Effects of a Short-Term Carbohydrate-Restricted Diet on Strength and Power Performance

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Abstract

Sawyer, JC, Wood, RJ, Davidson, PW, Collins, SM, Matthews, TD, Gregory, SM, and Paolone, VJ. Effects of a short-term carbohydrate-restricted diet on strength and power performance. *J Strength Cond Res* 27(8): 2255–2262, 2013—The purpose of the study was to examine the effects of switching from a habitual diet to a carbohydrate-restricted diet (CRD) on strength and power performance in trained men ($n = 16$) and women ($n = 15$). Subjects performed handgrip dynamometry, vertical jump, 1RM bench press and back squat, maximum-repetition bench press, and a 30-second Wingate anaerobic cycling test after consuming a habitual diet (40.7% carbohydrate, 22.2% protein, and 34.4% fat) for 7 days and again after following a CRD (5.4% carbohydrate, 35.1% protein, and 53.6% fat) for 7 days. Before both testing sessions, body weight and composition were examined using bioelectrical impedance analysis. Three 2×2 multiple analyses of variance were used to compare performance variables between the habitual diet and CRD. Subjects consumed significantly fewer ($p < 0.05$) total kilocalories during the CRD (2,156.55 $\pm$ 126.7) compared with the habitual diet (2,537.43 $\pm$ 99.5). Body mass decreased significantly ($p < 0.05$). Despite a reduction in body mass, strength and power outputs were maintained for men and women during the CRD. These findings may have implications for sports that use weight classes, and in which strength and power are determinants of success. A CRD may be an alternative method for short-term weight loss without compromising strength and power outputs. The use of a 7-day CRD could replace weight loss methods employing severe dehydration before competition.

Key Words low-carbohydrate diet, body composition, anaerobic exercise, bench press, back squat

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Introduction

Carbohydrate-restricted diets (CRDs) have been used for improvements in weight and cardiovascular risk and are becoming more widely used by competitive athletes (19,27). Erlanson-Albertsson and Mei (13) determined that individuals lost significantly more weight after 3 and 6 months while consuming a CRD compared with a conventional low-fat diet. Many studies examining CRD demonstrate a rapid weight loss, particularly early after inception. As such, competitive strength and power athletes with weight class restrictions have gravitated toward this dietary approach for short-term weight management. However, the short-term effects of switching from habitual diet to a CRD on strength and power performance are unclear.

Some studies have examined the effects of adopting a CRD for 4–6 weeks on performance. Conflicting results have been found concerning the effects of a CRD on power output during cycling (15,17,25,26,31). Fleming et al. (15) used a diet consisting of 61% fat, 8% carbohydrate, and 30% protein for 6 weeks and determined that a reduction in carbohydrate consumption caused a decrease in power output in trained men. Vogt et al. (31), in contrast, used a diet consisting of 53% fat for 5 weeks to determine changes in power output and determined that no differences existed in maximal power output while consuming a high-fat diet compared with a high-carbohydrate diet. The adaptation period to a CRD, particularly a ketogenic CRD, may vary between individuals, which could possibly explain the conflicting results. Furthermore, there is no consistent definition of a CRD in the literature, which may also contribute to different findings (15,17,31).

In contrast to the existing literature focused on endurance performance and macronutrient redistribution, the effects of a CRD on strength and power performance are not as clear. Dipla et al. (10) reported that a 7-day high-protein, low-carbohydrate diet significantly reduced body weight and body fat in active women. Upper-body and lower-body isokinetic strength were not different following the experimental diet. The study (10) used a diet consisting of 30% carbohydrate for the CRD. Although the subjects in the study by Dipla et al. (10) reduced their kilocalories to 30%, many individuals may choose to limit carbohydrate consumption to ≤10%. However, only women were studied, and isokinetic measurements of strength were used. To our knowledge, the short-term effects of a CRD of ≤50 g on isotonic strength and power have not been determined. Therefore, this study was designed to examine the effects of switching from habitual diet to a 7-day CRD on body weight, body composition, gender, and strength and power performance. Based on the results of Dipla et al. (10), we hypothesized that subjects would experience a decrease in body weight with no changes in strength and power performance.

Methods

Experimental Approach to the Problem

This study used a repeated measures design to determine the effect of consuming a CRD on strength and power compared with a habitual diet. To assess the changes in strength and power, each subject performed a battery of tests (described in the following) while consuming his or her habitual diet for 7 days and again after consuming a CRD for 7 days. The tests administered consisted of the following: hand dynamometry, countermovement vertical jump, 1RM bench press and back squat, maximum-repetition bench press, and 30-second Wingate anaerobic bicycle test. The independent variables were gender and diet. The dependent body mass variables were body weight (kg), fat-free mass (FFM; kg), fat mass (kg), percent body fat, and total body water (TBW; kg). The dependent dietary variables were total kilocalories, carbohydrate (g), fat (g), and protein (g). The mean values for total kilocalories, carbohydrate, fat, and protein during the habitual diet and CRD were used to calculate differences. The dependent strength and power variables included handgrip strength, countermovement vertical jump, 1RM bench press and back squat, maximum-repetition bench press, and 30-second Wingate anaerobic cycling test.

Subjects

The subjects included 31 trained individuals (16 men and 15 women). The mean age for the male subjects was 25.0 ± 4.7 years and that for the female subjects was 23.2 ± 2.6 years. The subjects provided informed consent, and completed a medical history questionnaire and a resistance training history form before the start of the study. Exclusion criteria included any musculoskeletal injuries sustained within the previous 2 years and consumption of a CRD within the previous 2 years of the start of the study. To be considered "trained" subjects must have performed resistance training >2 times per week for the previous 2 years. All testing was done between the months of February and May. All methods and procedures were approved by the Institutional Review Board of the Springfield College before data collection.

Procedures

Each subject performed 2 testing sessions. The first testing session occurred after each subject consumed a habitual diet for 7 days. After the first testing session, the subjects began the CRD. The second testing session occurred after each subject had consumed a CRD for 7 days. Before each testing session, subjects were required to refrain from performing resistance exercise for 48 hours. Alcohol was not consumed for the duration of the study. Subjects were instructed to refrain from consuming caffeine for 12 hours before each testing session. Participants arrived at the Human Performance Laboratory after a 12-hour fast between the hours of 6:00 and 8:00 AM. Weight and body composition were measured using the Tanita BC 418 Segmental Body Composition Analyzer (Tanita, Tokyo, Japan). The subject was then provided with a pretesting meal and, after consumption of the meal, was instructed to return to the testing laboratory after 2 hours. The pre-exercise meal was provided to each subject 2 hours before the start of each exercise testing session. The meal consisted of 400 kcal. The meal included 250 ml of water, 2 hard-boiled eggs, 28 g of cheddar cheese, and a protein shake (Advant Edge Whey Protein; EAS, Inc., Abbott Park, IL, USA). The individuals that regularly consumed caffeine were allowed to consume 300 ml of coffee with 15 ml of cream. To ensure that the breakfasts were isocaloric, kilocalories consumed in coffee were deducted from the protein shake. Subjects were allowed to drink water ad libitum during the 2 hours after breakfast and during the entire exercise testing session.

Testing Procedures. Upon returning to the laboratory, each subject performed a 5-minute warm-up using a cycle ergometer with 2 kg of resistance at a self-selected pace, followed by the performance of a standard dynamic warm-up. The tests were administered in the following sequence for each subject: handgrip dynamometry, vertical jump, 1RM bench press, 1RM back squat, maximum-repetition bench press power output and Wingate anaerobic test. Upper-body and lower-body tests were chosen to assess both maximal strength (handgrip dynamometry and 1RM bench press and back squat) and power (vertical jump, maximum-repetition bench press power output and Wingate anaerobic test).

Handgrip strength was assessed using a hand dynamometer (Marquette Hydraulic Handgrip Dynamometer Baseline, Elmsford, NY, USA). Each subject was given 3 attempts to perform the handgrip test separated by 1-minute rest. The grip size was adjusted until the third digit was at a 90° angle (2). Each subject held an elbow position at 180° for the duration of the test (2). The maximum hand dynamometer measurement was used as the maximal handgrip strength.

To assess lower-body power, a countermovement vertical jump was performed. Each subject performed 3 countermovement vertical jumps separated by 30 seconds of rest. During the countermovement vertical jump, each subject was instructed to start in a stationary position. The downward phase of the countermovement vertical jump consisted of the subjects flexing at the hips and flexing at the knees to ~90°. Subjects placed hands on hips until the completion of the vertical jump. The upward phase of the countermovement vertical jump consisted of each subject rapidly extending the hip and knee with plantar flexion of the ankle. Vertical jump height was recorded using a jump mat (Just Jump!; Probiotics, Inc., Huntsville, AL, USA). The maximum height achieved for the 3 trials was recorded as the maximal countermovement vertical jump height.

The back squat was chosen to assess lower-body strength and the bench press was chosen to assess upper-body maximal strength. The 1RM for back squat and bench press was determined using the methods described by Baechle and Earle (4). After 3 warm-up sets, the weight for the back squat and bench press was increased for each subject until only 1 repetition was performed before exhaustion. The rest between sets was 3 minutes in length (30).

To determine upper-body maximum power output, a Keiser power rack (POWER Rack; Keiser, Inc., Fresno, CA, USA) was used. The weight used for each subject was 65% of the maximum weight successfully lifted during the 1RM bench press. In addition to 65% of the free-weight 1RM, 20 psi were added for men and 10 psi for women. The maximum upper-body power output was the highest power output measured in pounds per square inch in 10 repetitions of bench press.

After the maximum-repetition bench press, a 30-second Wingate anaerobic test was performed using a cycle ergometer (Ergomedic 874E; Monark, Inc., Varberg, Sweden). The resistance used for each subject was determined by multiplying body mass by 0.07 (15). Upon the start of the test, the subject was instructed to pedal at a maximal pace for 30 seconds. Peak power output in watts was determined as the highest 5-second value recorded during each 30-second test (15).

Dietary Counseling. Each subject underwent dietary counseling ~7 days before the start of the testing protocol. During this time, each subject was instructed how to complete a dietary log. Each subject then completed a 5-day dietary log while consuming a habitual diet and again while consuming a CRD. The CRD consisted of ≤50 g of carbohydrates per day. During the dietary counseling, each subject was educated on low-carbohydrate foods. A list of foods that were acceptable to consume while on a CRD was provided. The subjects were advised to consume <50 g of carbohydrates per day, but no other stipulations were placed on macronutrient consumption during the CRD. During the CRD, the researcher contacted each subject every 48 hours to answer any questions about the diet. Body weight was measured every 48 hours during the CRD to determine if any body mass changes had occurred. If a reduction in body weight occurred during the CRD, subjects were instructed to consume more calories to maintain body weight. Diet logs were analyzed using dietary analysis software (Food Processor SQL Edition, version 10.4.0; ESHA Research, Salem, OR, USA). Each subject was required to complete a 1-week training log while consuming a habitual diet and was instructed to replicate this during the CRD.

The subjects were weighed every 48 hours to assess changes in body mass during both the habitual diet and the CRD. To ensure compliance, urinary ketones were recorded nightly while consuming the CRD. Each subject used Ketostix (Bayer Healthcare Pharmaceuticals, Richmond, CA, USA) to determine the presence of urinary ketones.

Statistical Analyses

All statistical analysis was performed using SPSS version 14 (SPSS, Inc., Chicago, IL, USA). All data are presented as mean ± *SD*. Significance was set a priori with an alpha of 0.05. To compare strength measures between genders, relative strength was calculated for the bench press, back squat, and hand dynamometry. Relative strength was calculated as the amount lifted divided by body weight to the two-thirds power (4). For all analyses of variance (ANOVAs), if significant interactions existed, a simple effects test was used to determine where the significant differences existed.

Three 2 × 2 repeated measures multiple analyses of variance (MANOVAs) were used to compare performance variables between the habitual diet and the CRD. The independent variables were diet and gender. For the first MANOVA, the dependent variables were absolute 1RM for the bench press and back squat, and maximal handgrip strength. For the second MANOVA, the dependent variables were relative 1RM for the bench press and back squat, and maximal handgrip strength. For the third MANOVA, the dependent variables were countermovement vertical jump height, Wingate peak power output, and Kaiser peak power output. The Levene's statistic was used to test for homogeneity of variance for gender and diet (Box's $M = 5.2$). Univariate ANOVAs were used as post hoc tests.

Table 1. Descriptive statistics of mean values for body mass variables for subjects ($N = 31$) during habitual diet and carbohydrate-restricted diet (CRD) (mean ± *SD*).

	Men		Women	
	Habitual	CRD	Habitual	CRD
Body weight (kg)	86.80 ± 8.65	85.06* ± 8.65	65.88 ± 9.01	64.07* ± 9.22
Fat-free mass (kg)	72.81 ± 6.15	71.68 ± 6.16	45.84 ± 10.38	45.19 ± 10.70
Fat mass (kg)	13.99 ± 4.24	13.38 ± 4.21	17.05 ± 5.30	15.80 ± 5.05
Total body water (kg)	53.30 ± 4.50	52.46* ± 4.50	35.73 ± 4.18	35.34* ± 4.41
% Body fat	15.95 ± 3.60	15.57 ± 3.16	25.54 ± 5.25	24.31* ± 5.14

*Significant difference between habitual diet and CRD for men and women ($p < 0.05$).

TABLE 2. Descriptive statistics of mean values for dietary variables for subjects during habitual diet and carbohydrate-restricted diet (CRD) (mean ± *SD*).

	Total kilocalories	Carbohydrate (g)	Protein (g)	Fat (g)
Habitual	2,537.43 ± 99.5	265.40 ± 15.99	144.97 ± 8.54	99.55 ± 4.50
CRD	2,156.55 ± 126.7	30.77 ± 1.94	201.22 ± 10.58	136.51 ± 8.92
Change	−380.88*	−234.63*	56.25*	36.96*

*Significant difference between habitual diet and CRD ($p < 0.05$).

Changes in body mass between habitual diet and CRD for men and women were analyzed using five 2 × 2 mixed factorial ANOVAs to determine if mean differences or interactions existed between gender and diet. The Levene's statistic was used to test for homogeneity of variance for gender. The basic assumptions for each variable were met except for total protein consumption. The dependent body mass variables were body weight (kg), FFM (kg), fat mass (kg), percent body fat, and TBW (kg).

Four 2 × 2 mixed factorial ANOVAs were used to analyze the dietary variables data for gender and diet. The independent variables were gender and diet. The dependent dietary variables were total kilocalories, carbohydrate (g), fat (g), and protein (g). The mean values for total kilocalories, carbohydrate, fat, and protein during the habitual diet and CRD were used to calculate differences.

RESULTS

During the first testing session, each subject performed handgrip dynamometry, vertical jump, 1RM bench press and back squat, maximum-repetition bench press, and a 30-second Wingate anaerobic test after having consumed a habitual diet for 7 days. Individuals were instructed to consume a normal diet for 7 days before the first testing session. During the second testing session, subjects performed the same test battery after consuming a CRD for 7 days. The basic statistical assumptions for each variable were met. Post hoc statistical power analysis was performed using G*Power 3 version 3.1.5 (Franz Faul, Uni Kiel, Germany). The statistical power for the power variables was 0.99, and for muscular strength, the statistical power was 0.83.

No significant interactions existed among variables except for gender and fat mass, gender and TBW, and gender and percent body fat. The changes in anthropometrics can be found in Table 1. Subjects experienced a significant decrease ($p < 0.05$) in body weight during the CRD compared with the habitual diet. There was no significant difference ($p > 0.05$) in FFM and fat mass after consuming a CRD compared with a habitual diet. Subjects had significantly less ($p < 0.05$) TBW after consuming the CRD compared with a habitual diet. Men had no significant change ($p > 0.05$) in percent body fat while consuming a habitual diet compared with a CRD. Women had significantly less ($p < 0.05$) percent body fat after consuming the CRD (24.3 ± 5.1%) compared with a habitual diet (25.5 ± 5.6%).

No significant interactions existed for any of the dietary variables. Men (2,846.0 ± 138.9 kcal) consumed significantly more ($p < 0.05$) total kilocalories compared with women (2,055.2 ± 143.5 kcal). Subjects consumed significantly more ($p < 0.05$) total kilocalories during a habitual diet (2,537.43 ± 99.5 kcal) compared with a CRD (2,156.55 ± 126.7 kcal).

By design, subjects consumed significantly less ($p < 0.05$) total carbohydrates during the CRD (30.8 ± 1.9 g) compared with the habitual diet (265.4 ± 16.0 g). Subjects consumed significantly ($p < 0.05$) more fat during the CRD (136.5 ± 8.9 g) compared with the habitual diet (99.6 ± 4.5 g). Men (212.1 ± 12.2 g) consumed significantly more ($p < 0.05$) total protein compared with women (134.1 ± 12.6 g). Subjects consumed significantly more ($p < 0.05$) protein during the CRD (201.2 ± 10.6 g) compared with the habitual diet (145.0 ± 8.5 g). Dietary variables are presented in Table 2.

There was no significant interaction ($\Lambda = 0.964$, $p > 0.05$) between gender and diet for the relative strength variables. Significant ($p < 0.05$) main effects for gender ($\Lambda = 0.196$, $p < 0.05$) and diet ($\Lambda = 0.415$, $p < 0.05$) for relative strength existed. Subjects had a significantly higher ($p < 0.05$) relative strength for handgrip (3.7 ± 0.1 load lifted/body weight$^{2/3}$) and back squat (8.9 ± 0.4 load lifted/body weight$^{2/3}$) during the CRD compared with the habitual diet handgrip strength (3.5 ± 0.1 load lifted/body weight$^{2/3}$)

TABLE 3. Descriptive statistics of mean values for relative strength variables for men and women ($N = 31$). Variables are reported as load lifted/body weight$^{2/3}$.

	Handgrip	Bench press	Squat
Habitual	3.47 ± 0.08	6.10 ± 0.21	8.63 ± 0.36
CRD	3.72* ± 0.08	6.18 ± 0.22	8.88* ± 0.36

*Significant difference between habitual diet and CRD (carbohydrate-restricted diet) ($p < 0.05$).

TABLE 4. Descriptive statistics of mean values for absolute strength and power for men and women ($N = 31$).

	Handgrip strength (kg)	Vertical jump (cm)	Bench press (kg)	Keiser output (psi)	Squat (kg)	Wingate peak power (W)
Habitual	46.93 ± 1.23	52.65 ± 1.36	84.15 ± 3.36	55.36 ± 1.84	117.84 ± 5.45	811.37 ± 28.22
CRD	49.53 ± 1.24	53.58 ± 1.31	84.34 ± 3.40	52.74 ± 1.65	118.78 ± 5.39	849.77 ± 30.76
Change	2.6*	1.2*	0.19	−2.62	0.94*	38.40

*Significant difference between habitual diet and CRD (carbohydrate-restricted diet) ($p < 0.05$).

and back squat (8.6 ± 0.4 load lifted/body weight$^{2/3}$). There was no significant change ($p > 0.05$) in relative bench press strength for subjects consuming the CRD (6.2 ± 0.2 load lifted/body weight$^{2/3}$) compared with the habitual diet (6.1 ± 0.2 load lifted/body weight$^{2/3}$). The descriptive statistics for relative and absolute strength and power variables are listed in Tables 3 and 4, respectively.

A 2 × 2 repeated measures MANOVA was used to determine differences in power measures for gender and diet. There was no significant interaction ($\Lambda = 0.783$, $p > 0.05$) between gender and diet for the power variables. Significant ($p < 0.05$) main effects for gender ($\Lambda = 0.154$, $p > 0.05$) and diet ($\Lambda = 0.573$, $p > 0.05$) for vertical jump existed. Subjects had a significant increase ($p < 0.05$) in vertical jump height while consuming the CRD (53.6 ± 1.3 cm) compared with habitual diet (52.6 ± 1.4 cm). Significant ($p < 0.05$) main effects for gender and diet for Keiser power output and Wingate peak power output were observed. There was no significant difference ($p > 0.05$) for Keiser power output while consuming a CRD (52.7± 1.7 psi) compared with a habitual diet (55.4 ± 1.8 psi). There was no significant difference ($p > 0.05$) for Wingate peak power output while consuming a CRD (849.8 ± 30.7 W) compared with a habitual diet (811.4 ± 28.2 W).

DISCUSSION

The aim of the current study was to determine the short-term effects of switching from a habitual diet to a CRD on strength and power performance. The principle finding of the current study was that strength and power outputs were maintained in trained men and women when switching from a habitual diet to a CRD. The maintenance in strength and power occurred despite a decrease in body weight and FFM.

During this study, both absolute strength and relative strength were greater during the CRD compared with the habitual diet for handgrip strength and back squat strength. The increase in strength is most likely not because of a training effect during the week of the CRD. The increase in handgrip strength during the CRD may have been because of familiarization with the handgrip dynamometer during the habitual diet. Subjects were instructed to perform similar exercise routines during each diet. The increase in strength observed during the CRD was most likely not because of a learning effect of the exercises or neuromuscular adaptations as a result of the training experience of the subjects. The subjects had a minimum of 2 years of experience performing free-weight exercises, and thus, movement patterns were assumed to be stable and neuromuscular adaptations were not a major contributor to increases in strength (4).

Upper-body strength remained unchanged during the CRD compared with a habitual diet for men and women. Similarly, Dipla et al. (10) investigated the effects of a 7-day isoenergetic CRD on maximal muscular strength in moderately trained women. The authors determined that maximal strength of the upper and lower limbs was not impaired by an isoenergetic CRD. They employed isokinetic dynamometry of the lower limbs to determine lower-body maximal strength measures and isometric dynamometry to determine strength of the upper limbs. The results reported by Dipla et al. (10) indicate that strength, measured isotonically, isometrically, and isokinetically, is maintained during a short-term CRD, despite decreases in body weight. Adam-Perrot et al. (1) stated that physical performance is maintained during a CRD by a physiological adaptation that allows the body to use fat as the primary fuel source. The researchers (1) speculated that the adaptation of the body to more efficiently use fat as a metabolic substrate would allow for the preservation of endogenous carbohydrate stores.

During the current study, power output during the 30-second Wingate sprint was maintained during the CRD, and similar results have been reported by Lambert et al. (20). In contrast, Fleming et al. (15) reported a reduction in peak power output during a 30-second Wingate sprint after consuming a CRD for 6 weeks. The diet composition or diet length used by Fleming et al. (15) may account for the disparities in results. The 6-week CRD may have led to greater glycogen depletion compared with this study or downregulation in glycolytic enzyme expression (15). During this study, subjects experienced less of a decrease in body mass compared with those reported by Fleming et al. (15). An increased loss of FFM may have decreased the force production, accounting for the decrease in peak power output.

Individuals during the current study were instructed to eat ad libitum. Mean caloric consumption decreased during the CRD by 314.4 kcal per day compared with the habitual diet. Previous researchers have reported similar reductions in caloric consumption during a CRD (12,22). The reduction in caloric consumption during the CRD may have occurred because of increased ketone production. Ketones, including β-hydroxybutyrate, are produced by the liver from acetyl-CoA as an alternative fuel source during times of reduced carbohydrate availability (7). Meckling et al. (22) suggested that β-hydroxybutyrate might act as an appetite suppressant, possibly accounting for the reduction in caloric intake. Alternatively, Brehm et al. (6) and Sondike et al. (29) stated that a reduction in caloric intake during a CRD may be because of a reduction in food choices while attempting to limit carbohydrate intake.

Subjects during the current study had an increase in protein consumption during the CRD. Previous researchers have determined that proteins have a greater satiating effect compared with carbohydrates or fats (8,18,21). Individuals during the CRD may have been more satiated because of increased protein consumption, accounting for the decrease in total caloric consumption.

Men and women consumed more protein during the CRD compared with the habitual diet. Researchers have determined that increased essential amino acid ingestion increases muscle protein synthesis (16,32). Increased essential amino acid ingestion stimulates mammalian target of rapamycin (mTOR) activity (9,14). Elevated mTOR activity stimulates an increase in protein translation, causing an increase in protein synthesis (11). During the current study, protein consumption increased, increasing the essential amino acids ingested and perhaps increasing mTOR activity (9,14). The body weight decrease experienced by the subjects during the CRD was a result of reductions in TBW, and not decreases in total body protein.

Researchers have reported that increased protein consumption increases satiety, leading to a reduction in total kilocalories consumed (21,28). The reduction in total kilocalories consumed may have contributed to the reduction in percent body fat for the women during the CRD. Baba et al. (3) reported that an increase in protein consumption leads to an increase in the thermogenic response to feeding, possibly contributing to weight loss.

As expected, men had higher measures of FFM compared with women while consuming both the CRD and the habitual diet. While consuming a CRD, subjects experienced a decrease in FFM by 0.89 kg. Williams et al. (33) reported similar reductions in FFM. Although individuals experienced a decrease in FFM while consuming a CRD, one could speculate that the increase in essential amino acid consumption increased mTOR activity, preserving muscle tissue (9,14).

Meckling et al. (22) reported that reductions in FFM occur at a higher rate during a hypocaloric CRD compared with a hypocaloric low-fat diet. The researchers suggested that a hypocaloric low-fat diet with adequate amounts of protein consumption might preserve FFM better than a CRD with sufficient protein consumption (22). Meckling et al. (22) employed a 10-week diet regimen in which 2 groups consumed either a low-fat diet or a CRD. The low-fat diet group had a reduction in total kilocalorie consumption of 2,540 $kJ \cdot d^{-1}$, whereas the CRD group had a reduction in total kilocalorie consumption of 3,195 $kJ \cdot d^{-1}$ (22). The greater reduction in caloric consumption for the CRD group compared with the low-fat diet group may explain the greater reduction in FFM during the CRD.

Dipla et al. (10) determined that moderately trained women experienced no reduction in FFM while consuming a CRD for 7 days. The differences in FFM alterations between the current study and that of Dipla et al. (10) may be explained by differences in carbohydrate consumption and total caloric consumption. Dipla et al. (10) used a diet considerably higher in carbohydrate consumption (30% of total caloric consumption) compared with the current study. During the current study, subjects consumed food ad libitum, leading to a reduction in total caloric consumption. Dipla et al. (10), in contrast, provided an isoenergetic diet during the carbohydrate-restricted phase of the study.

Men had less body fat and percent body fat while consuming a habitual diet and a CRD. Men and women did not experience a reduction in body fat during the CRD compared with a habitual diet. Women had a reduction in percent body fat during the CRD compared with a habitual diet. The reduction in percent body fat for women during the CRD and no change in percent body for men may be explained by the total kilocalories consumed by each group. The men consumed more total kilocalories during the CRD compared with women, possibly accounting for the lack of change for percent body fat of male subjects.

The reductions in percent body fat for the female subjects during the CRD are similar to the findings of Dipla et al. (10). During the current study, women had a reduction in percent body fat of 1.23%. Dipla et al. (10) reported a reduction of percent body fat in moderately trained women of 1.2%. The researchers caution the interpretation of these results because of the "limited ability of bioelectrical impedance to detect small changes" (10).

Subjects during the current study experienced a decrease in TBW while consuming the CRD compared with a habitual diet. Bergstrom et al. (5) determined that each gram of glycogen is stored with 3 g of water. Subjects during the current study likely had lower glycogen stores after the CRD as compared with following the habitual diet, indicated by an increase in ketone production. Individuals, therefore, most likely experienced a reduction in TBW as a result of decreases in glycogen stores (2). Dipla et al. (10) reported similar reductions in TBW in moderately trained women after consuming a CRD. The researchers (10) suggested that although the women lost TBW, the reduction does not totally explain the reduction in total body mass.

During the present research, subjects improved their handgrip strength and back squat strength while maintaining bench press strength. Vertical jump height increased during the CRD, and power output during the Keiser maximum-repetition bench press and 30-second Wingate anaerobic cycling test were maintained. The maintenance of strength and power during the CRD occurred despite a reduction in body mass and FFM. The improvement in handgrip strength and back squat strength was most likely not because of a training effect or neuromuscular adaptations (4). Women experienced a reduction in percent body fat during the CRD. The reduction in body fat experienced by the women may be because of a reduction in caloric consumption during the CRD compared with the habitual diet.

Practical Applications

The results of this study indicated that a 7-day CRD was effective for reducing body weight with no decrement in strength and power performance. These findings may have implications for sports that use weight classes, and in which strength and power are determinants of success. Wrestling, boxing, and powerlifting are examples of sports included in this category. Individuals participating in these types of sports could use a CRD 7 days before competition to lose necessary body weight and have no detriment in strength and power. A CRD could be used to replace potentially dangerous weight reduction strategies currently employed by some athletes, including starvation and extreme dehydration.

Caution should be used when interpreting these results because adaptation to a CRD likely takes several weeks (24). Our findings apply only to short-term changes in diet. The subjects during the current study were considered highly trained, with a training age of >2 years. Untrained or novice lifters may experience varying results in strength and power output after consuming a CRD compared with highly trained individuals.

Hydration status of the subjects during the habitual diet and CRD was not measured during the current study. Pialoux et al. (24) determined that hydration level can affect the accuracy of body composition measures obtained through bioelectrical impedance analysis. Future research should include measures of hydration status to ensure the subjects are euhydrated.

Future research should include the effects of a CRD on hormonal profile. Measurements could include an anabolic profile, namely, testosterone, insulin-like growth factor-I, human growth hormone, and catabolic hormones, including cortisol. In addition, the CRD should be extended longer than 7 days to determine if detriments in strength and power will occur. The CRD should also be extended to determine if weight loss will continue to occur at the same rate.

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