 1.6-3.2g/kg per day, which is not a large percentage of their total kcals, which typically ranges between 3157-4614kcal/day [25]. The protein intake during a LCKD must be adequate enough to prevent muscle degradation; however, exceeding the recommended protein intakes long-term will lead to protein oxidation and hinder the protein synthesis response[16,23]. As a result of an undefined LCKD, different percentages of kcal from protein, different time-frames for following the LCKD, and type of training tested, authors of current LCKD and exercise research have concluded inconsistent results, including benefitting performance, having no effect on performance, or impairing performance.

Several studies looked solely at physical effects of a LCKD on the body, both during resistance training and absent of any training [11,18,21,28]. Coupling the LCKD with resistance training, Jabekk et al. and Sawyer et al. tested long-term and short-term physical effects, respectively [11,21]. Jabekk revealed that ten weeks of resistance training and a LCKD reduced body fat (-5.6±2.9kg of fat) without decreasing LBM, while resistance training and a regular diet increased LBM (+1.6±1.8kg of LBM) without decreasing body fat in overweight women[11]. Sawyer tested strength and power training combined with a LCKD for one week, and found that power output remained the same, while total body mass decreased in both trained men and women[21]. A six-week study conducted by Volek also suggests a LCKD decreased body fat and increased LBM [28]. Paoli, et al. conducted a 4-week study testing explosive strength performance in elite gymnasts who consumed a ketogenic diet while training[18]. After 30 days, total body mass was decreased (from 69.6±7.3kg to 68.0±7.5kg) with a significant decrease in fat mass (FM) (from 5.3±1.3kg to 3.4±0.8kg, $p<0.001$) and a non-significant increase in LBM[18]. Preservation (or an increase of LBM) can be attributed to a number of factors, including adrenergic stimulation. Low blood sugar brought about by a LCKD stimulates secretion of adrenaline, and skeletal muscles are regulated by adrenergic influences [14]. Another strategy fighting catabolism of the muscle includes the stimulation of growth hormone secretion brought about by low blood sugar [14]. Lastly, dietary protein increases amino acid synthesis by increasing amino acid bioavailability[14]. From these studies that test different time allocations and adequate protein intakes, it can be predicted that a six-week LCKD will result in a loss of FM, and an increase of LBM causing slight increases in performance.

Inconsistencies among designs, methods, dependent and independent variables, and target populations in previous LCKD and exercise studies inhibit any conclusive generalizability to the power-lifting population specifically. The main issue among designs being the difficulty defining a universal LCKD, since other macronutrients and total energy intake can vary among all LCKD[30]. The variability of protein and fat intake can also impede the production of ketones, precluding any true metabolic changes of the LCKD[20]. Two trending dietary issues have been identified in current literature, including time allowed for keto-adaptation and varying intakes of protein and fat intake level[20,30]. Previous researchers have explored many effects of LCKDs on sports performance[11,18,21,28]. By reviewing past studies, a gap in literature can be identified targeting the power lifting population and the effects on anaerobic performance, specifically. This study will focus on expanding current literature by highlighting and testing these issues found in previous studies. This study will be the first, to the authors' knowledge, to test strictly power lifts used in a competition setting— including bench press, back squat, and deadlift. This will also be one of the first studies to use a validated power lifting training protocol shown to increase bench press by 11%, and both back squat and deadlift by 13%, and will take place over six weeks[6]. Current literature indicates that combining a LCKD and resistance training for longer than four weeks will result in the physical effect of a loss of FM and preservation of LBM[11,18,20,28,30]. If results of this study reveal no adverse effects of maintaining a LCKD for six weeks, they could add to the growing body of evidence supportive of power lifters being able to maximize gains while decreasing FM and maintaining LBM.

The aim of the research was to investigate the effectiveness of a LCKD in combination with a six-week power-lifting protocol on decreased FM and body weight and preservation of LBM and power performance on trained, power-lifting college males. We hypothesize that participants will experience a decrease in FM and a preservation in

LBM in combination with an increase in power after six weeks of training and consuming a LCKD. Expected limitations include reporting procedures, as compliance with both the training and diet will be self-reported.

Chapter 2: Methodology

Research Design

This will be a six-week randomized controlled trial, with a LCKD intervention group and a normal diet control group (CON). The LCKD group will be instructed to consume a carbohydrate-restricted, ketogenic diet with less than 7% of total kcals from CHO, approximately 50% of total kcals from fat, and approximately 45% of total kcals from protein. The LCKD will have no overt daily caloric target. The CON will be instructed to maintain their habitual diets without any changes. Both groups will be required to complete the same validated training protocol for the entire six weeks. The independent variables are the diet, and the dependent variables are body composition and power-lifting performance. Baseline measurements of body composition and one repetition maximums (1RM) of bench press, back squat, and deadlift will be compared to post-intervention measurements, and expressed as mean and statistical difference. All methods and procedures will be approved by the University's Institutional Review Board before data collection.

Timeframe

Subject recruitment will begin at the start of the Fall 2014 semester, and will last four weeks. Initial data collection and baseline testing will take place the week following the fourth week of recruitment. The six-week intervention will begin after the baseline testing week. Post intervention testing will immediately follow the sixth week of intervention.

Participants

Participants will be resistance-trained males, ages 18-25. Inclusion criteria includes sufficient experience with resistance training, which will be evaluated through individual assessment of proper lifting technique as outlined by the National Strength and Conditioning Association, and currently engaging in resistance training three to five times per week. Participants with current injuries that affect power lifting performance, and/or health conditions that put them at risk will be excluded. Participants must be free of diagnosed cardiovascular disease and fall into the "low risk" category, as defined by the American College of Sports Medicine[3]. Participants currently taking any medication that affects body composition will be excluded from participating in the study. Additionally, participants currently taking any dietary supplements or nutritional ergogenic aids will need to discontinue consumption seven days prior to baseline testing and abstain for the duration of the study.

Participants will be recruited through University bulk-emails, the University Recreation Center (UREC), and individual recruitment in the General Education health courses. Persons interested in participating will be screened to see if they meet the inclusion criteria for entrance into the study. Participation is entirely voluntary. Participants will be informed that they may withdraw from the study at any time without consequences. If at any time during the study participants experience any major adverse effects (i.e GI distress, severe headaches, or fatigue) they will be advised to inform one of the researchers and add carbohydrates back into their diet. All participants will review and sign an informed consent to be eligible to participate in the study.

Methods and Procedures

This study will be a six-week randomized controlled trial with an intervention group that consumes an ad libitum LCKD and a control group that consumes an ad libitum habitual diet, while both engage in power lifting training. Once informed consent is obtained, participants will be randomly assigned to either the control group or the LCKD intervention group. Testing and training will take place as follows:

Familiarization Session

An informational meeting will be held with each participant to discuss randomization and instructions for following the protocol. All participants will be instructed to refrain from consuming any nutritional ergogenic aids (i.e creatine, pre-workout supplements, no more than 450mg of caffeine a day). The control group will be instructed to continue with their normal diets without changing anything. Participants in the LCKD group will undergo detailed instructions and guidance on how to follow a LCKD prior to the start of the intervention. The LCKD group will be provided low-carbohydrate, two-day sample menus including food that can be found in campus dining halls (Appendix A), a list of high- and low-carbohydrate foods (Appendix D), and a list of protein shakes approved by the researchers that are relatively low in carbohydrates (Appendix B). Both groups will receive instructions on how to properly complete a dietary food intake record (FIR), which will be analyzed via Nutrition Data System for Research software (NDSR, University of Minnesota, MN), and how to complete a provided checklist that assesses if any high-carbohydrate foods were consumed each week (Appendix C). Participants will be instructed on proper form and techniques of all three lifts tested as defined by the International Powerlifting Federation[1] (Appendix E). Both groups will be given instructions on how to properly complete the workout checklists provided, and turn them in each week for investigators to monitor compliance (Appendix F).

Baseline and Post-Intervention Testing

Data collection during the baseline week will include 1RM for all three lifts to assess power, body weight and height measurement, ketone production, and body composition.

Body Composition

Height will be measured without shoes to the nearest 0.5 cm with a stadiometer, and weight will be obtained without shoes using a calibrated balance scale (Detecto, Webb City, MI) and estimated to the nearest 0.1 kg. Height and weight will be used to calculate body mass index (BMI) (kg/m2). A Dual-energy x-ray absorptiometry (DXA) scan using the DXA (General Electric Lunar) will be used to estimate total body fat percentage, FM, and LBM.

Urine Analysis

All subjects will submit a 50ml urine sample to assess baseline β-hydroxybutyrate (β-OHB) levels. These levels will assess the levels of ketones in the urine. Subjects will be instructed to use an alcohol wipe to sanitize the head of the penis prior to urinating, then fill the sample cup to the 50 ml line with urine. Urine samples will be collected at baseline and weeks one, three, and six of the intervention and reported as negative or positive ketone production. Ketone assessment will be made by a Siemens CLINITEK Status+ Analyzer (Siemens Healthcare Global, USA).

Dietary Compliance

Subjects will complete three-day FIRs at baseline and during intervention weeks two and five to assess total kcals and macronutrient intake. The FIRs will be recorded on three consecutive days, including one weekend day. All FIRs will be analyzed using Nutrition Data System for Research software (University of Minnesota, MN).

Power Lifting

All power lifting testing will take place in the UREC weight room facility. The 1RM tests will be conducted with the assistance of a Certified Strength and Conditioning Specialist and recorded by the researchers. The 1-RM testing protocol is reported elsewhere[4] (Figure 1).

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.

Training Protocol

Each participant will be required to participate in four training sessions a week, for six weeks. The training protocol used in this study was previously validated by Crewther, Heke, Keough[6]. Results from the previous study show 11% gains in bench press max, 13% gains in back squat, and 13% gains in deadlift. The validated protocol includes two workouts that are alternated each day (Table 1). Participants are prohibited from following any other structured workouts for the duration of the study. Workout spreadsheets will have calculated weight for each individual for each set of every exercise, and completed weight and repetitions will be filled out by the participants and turned in each week to ensure compliance with training (Appendix F). There will also be supervised training sessions offered to participants throughout the week with the researchers, or a Certified Strength and Conditioning Specialist. Participants will be instructed to attend at least one supervised session every week.

Diet Protocol

The LCKD itself will be composed of less than 7% of total kcals from carbohydrates, approximately 50% of total kcals from fat, and approximately 45% of total kcals from protein. Carbohydrates are restricted to no more than 50g of CHO per day per participant in the LCKD group, in order to bring participants to a state of ketosis. The participants in the normal diet control group will be instructed to continue their normal diet. Both groups will be instructed to cease the use of any nutritional ergogenic aids beginning one week prior to the intervention, and abstain throughout the entire study. The dietary intervention will coincide with the six weeks of training intervention. Dietary compliance will be monitored by mandatory self-recorded three-day FIR that will be turned in during the second week of the intervention, and during the fifth week of the intervention. Each participant in the LCKD will also be required to turn in a dietary checklist (Appendix C) each week which evaluates the quantity of servings of high-carbohydrate foods consumed in that week.

Data Analysis

Data will be analyzed using the SPSS 21.0 statistical software package (SPSS, Inc., Chicago, IL, USA). Descriptive statistics will be used to establish mean and statistical difference. A paired samples T-test will be used to determine the significant differences for each group. Multiple Analysis of Variance will be used to determine the effects of a LCKD and training on body composition and power lifting performance.

Chapter 3: Submission to the *Journal of Strength and Conditioning Research*

Effects of a Low-Carbohydrate Ketogenic Diet on Power Lifting Performance and Body Composition

Jessica L. Agee

Abstract

The aim of the study was to investigate a low-carbohydrate ketogenic diet (LCKD) as an effective strategy to decrease overall weight and fat mass, and preserve lean body mass (LBM) without compromising performance in trained, male power-lifters. This was a six-week randomized controlled trial, with a LCKD intervention group and a normal diet control group. LCKD was instructed to consume a diet with total calories less than 7% carbohydrates, 50% fat, and 45% protein, while the control group (CON) maintained an ad libitum diet. Both groups completed the same validated training protocol during the intervention. The CON had significant increases ($p < 0.05$) in one-repetition maximums for bench press, back squat, and deadlift, while the LCKD had a significant increase in deadlift ($p = 0.000$) with a maintenance of bench press and back squat performance. There were no changes in body composition measures. The main findings of the current study were that deadlift power increased, and LBM was maintained while consuming a LCKD and following a power-lifting training protocol for six weeks. Because of poor subject compliance, results of this study are inconclusive as to whether a LCKD can be used as an effective strategy for power-lifters to decrease total body weight and FM, while maintaining LBM performance.

Key Words- Low-carbohydrate ketogenic diet, body composition, power-lifting, bench press, back squat, deadlift

Introduction

Ketogenic diets have gained popularity in the last decade as a means to combat the rising obesity epidemic. The popularity of the low-carbohydrate diet seems predicated from the rapid weight-loss shown to take place within the first few days or weeks[5]. In addition to the increasing popularity of ketogenic diets for weight-loss among the average weight-conscious consumer, they have recently become a popular trend among competitive athletes as a means of rapid weight loss for performance benefits[5]. Low-carbohydrate ketogenic diets (LCKD) are widely used among sports that are divided into weight class divisions, such as wrestling, boxing, and weight lifting[18,21]. Rapid body weight reduction prior to competition in athletes who compete in specific weight categories can be an effective tool for performance success. Severe dehydration and a low-residue diet are the more common strategies used by competitive athletes to drop weight, but have also been shown to decrease max force production, muscular endurance, and power[22,25]. Because of the potential dangers that accompany these rapid weight-loss strategies, there is a necessity for further research in order to find a safe and efficacious method for competitive weight lifters to decrease weight quickly prior to competition while minimizing power and lean body mass (LBM) loss.

Limitations among current research begin with the subjective definition of a "low-carbohydrate diet"[30]. Westman et al. describes an individualized "threshold effect" where carbohydrate (CHO) intake is low enough to produce ketones in the urine[30]. In general, CHO restriction should be less than 50g/day or less than 7% of total kilocalories (kcal) from CHO in order to produce ketones and see true metabolic changes[2,30]. Studies that exceed 50g/day may not bring about any changes, and will therefore lead to insufficient results. Another issue reported by Westman et al. is that LCKDs only restrict one macronutrient[30]; fat and protein intake levels are therefore not consistent among LCKD, which could bring about unwarranted metabolic changes. The protein intake during a LCKD must be adequate enough to prevent muscle catabolism; however, exceeding the recommended protein intakes long-term will lead to protein oxidation and hinder the protein synthesis response[16,23]. A variety of different macronutrient intakes prevents any uniformity of LCKD, particularly regarding total energy intake, and makes it difficult to compare results from LCKD and performance research.

Another difference among study designs is time-frame. Accurate time allotted for keto-adaptation is individualized, but can take anywhere from two to four weeks[30]. When considering training status, adaptation has not shown to occur any faster in a trained individual compared to an untrained individual[20]. Also, CHO restriction must be closely monitored. Intermittent CHO restriction can severely affect adaptation, and has resulted in a decrease in exercise tolerance[20]. As a result of an undefined LCKD, different percentages of kcal from protein, different time-frames for following the LCKD, and type of training tested, current LCKD and exercise research has led to inconsistent results, including benefitting performance, having no effect on performance, or impairing performance[2,7,11,14,20,21,23,28].

By reviewing past studies, a gap in literature can be identified targeting the power-lifting population and the effects on anaerobic performance, specifically. This study focused on expanding current literature by highlighting and testing these issues found in previous studies. This study will be the first, to the authors' knowledge, to test strictly power lifts used in a competition setting— including bench press, back squat, and deadlift. This will also be one of the first studies to use a validated power lifting training protocol shown to increase bench press by 11%, and both back squat and deadlift by 13%, and will take place over six weeks[6]. Current literature indicates that combining a LCKD and resistance training for longer than four weeks will result in a loss of fat mass (FM) and preservation of lean body mass (LBM)[11,18,20,28,30].

The aim of the research was to investigate the effectiveness of a LCKD in combination with a six-week power-lifting protocol on decreased FM and body weight and preservation of LBM and power performance on trained, power-lifting college males. We hypothesized that subjects will experience a decrease in FM and a preservation of LBM in combination with an increase in power after six weeks of training and consuming a LCKD.

Methods

Experimental Approach to the Problem

This was a six-week randomized controlled trial, with a LCKD intervention group and a normal diet control group (CON). The LCKD group was instructed to consume a carbohydrate-restricted, ketogenic diet with less than 7% of total kcals from CHO, approximately 50% of total kcals from fat, and approximately 45% of total kcals from protein. The LCKD had no overt daily caloric target. The CON were instructed to maintain their habitual diets without any changes. Both groups were required to complete the same validated training protocol for the entire six weeks. The independent variables were the diet, and the dependent variables were body composition and power-lifting performance. Baseline measurements of body composition and one repetition maximums (1RM) of bench press, back squat, and deadlift were compared to post-intervention measurements, and expressed as mean and statistical difference. All methods and procedures were approved by the University's Institutional Review Board before data collection.

Subjects

Subjects were recruited through University student mailings, the University Recreation Center, campus flyers, and individual recruitment in the General Education health courses. Inclusion criteria included sufficient experience with resistance training, which was evaluated through individual assessment of proper lifting technique as outlined by the National Strength and Conditioning Association[4], and currently engaged in resistance training three to five times per week. Subjects with current injuries that affect power lifting performance, and/or health conditions that put them at risk were excluded. Subjects had to be free of diagnosed cardiovascular disease and fall into the "low risk" category, as defined by the American College of Sports Medicine[3]. Subjects that took any medication that affects body composition at the time of the study were excluded from participating in the study. Additionally, subjects taking any dietary supplements or nutritional ergogenic aids at the time of data collection were asked to discontinue consumption seven days prior to baseline testing and abstain for the duration of the study.

Procedures

Familiarization Session

An informational meeting was held with each subject to discuss randomization and instructions for following the protocol. All subjects were instructed to refrain from consuming any nutritional ergogenic aids (i.e. creatine, pre-workout supplements, no more than 450 mg of caffeine a day). The CON group was instructed to continue with their normal diets without changing anything. Subjects in the LCKD group were given detailed instructions and guidance on how to follow a LCKD prior to the start of the intervention. The LCKD group was provided very low-carbohydrate, two-day sample menus including foods that were available for purchase in campus dining facilities, and comprehensive lists of high- and low-carbohydrate foods and approved low-CHO protein shakes. Both groups received instructions on how to properly complete a dietary food intake record (FIR) and a checklist that assessed weekly consumption of high-carbohydrate foods. Subjects were instructed on proper form and techniques of all three lifts tested as defined by the International Powerlifting Federation Technical Rules Book[1]. Both groups were given instructions on how to properly complete the workout checklists provided, and turn them in each week for investigators to monitor compliance.

Testing Procedures

Baseline data collection included 1RM for all three lifts to assess power, body weight and height measurement, ketone production, and body composition. Post-intervention testing procedures were the same as baseline, and results from all tests were compared to the individual's baseline values.

Body Composition

Height was measured without shoes to the nearest 0.5 cm with a stadiometer, and weight was obtained without shoes using a calibrated balance scale (Detecto, Webb City, MI) and estimated to the nearest 0.1 kg. Height and weight were used to calculate body mass index (BMI) (kg/m^2). A Dual-energy x-ray absorptiometry (DXA) scan using the DXA (General Electric Lunar) was used to estimate total body fat percentage, FM, and LBM.

Urine Analysis

All subjects submitted a 50ml urine sample to assess baseline β-hydroxybutyrate (β-OHB) levels. These levels assessed the levels of ketones in the urine. Subjects were instructed to use an alcohol wipe to sanitize the head of the penis prior to urinating, then fill the sample cup to the 50 ml line with urine. Urine samples were collected at baseline and weeks one, three, and six of the intervention and reported as negative or positive ketone production. Ketone assessment was made by a Siemens CLINITEK Status+ Analyzer (Siemens Healthcare Global, USA).

Dietary Compliance

Subjects completed three-day FIRs at baseline and during intervention weeks two and five to assess total kilocalories (kcals) and macronutrient intake. The FIRs were recorded on three consecutive days, including one weekend day. All FIRs were analyzed using Nutrition Data System for Research software (University of Minnesota, MN).

Power-Lifting

The 1RM tests were conducted with the assistance of a Certified Strength and Conditioning Specialist and recorded by the researchers. The 1-RM testing protocol reported elsewhere[4] (Figure 1).

Training Protocol

Each subject participated in four training sessions a week, for six weeks. The training protocol used in this study was previously validated by Crewther, Heke, Keough[6]. The validated protocol included two workouts that are alternated each day (Table 1). Subjects were prohibited from following any other structured workouts for the duration of the study. Completed weight and repetitions were reported by the subjects each week to ensure compliance with training. Supervised training sessions were offered to subjects throughout the week with researchers, or a Certified Strength and Conditioning Specialist. Subjects were instructed to attend at least one supervised session every week. Compliance was monitored via the supervised training sessions and by weekly collection of the subjects' workout logs.

Diet Protocol

The LCKD was composed of less than 7% of total kcals from CHO, approximately 50% of total kcals from fat, and approximately 45% of total kcals from protein. CHO were restricted to less than 50g of CHO per day in the LCKD group, in order to bring subjects to a state of ketosis. Both groups ceased the use of any nutritional ergogenic aids beginning one week prior to the intervention, and abstained throughout the entire study. Dietary compliance was monitored by mandatory self-recorded three-day FIRs that were turned in during the second and fifth week of the intervention. Each subject in the LCKD also turned in a dietary compliance checklist each week which evaluated the quantity of servings of carbohydrate foods consumed that week.

Statistical Analysis

Data was analyzed using the SPSS 21.0 statistical software package (SPSS, Inc., Chicago, IL, USA). Descriptive statistics were used to establish mean and statistical difference. A paired samples T-test was used to determine the significant differences for each group. Multiple Analysis of Variance was used to determine the effects of a LCKD and training on body composition and power lifting performance.

Results

The subjects included 27 resistance trained males. The mean age of the subjects was 20 ± 1.7 (Table 2). All subjects provided informed consent and completed an exercise history questionnaire prior to the start of the study. Three subjects dropped out prior to randomization. Thirteen subjects were randomly assigned to the LCKD group, and 17 subjects were placed in the CON. Of the 13 LCKD subjects, five completed the post-intervention body composition testing, and four completed the post-intervention 1RM testing. Reasons for drop-outs include failure to adhere to the diet and scheduling conflicts. One subject could not complete the study due to an unrelated illness. Out of the 17 CON subjects, seven completed the bench press post-intervention testing, and eight completed the back squat and deadlift post-intervention testing; one subject could not complete the post-intervention bench press 1RM because of an injury. Nine subjects in the control group completed the post-intervention body composition testing. Reasons for drop-outs of control subjects were due to scheduling conflicts.

The remaining subjects' pretesting descriptive characteristics are reported in Table 2. Eleven subjects completed the 1RM testing, and 14 completed the body composition testing. A MANOVA test was used to determine differences in the overall power of the three lifts combined, as well as differences in body composition changes between the two groups. Results indicate that there was no statistical evidence of differences in multivariable means of performance or body composition between the LCKD group and the control diet group.

Analysis of the three-day FIRs indicate that CON subjects were consuming an average 2,978 kcals a day, with about 36% of kcals from fat, 43% of kcals from carbohydrates, and 18% of kcals from protein (Table 3). During the intervention the CON maintained a diet between 2,800 and 2,900 kcals a day, with approximately 40% of kcals from fat, 38% of kcals from CHO, and 24% of kcals from protein. At baseline, the LCKD subjects were consuming an average of 2,600 kcals a day, with 46% of kcals from CHO, 17% of kcals from protein, and 35% of kcals from fat. Mid-way through the intervention the LCKD subjects' average daily intake dropped to 2,132 kcals a day, with about 48% of kcals from fat, 23% from CHO, and 29% of kcals from protein. During the last two weeks of the intervention, average total kcal consumption of the LCKD group decreased dramatically to 1,063 kcals a day, with 61% of kcals from fat, 8% of kcals from CHO, and 31% of kcals from protein. It is important to note that the nutrient averages from Weeks 5-6 of the three-day FIRs are from one LCKD subject, as the other three remaining LCKD subjects failed to comply with turning in the Dietary Checklists and the three-day FIRs.

None of the subjects were producing ketones at baseline. During the first week of the intervention 75% of the subjects in the LCKD group were producing ketones. At week three and six of the intervention ketone production dropped to 50% and then 25%, respectively. Of the 25% of LCKD subjects producing ketones during the last week of the intervention, the subject who turned in the three-day FIR consuming 8% of kcals from carbohydrates was the subject producing ketones throughout the entire study. None of the CON subjects had traces of ketones in their urine during the intervention.

There were no significant changes or differences in body composition for the LCKD or CON groups (Table 4).

Results from paired samples t-tests reveal that for both groups combined there is a high correlation between the Pre- and Post-measurements of all 1RM lifts. It is important to note that both groups experienced increases in all three lifts tested. The CON group experienced a significant increase in 1RM for all three lifts (bench press: 6.80 ± 4.52 kg, $p < 0.05$), back squat: (16.48 ± 8.03 kg, $p < 0.05$), deadlift: (19.04 ± 11.77 kg, $p < 0.05$) while the LCKD group saw a significant increase in deadlift (18.18 ± 0.05 kg, $p = 0.000$), and maintained back squat and bench press performance (Table 5).

Discussion

The aim of the current study was to determine the effects of a six-week LCKD and training protocol on power lifting performance and body composition. The main findings of the current study were that deadlift power can increase, and LBM can be maintained while consuming a LCKD and following a resistance training protocol for six weeks.

Similarly to the current study, several studies examined the physical effects of a LCKD on body composition, both during resistance training and absent of any training[11,18,21,28]. Coupling the LCKD with resistance training, Jabekk et al. and Sawyer et al. tested long-term and short-term physical effects, respectively[11,21]. Jabekk revealed that 10 weeks of resistance training and a LCKD reduced body fat (-5.6±2.9kg of fat) without decreasing LBM, while resistance training and a regular diet increased LBM

(+1.6±1.8kg of LBM) without decreasing body fat in overweight women[11]. Sawyer tested strength and power training combined with a LCKD for one week, and concluded that power output remained the same, while total body mass decreased in both trained men and women[21]. A six-week study conducted by Volek also showed a LCKD decreased body fat and increased LBM[28]. Paoli, et al. conducted a 4-week study testing explosive strength performance in elite gymnasts who consumed a ketogenic diet while training[18]. After 30 days, total body mass was decreased (from 69.6±7.3kg to 68.0±7.5kg) with a significant decrease in FM (from 5.3±1.3kg to 3.4±0.8kg, $p<0.001$) and a non-significant increase in LBM[18]. The design of the present study is comparable to the previous studies', indicating that consuming a LCKD while resistance training for 1-10 weeks may lead to a decrease in total body weight and total body fat, while preserving LBM and performance.

Preservation of LBM can be attributed to a number of factors, possibly seen in the present study, including adrenergic stimulation. Low blood sugar brought about by a LCKD stimulates secretion of adrenaline, and skeletal muscles are regulated by adrenergic influences[14]. Another strategy fighting catabolism of the muscle includes the stimulation of growth hormone secretion also brought about by low blood sugar[14]. Lastly, dietary protein increases amino acid synthesis by increasing amino acid bioavailability[14]. The current study supports growing evidence from past research that consuming a LCKD while training will most likely result in a maintenance of LBM causing increases specifically in deadlift performance.

During the current study's intervention, the LCKD group's total energy intake began to decline, becoming approximately less than half of their initial intake by the end of the intervention (Table 3). Westman et al. reports that many subjects consuming a LCKD will fail to replace the restricted CHO with other macronutrients, which will decrease overall intake[30]. Despite the reduction in overall intake, there was still an increase in percentage of kcals from protein and fat. It has been reported that LCKD may improve satiety and decrease hunger and cravings because of the increased protein intake, which could contribute to the reduction of total energy intake and ultimately weight loss[12,13,15].

During this study 62% of the LCKD subjects did not complete the body composition testing, and 69% did not complete the 1RM testing. In the control diet group, 53% did not complete all of the 1RM tests, while 47% did not complete the body composition testing. These substantial drop-out rates indicate that the type of diet and training protocol used in this study may not be suitable for the population tested (i.e. college-aged, recreational power-lifting males), but may be more applicable to the more competitive power-lifters whom are more dedicated to maximizing performance gains.

Strengths of the present study include the duration of the intervention. The keto-adaptation period is individualized, but typically occurs within four weeks[8]. The six-week timeframe of the study would allow for keto-adaptation in most subjects adhering to a LCKD. Another strength used in this research includes implementing a validated power-lifting protocol that has shown gains in all three main power-lifts[6]. It is evident in the current study that with the validated lifting protocol all subjects were able to gain an average of approximately 7% in bench press ($p = 0.001$), 10% in back squat ($p = 0.000$), and 12% in deadlift ($p = 0.000$), despite which diet the subjects followed. These results are comparable to the original study by Crewther, Heke, Keough[6], which concluded 11% gains in bench press, and 13% gains in both back squat and deadlift.

Caution should be used when interpreting the results of the present study, as the sample size restricts the generalizability. The relatively small sample size, particularly in the LCKD group, greatly affects the statistical significance of the study. Another limitation of the current study is that compliance and adherence was self-reported and poor. Even though ketone production was monitored by the researchers, all LCKD subjects were not producing ketones for the entire duration of the study. The “threshold effect” as defined by Westman et al. may not have been met in all LCKD subjects, which could have prevented the true metabolic changes that accompany a LCKD[30].

Practical Applications

It is common practice among competitive weight lifters to train at a body mass that is 5-10% higher than their competition weight class, and then try to lose one to two kg before competition to make the weight class at which they want to compete[25]. The power-lifter’s perceived ideal weight can be achieved through many traditional strategies, most of which can be detrimental to the body and performance. Several of the more common weight-loss techniques include using extremely low-calorie diets, dehydration, saunas, or diuretics. All of these strategies can impair health, psychological function, water and electrolyte balance, glycogen storage and decrease LBM, and in the case of diuretics, are sometimes illegal in competition[18]. Because of poor subject compliance, results of this study are inconclusive as to whether a LCKD can be used as an effective strategy for power-lifters to decrease total body weight and FM, and maintain LBM performance. Therefore, more research is warranted that targets the competitive power-lifting population specifically, in order to determine if LCKDs are a safe alternate weight-loss strategy prior to competition.

Tables

***Table 1- Resistance Training Protocol for Male College Students on Either an Ad Libitum or Low-carbohydrate Ketogenic Diet*[6]**

Day One++	**Day Two**++	**Week 1** *50,70,80,80% 1RM	**Week 2** *50,70,80,85% 1RM	**Week 3** *50,75,80,90% 1RM
Squats	*Deadlifts*	4 x 12,8,6,6*	4 x 12, 8, 6, 4*	4 x 12, 8, 5, 2*
Bench press	*Military Press*	4 x 12,8,6,6*	4 x 12, 8, 6, 4*	4 x 12, 8, 5, 2*
Leg curls	*Pull-downs*	4 x 12,8,6,6*	4 x 12, 8, 6, 4*	4 x 12, 8, 5, 2*
DB chest flies	*Close grip bench*	3 x 8 RM	3 x 10 RM	3 x 12 RM
Calf raises	*Barbell bicep curls*	3 x 8 RM	3 x 10 RM	3 x 12 RM
Bar dips	*Shrugs*	3 x 8 RM	3 x 10 RM	3 x 12 RM

Day One++	**Day Two**++	**Week 4** *55,75,85,85,92% 1RM	**Week 5** *55,75,85,90% 1RM	**Week 6** *60,75,85,90,94% 1RM
Squats	*Deadlifts*	5 x 12,8,4,3,3*	4 x 12,8,4,1-3*	5 x 12,6-8,5,4-6,1-3*
Bench press	*Military Press*	5 x 12,8,4,3,3*	4 x 12,8,4,1-3*	5 x 12,6-8,5,4-6,1-3*
Leg curls	*Pull-downs*	5 x 12,8,4,3,3*	4 x 12,8,4,1-3*	5 x 12,6-8,5,4-6,1-3*
DB chest flies	*Close grip bench*	3 x 8 RM	3 x 10 RM	3 x 12 RM
Calf raises	*Barbell bicep curls*	3 x 8 RM	3 x 10 RM	3 x 12 RM
Bar dips	*Shrugs*	3 x 8 RM	3 x 10 RM	3 x 12 RM

++ Days one and two are alternated 2x a week
RM: Repetition Maximum
*Set x repetitions at given intensity for first three exercises

Table 2- Baseline Subject Demographics for Male College Students on Either an Ad Libitum or Low-Carbohydrate Ketogenic Diet

	LCKD (n=13)	**CON** (n=17)
Age	19.23 ± 1.2	20.67 ± 1.8
BMI (kg/m^2)	26.70 ± 2.9	25.76 ± 2.3
Height (cm)	177.80 ± 7.36	178.96 ± 6.13
Weight (kg)	85.58 ± 15.5	81.54 ± 9.6
Fat (%)	17.98 ± 6.8	14.10 ± 4.3
Fat Mass (kg)	14.68 ± 7.2	11.23 ± 4.1
Fat Free Mass (kg)	68.46 ± 9.4	70.98 ± 7.4

*Data represented as mean ± statistical difference, no significant difference between groups ($p < 0.05$)

Table 3- Mean Values for Dietary Variables for Male College Students on Either an Ad Libitum or Low-Carbohydrate Ketogenic Diet

	CON			LCKD		
	Baseline	**Week 2-4**	**Week 5-6**	**Baseline**	**Week 2-4**	**Week 5-6**
Total Calories	2978	2893	2831	2624	2132	1063
CHO (g)	319	270	266	303	128	24
CHO (%)	43%	37%	38%	46%	23%	8%
Pro (g)	134	169	163	109	150	79
Pro (%)	18%	24%	23%	17%	29%	31%
Fat (g)	119	117	124	102	114	72
Fat (%	36%	39%	40%	35%	48%	61%

Table 4- Pre and Post Intervention Body Composition Measurements for Male College Students on Either an Ad Libitum or Low-Carbohydrate Ketogenic Diet

	BMI (kg/m²)	**Weight (kg)**	**Fat (%)**	**Fat Mass (kg)**	**Fat Free Mass (kg)**
LCKD *(n=5)*					
pre	26.7 ± 2.92	85.6 ± 15.55	18.0 ± 6.82	14.7 ± 7.25	68.5 ± 9.44
post	25.1 ± 2.60	80.3 ± 13.42	15.1 ± 3.06	11.7 ± 3.67	69.0 ±10.33
changes	-1.62 ± 2.27	-5.32 ± 7.12	-2.90 ± 4.25	-2.96 ± 4.37	0.51 ± 1.83
CON *(n=9)*					
pre	25.8 ± 2.32	81.5 ± 9.57	14.1 ± 4.34	11.2 ± 4.09	71.0 ± 7.40
post	25.6 ± 2.30	81.2 ± 9.86	13.21 ± 3.40	10.6 ± 3.68	71.6 ± 7.23
changes	-0.11 ± 0.48	-0.30 ± 1.43	-0.89 ± 2.16	-0.67 ± 1.60	0.61 ± 1.46

*Data represented as mean ± statistical difference, no significant difference in change within group.

Table 5- Pre and Post Intervention Measurements of 1RM of Bench Press, Back Squat, and Deadlift for Male College Students on Either on an Ad Libitum or Low-Carbohydrate Ketogenic Diet

	Bench Press (kg)	**Back Squat (kg)**	**Deadlift (kg)**
LCKD *(n=4)*			
pre	85.8 ± 8.79	109.7 ± 18.86	119.3 ± 16.34
post	93.2 ± 13.39	119.3 ± 20.79	137.5 ± 16.36
changes	7.38 ± 5.99	9.68 ± 11.79	18.18 ± 0.05*
CON *(n=7 for bench press, n=8 for back squat and deadlift)*			
pre	106.5 ± 17.24	134.7 ± 17.08	143.8 ± 13.64
post	113.3 ± 14.39	151.1 ± 14.54	162.8 ± 18.07
changes	6.80 ± 4.52*	16.48 ± 8.03*	19.04 ± 11.77*

++ Data represented as mean ± statistical difference

*Significant difference in change within group ($p < 0.05$)

Figures

Figure 1- One Repetition Maximum Testing Protocol[4] used by researchers to establish 1RM for bench press, back squat, and deadlift.

1-RM TESTING PROTOCOL

1. Instruct the athlete to warm up with a light resistance that easily allows 5-10 repetitions.
2. Provide a 1-min rest period.
3. Estimate a warm-up load that will allow the athlete to complete 3-5 repetitions by adding
   - 10-20lb (4-9kg) or 5-10% for upper-body exercise or
   - 30-40lb (14-18kg) or 10-20% for lower-body exercise
4. Provide a 2-min rest period.
5. Estimate a conservative, near-maximum load that will allow the athlete to complete 2-3 repetitions by adding
   - 10-20lb (4-9kg) or 5-10% for upper-body exercise or
   - 30-40lb (14-18kg) or 10-20% for lower-body exercise
6. Provide a 2-4-min rest period.
7. Make a load increase
   - 10-20lb (4-9kg) or 5-10% for upper-body exercise or
   - 30-40lb (14-18kg) or 10-20% for lower-body exercise
8. Instruct the athlete to attempt a 1-RM.
9. If the athlete was successful, provide a 2-4-min rest period and go back to step 7.

If the athlete failed, provide a 2-4-min rest period, decrease the load by subtracting

- 5-10lb (2-4kg) or 2.5-5% for upper-body exercises or
- 15-20lb (7-9kg) or 5-10% for lower-body exercises

AND then go back to step 8.

Continue increasing or decreasing the load until the athlete can complete one repetition with proper exercise technique. Ideally the athlete's 1-RM will be measured within 5 testing sets.

Appendices

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Appendix A-Sample Menus

Breakfast (712kcal, 8g of CHO)	
Omelet	
4 eggs	285kcal, 2g CHO
2 tbsp of butter	204kcal
¼ cup cheddar cheese	114kcal
½ avocado	109kcal, 6g CHO
Snack (289kcal, 14g of CHO)	
Low Carbohydrate Protein Shake	140kcal, 2g CHO
8 ounces of whole milk	149kcal, 12g CHO
Lunch (813kcal, 1g of CHO)	
8 oz 80% lean hamburger patty, no bun	626kcal
1 slice of provolone cheese	100kcal, 1g CHO
2 medium slices of bacon	87kcal
Snack (204kcal, 11g CHO)	
1 cup of celery	16 kcal, 3g CHO
2 tbsp. of peanut butter	188kcal, 8g CHO
Dinner (792kcal, 6g CHO)	
8 ounce chicken leg quarter, skin eaten	522kcal
1 cup of broccoli	30kcal, 6g CHO
2 tbsp. of canola oil	240kcal

Totals: 2,810kcal
47g of CHO
6.7% CHO

Breakfast (465kcal, 12g CHO)

4 medium slices of bacon	173kcal
2 large hard boiled eggs	154kcal, 1g CHO
8 ounces full fat yogurt	138kcal, 11g CHO

Snack (171kcal, 2g CHO)

2 ounces of mozzarella cheese (2 slices or 2 cheese sticks)	171kcal, 2g CHO

Lunch (611kcal, 7g CHO)

2 medium pork chops	405kcal
1 cup of cottage cheese	206kcal, 7g CHO

Snack (321kcal, 17g CHO)

8 ounces of whole milk	149kcal, 12g CHO
1 ounce of almonds (22 almonds)	172kcal, 5g CHO

Dinner (989kcal, 5g CHO)

8 ounce Steak, fat eaten	538kcal
2 cups of raw spinach	14kcal, 2g CHO
½ cup of feta cheese	198kcal, 3g CHO
2 tbsp. of olive oil	239kcal

Totals: 2,557kcal
43g of CHO
6.7% CHO

Appendix B- Approved Protein Supplements

Powders

Name	Serving Size (g)	Carbs (g)	Protein (g)	Fat (g)	Calories
SDS Nutrition About Time: 100% Whey	28.4	0	24	0	101
Isopure	31	0	25	1	105
ISO-ology	34	1	30	0.5	120
ULTIMATE NUTRITION ISO Sensation	32	1	30	N/A	130
Dymatize Iso-100	31	2	25	0.5	110
Gaspari Nutrition IsoFusion	35	2	25	1	120
Optimum Nitrition Hydro Whey	39	2	30	1	140
MRE Protein: "Ultra-Loaded" Whey Protein Isolate	28	2.5	25	0	110
GNC Wheybolic Extreme	26	3	20	0.5	90
GNC 100% Whey Isolate	33	3	28	0.5	130
bodylogix Natural Whey	30	3	24	1	120
Wheyology	34	3.5	25	3	125
Gaspari Nutrition Myofusion	35	4	25	3	140
Provosyn	41	4	21	11	210
Optimum Nutrition Gold Standard 100% Whey	33	4	24	2	130
Muscle Tech Platinum 100% Whey	34	4	24	1.5	130
Muscle Pharm Combat Powder	34.8	5	24	1.5	130

Ready To Drink

Name	Serving Size	Carbs (g)	Protein (g)	Fat (g)	Calories
Carnivor Liquid Protein	4 fl oz	0	50	0	200
Nature's Bast Isopure Zero Carb	20 fl oz	0	40	0	160
"Pure Protein" Protein Shake	11 fl oz	2	35	1	160
EAS AdvantEDGE Carb Control	330mL	3	17	2.5	100
OhYeah!	14 fl oz	4	32	9	220
ABB Performance Pure Pro	12 fl oz	5	35	0.5	160
Designer Whey Protein Shake	10.5 fl oz	5	18	2	100

Appendix C- Dietary Compliance Checklist

Dietary Compliance Checklist

You have been randomized to the experimental group. For more details on your assigned diet and foods to stay away from, please see handout titled "Low Carbohydrate Foods and Foods to Avoid". This checklist is to ensure compliance with your assigned diet. If you consume any of the foods listed here, please log them in this checklist weekly, and turn in to a researcher at the end of each week. Be as specific as possible with what you had and how much.

Day	Food Group (circle one)	Item	Quantity
Sunday	**Fruit (fresh, dried, or frozen) Starchy vegetables Beans Pasta Breads (bagels, toast, buns, English muffins) Cereal (hot or cold) Candy, Cookies, Cakes, Chips Oil, fats, and nut seeds Sports drinks/ Sugary drinks Alcohol Milk/dairy/alternatives**		
Monday	**Fruit (fresh, dried, or frozen) Starchy vegetables Beans Pasta Breads (bagels, toast, buns, English muffins) Cereal (hot or cold) Candy, Cookies, Cakes, Chips Oil, fats, and nut seeds Sports drinks/ Sugary drinks Alcohol Milk/dairy/alternatives**		
Tuesday	**Fruit (fresh, dried, or frozen) Starchy vegetables Beans Pasta Breads (bagels, toast, buns, English muffins) Cereal (hot or cold) Candy, Cookies, Cakes, Chips Oil, fats, and nut seeds Sports drinks/ Sugary drinks Alcohol Milk/dairy/alternatives**		

Wednesday	**Fruit (fresh, dried, or frozen)** **Starchy vegetables** **Beans** **Pasta** **Breads (bagels, toast, buns, English muffins)** **Cereal (hot or cold)** **Candy, Cookies, Cakes, Chips** **Oil, fats, and nut seeds** **Sports drinks/ Sugary drinks** **Alcohol** **Milk/dairy/alternatives**		
Thursday	**Fruit (fresh, dried, or frozen)** **Starchy vegetables** **Beans** **Pasta** **Breads (bagels, toast, buns, English muffins)** **Cereal (hot or cold)** **Candy, Cookies, Cakes, Chips** **Oil, fats, and nut seeds** **Sports drinks/ Sugary drinks** **Alcohol** **Milk/dairy/alternatives**		
Friday	**Fruit (fresh, dried, or frozen)** **Starchy vegetables** **Beans** **Pasta** **Breads (bagels, toast, buns, English muffins)** **Cereal (hot or cold)** **Candy, Cookies, Cakes, Chips** **Oil, fats, and nut seeds** **Sports drinks/ Sugary drinks** **Alcohol** **Milk/dairy/alternatives**		
Saturday	**Fruit (fresh, dried, or frozen)** **Starchy vegetables** **Beans** **Pasta** **Breads (bagels, toast, buns, English muffins)** **Cereal (hot or cold)** **Candy, Cookies, Cakes, Chips** **Oil, fats, and nut seeds** **Sports drinks/ Sugary drinks** **Alcohol** **Milk/dairy/alternatives**		

Appendix D- Low Carbohydrate Foods and Foods to Avoid

Low Carbohydrate Foods and Foods to Avoid

This handout is meant to give you a better idea of what foods to choose in order to maintain your low-carbohydrate diet. It will give you general DOs and DON'Ts in terms of food choices so that you have a general idea of some low-carb and high-carb foods. The first column will consist of your low-carb foods, while the "avoid" column will consist of high-carb foods that you will want to avoid and eliminate from your diet. Keep in mind that this list is not exhaustive and there other low-carb foods that are not on this list.

Experimenting and combining low-carb foods in different ways will keep your diet from becoming monotonous. Meal prepping in advance may be beneficial if you have limited time during the week to cook meals so that you always have food ready to eat. Having meals and snacks ready in advance may also prevent any temptation or impulse to eat high-carb foods that are not permitted while following this regiment.

It is important to pay attention to what you eat because some of these foods do contain carbohydrates. If you over-consume a particular food you may easily go over your daily 50 g CHO limit. Yogurt and cottage cheese especially should be consumed in moderation.

	Low/No CHO foods		**Avoid**
Meats, Fish, & Alternative	Steak Ground hamburger Bacon* Sausage* Pork Ham* Salmon Cod Flounder Lamb Tofu* Prepackaged lunch meats	Chicken (skin on) Eggs Veal Venison Duck Tuna* Shellfish Tilapia Shrimp Lobster (all unbreaded meat)	Any breaded meats or fish Look for additives in canned tuna Tempeh Seitan
Dairy Products & Alternatives	Cottage cheese (1/2 c) Brie (1 oz) Camembert (1 oz) Blue cheese (1 oz) Cheddar (1 oz) Sheep and goat cheeses (1 oz) Mozzarella (1 oz)	Whole milk (<1c/day) High-fat yogurts (plain only) Cream (40% fat or more) Sour cream Almond milk (unsweetened) Coconut milk (unsweetened) Feta (1 oz)	Ice cream Yogurts with added fruit Low fat dairy Milk
Oils, Fats, & Nuts/Seeds	Peanut butter (no added sugar) Almond butter (no added sugar)	Butter Canola oil Vegetable oil Almonds	Margarine

	Sunflower butter (no added sugar) Olive oil Coconut oil Mayonnaise*	Shortening Sesame oil Sunflower seeds Pine nuts Peanuts Walnuts Macadamia nuts Pumpkin seeds Pecans	
Vegetables	Cabbage Broccoli Brussel sprouts Kale Spinach Celery Bok choy Bell pepper Alfalfa sprouts Chives Endive Fennel Radicchio Artichoke hearts	Avocado (1/2 whole) Eggplant Asparagus Zucchini Cucumber Swiss chard Tomatoes Radishes Chicory greens Daikon Mushrooms Iceberg/Romaine Olives	Potatoes (all types/forms) Corn Peas Parsnips Plantains Beets Carrots Onions
Fruits	No fruit allowed		Avoid all fruit
Grains	No grains allowed		Avoid all breads, pastas, wheat, spelt, rye, barley, cereals
Herbs/Spices	Basil Dill Garlic Oregano Rosemary Tarragon Cinnamon Nutmeg Paprika	Cayenne pepper Cilantro Ginger Pepper Sage Turmeric Curry Thyme Salt	Spice mixtures may contain added sugar
Salad Dressings	Lemon juice (2 tbs) Caesar (2 tbs) Italian (2 tbs)	Oil and vinegar (2 tbs) Blue cheese (2 tbs) Ranch (2 tbs) Balsamic vinegar	No dressings with added sugar and no more than 2 grams of net carbs per serving
Beverages	Clear broth* Flavored seltzer* Water	Carbonated water Decaf coffee or tea Diet soda	Beer/wine/liquor Gatorade Endurance/energy drinks Regular soda Fruit beverages Chocolate milk

Other	Mustard* Soy sauce Horseradish Salsa* Pesto* Cider/wine vinegars Low-carb protein powders* (e.g. Isopure, most whey proteins—See handout)	Artificial sweeteners Jams, jellies, preserves Chips, pretzels Cookies, cakes, candy Ketchup, Tartar sauce Steak sauce Barbeque sauce Teriyaki sauce
***Check all labels for added sugars or fillers that may add carbs**		

Appendix E- Proper Lifting Techniques

Bench Press Performance Checklist

Adapted from the International Powerlifting Federation Technical Rule Book

1. Lie flat on the bench with head, shoulders and buttocks in contact with the bench surface with feet flat on the floor. Hands and fingers must grip the bar positioned in the rack stands with a "thumbs around" grip.

2. After correctly positioning himself, spotters may assist in removing the bar from the racks.

3. After removing the bar from the racks, elbows should be locked, motionless and the bar properly positioned.

4. Lower the bar to the chest (the chest finishes at the base of the sternum / breastbone), hold it motionless on the chest then return the bar to arm's length with no excessive and immoderate uneven extension of the arms.

5. Once held motionless in this position, the bar may be racked with or without the assistance of a spotter.

****Please be sure to adhere to the above guidelines to ensure both proper lifting technique and safety.****

Deadlift Performance Checklist

Adapted from the International Powerlifting Federation Technical Rule Book

1. Face the front of the platform with the bar laid horizontally in front of the feet, gripped with an optional grip in both hands and lifted until the lifter is standing erect.

2. On completion of the lift, the knees shall be locked in a straight position and the shoulders back.

3. The bar is held motionless when in the apparent finished position.

4. No downward movement is allowed until reaching the erect position with the knees locked.

5. Return the bar to the platform while maintaining control throughout the descent without releasing the bar from the palms of the hand.

****Please be sure to adhere to the above guidelines to ensure both proper lifting technique and safety.****

Squat Performance Checklist

Adapted from the International Powerlifting Federation Technical Rule Book

1. Face the front of the platform. The bar should be held horizontally across the shoulders, hands and fingers gripping the bar, and the top of the bar not more than the thickness of the bar below the outer edge of the shoulders.

2. After removing the bar from the racks, move backwards to establish the starting position defined as motionless, erect with knees locked, and the bar properly positioned.

3. Begin the lift by bending the knees and lowering the body until the top surface of the legs at the hip joint is lower than the top of the knees.

4. Recover at will to an upright position with the knees locked. Double bouncing at the bottom of the squat or any downward movement is not permitted.

5. Move forward and return the bar to the racks. For reasons of safety, the lifter may request the aid of a spotter in returning the bar to, and replacing it in the racks.

****Please be sure to adhere to the above guidelines to ensure both proper lifting technique and safety.****

Appendix F- Sample Week One Workout Compliance Checklist

Week 1 **Participant Number_____________** **Date______________**

Day 1

EXERCISE	%-MAX	CALCULATED WEIGHT	WEIGHT COMPLETED	REPS COMPLETED
Squats	x 12 @ 50%			
	x 8 @ 70%			
	x 6 @ 80%			
	x 6 @ 80%			
Bench Press	x 12 @ 50%			
	x 8 @ 70%			
	x 6 @ 80%			
	x 6 @ 80%			
Leg Curls	x 12 @ 50%			
	x 8 @ 70%			
	x 6 @ 80%			
	x 6 @ 80%			
DB Chest Flys	3 x 8 @ max weight			
Calf Raises	3 x 8 @ max weight			
Bar Dips	3 x 8 @ max weight			

90 seconds rest between sets

****120 seconds rest between exercises****

How hard was today's workout (6-20)? _____________________

(Respond according to the Borg's RPE Scale Handout.)

Notes:

If any exercises were not performed as prescribed, please indicate what was done.

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