

Research article

Effects of Short-Term Carbohydrate Restrictive and Conventional Hypoenergetic Diets and Resistance Training on Strength Gains and Muscle Thickness

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Abstract

Hypoenergetic diets and resistance training (RT) have been suggested to be important components of weight loss strategy programs; however, there is little evidence as to the chronic effects of different macronutrient compositions on strength performance and muscle mass with RT. The purpose of this study was to compare the effects of carbohydrate restrictive (CRD) and conventional (CONV) diets combined with RT on strength performance and muscle thicknesses in overweight and obese participants already involved in RT programs. Twenty-one volunteers engaged in an eight-week progressive RT program three times per week were assigned to a CRD (< 30 g carbohydrate; n = 12; 30.7 ± 3.9 km·m⁻²) or a CONV (30% energy deficit; 55%, 15% and 30% energy from carbohydrate, protein and fat, respectively; n=9; 27.7±2.5 km·m⁻²). Method: At baseline and week 8, the participants underwent body composition assessment by anthropometry, measurement of muscle thickness by ultrasound, and three strength tests using isotonic equipment. Both groups had similar reductions in body mass and fat mass as well as maintenance of fat-free mass. Muscle strength increased 14 ± 6% in the CRD group (p = 0.005) and 19 ± 9% in the CONV group (p = 0.028), with no significant differences between the groups. No significant differences were detected in muscle thicknesses within or between the groups. In conclusion, hypoenergetic diets combined with RT led to significant increases in muscle strength and were capable of maintaining muscle thicknesses in the upper and lower limbs of overweight and obese participants, regardless of the carbohydrate content of the diets.

Key words: Overweight, obesity, exercise, body composition, ultrasonography.

Introduction

Hypoenergetic diets and physical activity are basic components of multi-component weight-loss strategies (American College of Sports Medicine, 2009). A considerable body of evidence (Hession et al., 2009; Noakes et al., 2006) has shown that carbohydrate restrictive diets (CRD), with daily carbohydrate intake below 150 g (Westman et al., 2007), promote greater weight loss than conventional (CONV) hypoenergetic diets with normal macronutrient composition.

Evidence on the effects of CRD on exercise performance is controversial. Previous studies have indicated detrimental effects on aerobic performance (Lambert et al., 1994; Langfort et al., 1997; Pitsiladis and Maughan, 1999), while others found no alterations (Mitchell et al., 1997; Phinney et al., 1993; Vogt et al., 2003).

Studies regarding the effects of CRD associated with resistance training (RT) on changes in strength and fat free mass (FFM) are very scarce. Kerksick et al. (2009) and Wycherley et al. (2013) reported that CRD did not impair the gains in muscular strength of participants during 14-week and 12-week programs, respectively. Brinkworth et al. (2007) reported that 10 weeks of CRD unaccompanied by RT did not impair isometric strength in overweight women. Another study (Wood et al., 2012) compared the effects of a low-fat diet with a CRD combined with progressive RT on preservation of FFM in older men and concluded that both types of diet similarly preserve FFM. However, this study did not measure strength performance changes during the 12-week program.

A study from our laboratory compared the short-term effects of hypoenergetic diets with different daily carbohydrate content on the strength performance of sedentary women (Meirelles et al., 2010). The data showed no detrimental effects on isokinetic leg strength after 7 days of CRD (less than 30 g of carbohydrate) or CONV (approximately 47% of total energy intake prevented from carbohydrate).

In spite of the popularity and effectiveness of CRD on body mass loss (Blanck et al., 2006; Helge et al., 2001), the chronic effects of such diet in association with a RT program have not been extensively investigated. Previous studies have dealt with individuals that were sedentary prior to the beginning of the exercise and diet interventions. Therefore, the main objective of the present study was to compare the effects of two different hypoenergetic diets (CRD or CONV) on strength performance and muscle thicknesses during a progressive RT program in resistance-trained overweight and obese participants. A secondary objective was to determine the impact of an 8-week program on body mass and fat loss. It was hypothesized that CRD would induce greater short-term body weight loss, but both diets would maintain muscle thickness and elicit strength gains.

Methods

Study design and sample

The intervention included eight weeks of an experimental diet (CRD or CONV) and progressive resistance training. Initially, participants reported their dietary and physical activity histories, and underwent body composition and muscle thickness assessments and strength tests. At the end of the first four weeks, body composition and strength

tests were repeated, and at the end of another eight weeks, all procedures were repeated.

The participants were allowed to choose their diets, considering dietary habits and food preferences. The participants met weekly with a nutritionist during the initial four weeks and every two weeks in the second month. At each meeting, participants underwent nutritional counseling and completed a 24-hour food intake recall.

Twenty-one participants with at least three months of experience in RT and with a body mass index ≥ 25 kg/m² from four fitness centers of Rio de Janeiro city participated in the study. Twelve participants were assigned to the CRD group (10.0 \pm 9.2 months experience; 32 \pm 10 years; 30.7 \pm 3.9 kg·m⁻²; 8 women) and nine to the CONV group (11.5 \pm 10.4 months experience; 45 \pm 10 years; 27.7 \pm 2.5 kg·m⁻²; 5 women).

Exclusion criteria were as follows: limb injuries, pregnancy, diabetes, use of ergogenics or medication for the treatment of obesity, dyslipidemias, hypertension and renal or hepatic abnormalities in the previous six months. All participants signed a written informed consent form. The study was approved by the Universidade Presidente Antonio Carlos' Ethical Review Board (#097/06), and all experimental procedures conformed to Declaration of Helsinki. This study was registered at www.clinicaltrials.gov, under NCT01096836.

CRD participants were instructed to reduce carbohydrate intake to less than 30 g per day during the first four weeks; afterwards, they were allowed to add 10 g of carbohydrate each week until the end of the study. Participants received handouts listing the amounts of carbohydrate in frequently eaten foods and guidelines regarding food choices, as well as recommendations for the daily use of vitamin and mineral supplements.

A registered nutritionist prescribed the structured CONV diet based on each individual's nutritional habits.

The diet was designed to comprise approximately 70% of an individual's energy requirements (Food and Agriculture Organization, 2004), with approximately 55% of the energy originating from carbohydrates, 15% from proteins, and approximately 30% from fats (Institute of Medicine, 2006). The participants also received a standard exchange list and additional handouts consisting of dietary instructions encouraging the consumption of fruits, vegetables, legumes, and whole cereals, as well as a recommendation to avoid candy, soft drinks, sugar-based beverages, chocolate, and other high-calorie foods.

Individual meetings were held weekly, when instructions were given to participants from both groups to reinforce the principles of the program. The meetings consisted of dietary and training counseling. All participants were encouraged to consume at least two liters of water every day, lean meats, and to avoid high-fat meat products.

Measurement of muscle thickness

Muscle thicknesses were measured by B-mode ultrasound (US) using a 7.5 MHz linear transducer (Toshiba Nemio[®], Japan). The midpoint of the arm was determined by anatomical sites of the elbow flexors and extensors, between the lateral border of the acromion and the humeral radial fossa. Knee extensor thickness was measured between the proximal border of the patella and the inguinal ligament.

Muscle thicknesses were measured between the adipose tissue and bone interfaces at previously identified anatomical landmarks and recorded to ensure that the same site was used for the re-test (Figure 1). This technique has been used to assess the muscle thickness response to resistance exercise in previous studies (Klemp et al., 2016; Starkey et al., 1996; Schoenfield et al., 2015a; 2015b).

The cross-sectional images were frozen on the

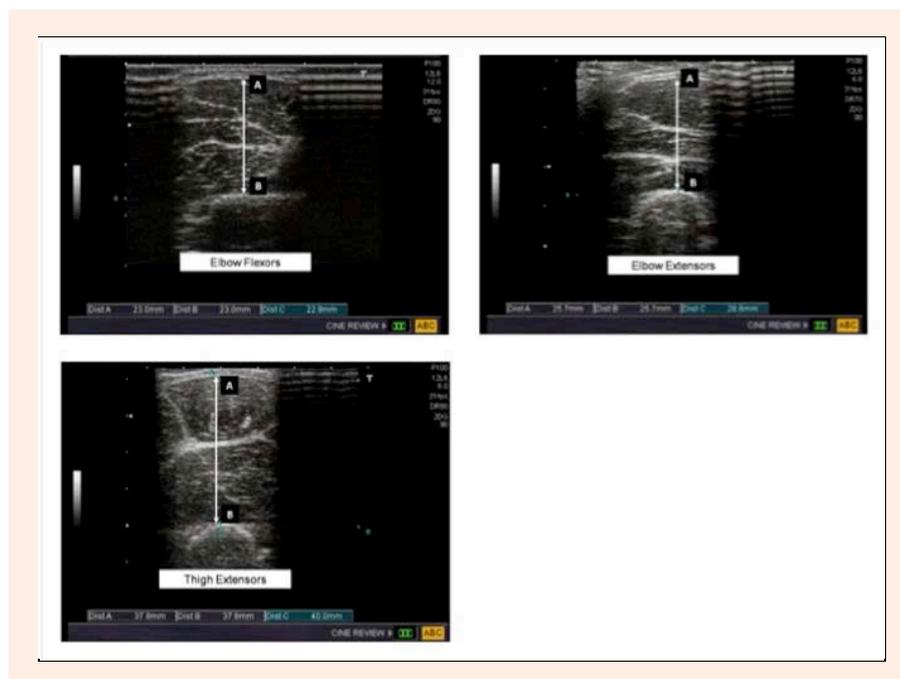


Figure 1. Typical example of ultrasound images obtained in three muscular sites. Panels A and B represent adipose/muscle interface and muscle/bone interface, respectively; arrow represents the measured thicknesses.

video display screen and measured with virtual calipers from US equipment. This protocol was based on a modification of the study performed by Starkey et al. (1996). In our laboratory, the day-to-day intra-class correlation coefficient (R) and the absolute typical error (TEM = standard deviation/ $\sqrt{2}$) of the muscle thickness measures had the following values: R = 0.970, TEM = 1.3 mm for elbow flexors; R = 0.971, TEM = 1.6 mm for elbow extensors; and R = 0.929, TEM = 1.9 mm for knee extensors (Gomes et al., 2010).

To facilitate the access to each anatomical site, elbow flexor and knee extensor thickness measurements were performed with participants lying in the supine position. Elbow extensors were measured with participants lying in the prone position, with the limbs straight in a resting position. The probe was maintained perpendicular to the longitudinal arrangement of the muscles and was carefully positioned over the skin to avoid the compression of underlying tissues.

Body composition measurements

Body mass, standing height, waist girth, and skinfolds were measured by a certified anthropometrist, according to international standards developed by the International Society for the Advancement of Kinanthropometry (Marfell-Jones et al., 2006). Skinfolds were measured at the following sites: abdomen, chest, and thigh for men, and suprailiac, triceps, and thigh for women. Skinfolds at each site were measured twice; when the two measures differed by more than 10%, a third measure was taken. The mean value of the two closest measures was used for data analysis. Measurements were always taken at the same time of the day, with participants wearing shorts (men) or shorts and a top (women), in a room with controlled temperature. Body density was estimated using the equations proposed by Jackson and Pollock (1978) and Jackson et al., (1980) for men and women, respectively. Siri's equation (1961) was used to predict the percent body fat. Hydrostatically derived prediction equations proposed by Jackson and Pollock (1978) and Jackson et al., (1980) were highly correlated to body fat determined from hydrostatic weighing and with low cross-validated estimated error for similar sub-samples, for men and women, respectively. Both studies demonstrated that body density and body fat values determined from the three skinfold equations were not significant different from those using seven skinfolds.

All tests were performed prior to and following the 8-week training and were always performed by the same experienced evaluators.

Resistance training program

Progressive resistance training was performed three times per week, every other day. It consisted of 2 sets of eleven exercises with 8-10 repetitions maximum (8-10 RM, which is defined as the maximum load lifted in a minimum of 8 to a maximum of 10 correct movement executions until volitional fatigue) and 2 min rest intervals between sets. Progressive resistance training routines, including exercise types and loads, did not substantially

differ from those which the participants were familiar with. However, the new training loads were prescribed based on the results of the strength tests performed prior to the beginning of the training period. One of the study's objectives was to keep a high external validity concerning the training conditions.

Training sessions for both men and women included the following exercises: leg presses, triceps push-downs, biceps pulldowns, bench presses, seated rows, knee extensions, and abdominal crunches. Men also performed seated calf raises, shoulder presses, chest flies, and lat pulldowns. Women also performed hip adductions and abductions, knee flexions, and hip extensions. When participants were able to perform 12 or more repetitions in the second set of any exercise, the load was increased by approximately five per cent in the subsequent training session. Participants were also required to maintain their habitual low-intensity aerobic physical activity.

All strength tests were performed with the same equipment used for training. The strength tests consisted of a maximum of eight to 10 repetitions (8-10 RM) of leg press, triceps pushdown, and biceps pulldown. Test-retest intraclass correlation coefficients for 8-10 RM tests were reported to range from 0.98 to 0.99 in our previous study (Pereira and Gomes, 2003). Total body strength (TBS) was considered the sum of the total load multiplied by total repetitions performed in these three exercises.

An experienced physical education professional from the research team was responsible for prescribing the training routines, while the fitness center instructors supervised the day-to-day training. Attendances at the training sessions and outside activities were checked during the weekly meetings between the researchers and the participants. All participants attended more than 90% of the training sessions.

Statistical analysis

Non-parametric statistics were used due to the heterogeneity and the non-Gaussian distribution of the data. The Wilcoxon test was applied to within-group differences and the Mann-Whitney test to between-groups differences. Analyses were performed using a statistical software package (SPSS-PC, version 17.0, 2008, SPSS Inc., Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

Results

Habitual energy intake and percentages of carbohydrates, proteins, and fat were similar between groups: 2486 ± 567 kcal; $51 \pm 14\%$; $18 \pm 5\%$; and $31 \pm 9\%$, respectively, in the CRD participants; and 2115 ± 475 kcal; $51 \pm 9\%$; $22 \pm 9\%$; and $28 \pm 8\%$, respectively in the CONV participants. After eight 8 weeks of intervention, the participants of the CRD group had a significantly reduction of energy consumption of 37% ($p = 0.046$) and a reduction of carbohydrate consumption of 72% ($p = 0.028$). The participants in the CONV group had a significantly reduced energy intake of 31% ($p = 0.028$) and total fat intake reduction of 39% ($p = 0.028$); however, their carbohydrate intake did not significantly change. The intake of protein did not

significantly decrease in both groups. At the end of eight weeks, significant between-group differences were detected only in carbohydrate consumption (CRD: 83 ± 43 g and CONV: 171 ± 54 g; $p = 0.008$). None of the participants reported adverse effects as a result of neither of the diets.

Habitual daily protein intake did not differ between the groups (1.8 ± 0.6 g/kg and 2.0 ± 1.2 g/kg, for CRD and CONV, respectively). At the eightieth week, protein intake was reduced to 1.5 ± 0.8 g/kg and 1.6 ± 0.7 g/kg, respectively; however, the reduction was not statistically significant.

Gains in strength in each exercise test are shown in Table 1. No significant differences in baseline were observed between groups. At the end of the study, both groups significantly increased strength in the three muscle groups tested ($p < 0.05$), with no significant difference between groups in the leg presses, triceps pushdowns, or biceps pulldowns ($p = 0.161$, $p = 0.203$, and $p = 0.460$, respectively).

Table 1. Muscle strength (10 repetition maximum tests) of participants on carbohydrate restrictive (CRD) and conventional (CONV) diets associated to resistance training during eight weeks. Data are means (\pm SD).

	Week 0 (kg)	Week 8 (kg)
Biceps pulldowns		
CRD	48.8 (16.5)	52.7 (17.3)*
CONV	43.8 (16.2)	54.6 (22.6)*
Triceps pushdowns		
CRD	36.2 (17.6)	39.9 (20.5)*
CONV	30.4 (15.3)	35.4 (18.4)*
Leg presses		
CRD	112.1 (35.1)	131.0 (46.1)*
CONV	84.0 (21.0)	114.3 (38.1)*

* $p < 0.05$ compared to baseline values (Wilcoxon test)

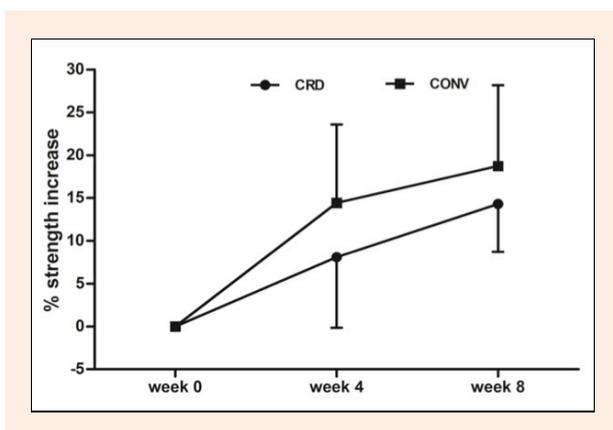


Figure 2. Percent changes in total body strength (total load multiplied by total repetitions) performed in leg press, triceps pushdown and biceps pulldown of participants on carbohydrate restrictive (CRD) and conventional (CONV) diets associated to a resistance training program during eight weeks. Values are mean and standard deviation.

The participants of both groups increased total body strength (TBS) as a result of the resistance training. The CRD participants increased TBS by $14 \pm 6\%$ ($p = 0.005$) and the CONV participants increased TBS by $19 \pm 9\%$ ($p = 0.028$), with no significant differences between

the groups (Figure 2). Similar results were found when values were expressed as strength-to-body mass ratio.

No significant differences were detected in muscle thicknesses within or between the groups as a result of the interventions (Table 2).

Table 2. Muscle thicknesses (mm) of participants on carbohydrate restrictive (CRD) and conventional (CONV) diets associated to resistance training during eight weeks. Data are means (\pm SD).

	Week 0 (kg)	Week 8 (kg)
Elbow flexors		
CRD	27.4 (5.7)	26.7 (5.6)
CONV	25.6 (3.8)	25.4 (4.1)
Elbow extensors		
CRD	23.4 (5.1)	25.5 (6.3)
CONV	24.5 (5.2)	25.9 (7.0)
Knee extensors		
CRD	37.7 (8.6)	36.9 (7.5)
CONV	32.8 (6.4)	34.1 (5.8)

Body mass loss was significant in both groups ($5.4 \pm 3.5\%$; $p = 0.001$ in CRD group; and $3.7 \pm 3.0\%$; $p = 0.015$ in CONV group). The percent fat mass was significantly reduced in the CRD (from $29.8 \pm 6.0\%$ to $25.1 \pm 6.9\%$; $p = 0.005$) and in the CONV group (from $27.7 \pm 4.9\%$ to $24.8 \pm 6.0\%$; $p = 0.017$). The waist girth also significantly reduced (from 90.5 ± 14.0 cm to 86.5 ± 12.6 cm; $p = 0.002$ in the CRD group; from 88.2 ± 12.4 cm to 84.8 ± 10.9 cm; $p = 0.008$ in the CONV group). The fat-free mass did not significantly change (from 58.3 ± 11.2 kg to 59.3 ± 11.2 kg in CRD group; and from 58.6 ± 17.0 kg to 58.6 ± 16.9 kg in CONV group). No significant differences between the groups were detected in all morphological variables measured.

Discussion

The main result of this study was that, irrespective of carbohydrate content, the hypoenergetic diets did not impair strength gains, and the volunteers were able to maintain muscle thickness during resistance training. Furthermore, significant similar reductions were observed in body mass and body fat in both diet groups.

Although the total weight loss of the groups was modest, our results showed that half of the CRD participants and one third of CONV ones lost more than 5% of their initial body mass after the 8-week program. This magnitude of weight loss has been shown to be enough to confer significant improvements in chronic disease risk factors (Magkos et al., 2016). More importantly, data from the present study revealed that short-term hypoenergetic diets associated with RT were able to significantly reduce fat mass and preserve muscle thicknesses in major muscle groups, even with low carbohydrate contents, as in the CRD group.

Similar results were found by Kerksick et al. (2009), who reported that energy restriction was mainly responsible for significant improvements in muscle endurance and maximal strength of participants in a 14-week pneumatic resistance-based circuit exercise training program, as well as significant body mass and body fat

losses. These changes were independent of the carbohydrate content of hypoenergetic diets containing 7–55% of energy as carbohydrates. Moreover, Brinkworth et al. (2007) and Wycherley et al. (2013) observed that reductions in carbohydrate ingestion did not impair the isometric strength of sedentary participants after eight or 12 weeks of moderate energy restriction diets, respectively.

The current study took a different approach, using traditional progressive resistance training with isotonic machines and a rigorous monitoring of strength changes. This type of exercise is more popular and has been recognized as a useful tool in reducing health risks since it helps to increase fat-free mass and the loss of fat mass during periods of energy restriction (Beavers et al., 2014; Nicklas et al., 2015).

The daily amount of carbohydrates allowed in the present study corroborates previous studies (Brinkworth et al., 2007; Mitchell et al., 1997). Individuals were instructed to gradually increase carbohydrate consumption from the fifth week until the end of intervention to facilitate their return to their habitual diets. The energy was restricted to 30% of the individual energetic requirement in the CONV group, as frequently utilized by other authors who reported appropriate body mass loss rates (Brinkworth et al., 2007; Noakes et al., 2006).

Although it is not possible to establish an exact mechanism from the current intervention, our findings demonstrated that it is possible that the amounts of carbohydrates, protein, and energy ingested under both prescribed dietary regimes were enough to provide the substrates needed during resistance training and to satisfy the nutritional needs for muscle mass preservation. Nevertheless, it is likely that the subjects in the CRD group have not been able to fulfill their muscle glycogen reserves, given the low carbohydrate intake and continued resistance training. Therefore, it is reasonable to speculate that some metabolic adaptations may occur to support the strength and muscle thicknesses maintenance, as observed in the present study.

Mitchell et al. (1997) reported that depletion of muscle glycogen stores caused no impairment in strength performance of resistance-trained men. In addition, Harber et al. (2005) showed that muscle protein synthesis might increase even during a pronounced reduction in blood insulin concentration. It probably occurs due to the increases in growth hormone secretion secondary to the normal or higher protein contents of prescribed diets. Moreover, previous studies that tested the combined effects of RT and very low energy diets demonstrated maintenance of fat-free mass (Donnelly et al., 1993) and hypertrophy in trained muscles (Bryner et al., 1999) after 12 weeks of diets of only 800 kcal and approximately 100 g of carbohydrate daily. Nevertheless, real chronic adaptations occurring during CRD and RT deserve further investigation.

In the present study, body mass, body fat, and waist girth were significantly reduced, whereas fat-free mass was maintained in both CRD and CONV diet groups. Similar to findings by Jabekk et al. (2010) and Wood et al. (2012), which followed overweight women and men submitted to 10 weeks and 12 weeks of RT

combined with CRD, respectively.

Factors contributing to these results may include the fact that participants of both groups did not significantly change their protein ingestion and equally adhered to the resistance training program. It is known that protein intake itself might have appetite-suppressant properties (Paddon-Jones et al., 2004) and that resistance training is effective in preventing fat-free mass loss (American College of Sports Medicine, 2009; Beavers et al., 2014; Nicklas et al., 2015).

A potential limitation to the present study was the fact that volunteers could select their own dietary intervention. Longer studies using more sophisticated methods to monitor changes in body composition are needed to clarify the effects of hypoenergetic diets combined with RT on the health and strength changes in obese and overweight people.

Conclusion

Data from this study indicate that overweight and obese individuals submitted to resistance training while undergoing a short-term hypoenergetic dietary intervention may be capable of gaining muscle strength and maintain muscle thicknesses. Simultaneously, the participants experienced significant reductions in body mass and body fat, regardless of their carbohydrate intake. In addition to the existing literature on the numerous health benefits of carbohydrate restriction, this research supports the conclusion that, in combination with resistance training, CRD is a plausible method to maintain muscle mass during energy restriction programs. These results may be important to alert health professionals that CRD may be an alternative intervention for treating these subjects, as long as there is no specific contraindication.

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Key points

- The study deals with the effects of carbohydrate restrictive diet associated to a typical resistance training program, in obese and overweight individuals.
- The study presents greater external validity, since it was devised in an actual fitness center setting with physically active participants enrolled in exercise programs in three fitness centers of Rio de Janeiro.
- The study was registered at the US Clinical Trials.

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