Original Paper

Effects of Resistance *vs.* Aerobic Training Combined With an 800 Calorie Liquid Diet on Lean Body Mass and Resting Metabolic Rate

Randy W. Bryner, EdD, Irma H. Ullrich, MD FACN, Janine Sauers, MS, David Donley, MS, Guyton Hornsby, PhD, Maria Kolar, MD, and Rachel Yeater, PhD

Department of Human Performance and Applied Exercise Science (R.W.B., J.S., D.D., G.H., R.Y.), and Department of Medicine, School of Medicine (I.H.U., M.K.), West Virginia University, Morgantown, West Virginia

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Objective: Utilization of very-low-calorie diets (VLCD) for weight loss results in loss of lean body weight (LBW) and a decrease in resting metabolic rate (RMR). The addition of aerobic exercise does not prevent this. The purpose of this study was to examine the effect of intensive, high volume resistance training combined with a VLCD on these parameters.

Methods: Twenty subjects (17 women, three men), mean age 38 years, were randomly assigned to either standard treatment control plus diet (C+D), n=10, or resistance exercise plus diet (R+D), n=10. Both groups consumed 800 kcal/day liquid formula diets for 12 weeks. The C+D group exercised 1 hour four times/week by walking, biking or stair climbing. The R+D group performed resistance training 3 days/week at 10 stations increasing from two sets of 8 to 15 repetitions to four sets of 8 to 15 repetitions by 12 weeks. Groups were similar at baseline with respect to weight, body composition, aerobic capacity, and resting metabolic rate.

Results: Maximum oxygen consumption (Max VO_2) increased significantly ($p<0.05$) but equally in both groups. Body weight decreased significantly more ($p<0.01$) in C+D than R+D. The C+D group lost a significant ($p<0.05$) amount of LBW (51 to 47 kg). No decrease in LBW was observed in R+D. In addition, R+D had an increase ($p<0.05$) in RMR O_2 ml/kg/min (2.6 to 3.1). The 24 hour RMR decreased ($p<0.05$) in the C+D group.

Conclusion: The addition of an intensive, high volume resistance training program resulted in preservation of LBW and RMR during weight loss with a VLCD.

INTRODUCTION

Obesity is a major health problem in the United States affecting more than 34 million Americans [1]. Weight loss through dieting alone has been shown to result in a dramatic and sustained reduction in resting metabolism [2,3]. Very-low-calorie diets (VLCD) are often recommended in cases of extreme clinical obesity [4]. Their use has primarily been limited to persons who have failed to lose weight in more conventional diet programs and whose body mass index (BMI) is greater than 30 [5]. The problem often associated with the VLCD is the significant loss of lean tissue and a subsequent decrease in resting metabolism, especially in the early phase of the diet [6]. Endurance exercise in combination with severe energy restriction has been shown to result in less decrease in fat free mass (FFM) as compared with dieting alone [7,8]. However, a number of other studies have reported that endurance training in conjunction with very-low-calorie diets have either produced no effect [9–12] on the retention of FFM, or even caused an augmented loss compared with the very-low-calorie diets alone [13,14].

It has been suggested that resistance-training may be more effective than aerobic exercise in preserving or increasing FFM and resting metabolic rate (RMR) [15], especially in conjunction with a VLCD [16]. This combination, however, has not been extensively studied. A limited number of studies have

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Address reprint requests to: Randy W. Bryner, EdD, Department of Human Performance and Applied Exercise Science, PO Box 9227, 8317 HSC, Morgantown, WV 26506.

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combined resistance training with a VLCD and reported no added benefit for the retention of FFM compared to the VLCD alone [12,17]. However, resistance training during severe energy restriction and large-scale weight loss has been shown to produce significant hypertrophy in the skeletal muscle in which training occurred [18]. It does not attenuate the loss, however, of FFM in non-exercised tissue. It is possible that previous studies using resistance exercise protocols have utilized an insufficient volume of exercise. A review of several weight loss studies involving exercise concluded that those which produced the greatest weight loss involved either intensive training programs or were of relatively long duration [19]. The purpose of this study was to compare the effects of an intensive high volume resistance training program with a standard treatment control aerobic training program in subjects consuming a VLCD for 12 weeks. Changes in body weight, FFM and RMR were compared between groups.

METHODS

Participants

Twenty subjects (17 women, three men) with a mean age of 36.7±11.5 years, weight of 95.1±13.0 kg, and a BMI of 35.2±2.9 kg/m^2 were recruited through newspaper advertisements to participate in a 12-week diet and exercise study. The criteria for participation in the study were no involvement in a regular exercise or weight loss program for at least 6 months prior to the first visit and no known cardiovascular, endocrinologic or orthopedic disorders. After informed consent was obtained, all potential subjects underwent a complete medical examination to determine their ability to participate. Eligible subjects were randomly assigned to one of two groups: standard treatment control plus VLCD (C+D, females=8, males=2), or resistance exercise plus VLCD (R+D, females=9, males=1). Each subject was given a maximum stress test, body composition analysis, and RMR determination prior to the start of the study. Subject characteristics can be found in Table 1.

Resting Metabolic Rate

The RMR of subjects was determined at baseline and week 12. Following an overnight fast of at least 12 hours, subjects reported to the Human Performance Laboratory for the determination of RMR. Subjects were fitted with a Hans Rudolf face mask which was connected to an Aerosport metabolic system for the determination of breath by breath oxygen analysis. Subjects rested quietly in a supine position for 30 minutes in a thermo-neutral environment. The mean oxygen consumption (VO_2) was calculated over the final 5 minutes and was used to determine the RMR. A menstrual history was taken for each of the female subjects at the start of the study. The goal of the study was to keep the phase of the menstrual cycle constant for the baseline and week 12 RMR test. However, since the study was exactly 12 weeks in duration, three of the females (one in C+D; two in R+D) who had a regular cycle during the study were post tested in the alternate cycle phase due to variations in cycle length.

Table 1. Subject Characteristics at Baseline (Mean±SD)

	C+D (N=10)	R+D (N=10)
Age (years)	39.0±11.6	35.8±13.2
Body weight (kg)	93.8±15.1	97.7±15.2
BMI	35.2±3.9	35.5±2.0
Fat (%)	44.5±7.0	46.2±6.8
LBW (kg)	51.4±10.6	51.6±7.9
Peak VO_2 (ml/kg/minute)	21.2±2.6	21.1±4.2
RMR (kcal/day)	1569.2±202.39	1737.1±393.4
RMR (ml/kg/minute)	2.2±0.5	2.6±0.5

C+D, standard treatment control plus VLCD; R+D, resistance treatment plus VLCD

BMI, body mass index (kg/m^2); LBW, lean body weight; VO_2, oxygen consumption; RMR, resting metabolic rate.

Peak Oxygen Consumption and Hydrostatic Weighing

Peak oxygen consumption (PVO_2) was determine at baseline and at 12 weeks by a symptom limited treadmill graded exercise test (GXT) using a modified Balke treadmill protocol [20]. Participants received a verbal overview of the GXT procedure and were fitted with a noseclip and a Hans Rudolph non-rebreathing mouthpiece for collection of expired air during the GXT. Breath by breath oxygen analysis was done with an Aerosport metabolic system. The protocol was initiated at a comfortable but brisk walking speed at 0% elevation. Treadmill speed remained constant throughout while the elevation was raised 1% each minute until volitional fatigue. Criteria for considering the GXT a maximal effort included at least two of the following: a plateau in maximal oxygen consumption, a respiratory ratio greater than 1.0, or voluntary discontinuation by the participant despite urging from the staff. Hydrostatic weighing was used to determine percent fat and fat free mass at baseline and at 12 weeks by a previously validated method [21].

Diet

All participants were given the same diet for the entire 12-week study period. The VLCD consisted of a liquid formula (40% protein, 49% carbohydrate, 11% fat) ingested five times a day yielding a total of 800 kcals daily. Two multivitamin tablets were also consumed daily. Diet and vitamins were provided by Health Management Resources Inc., Boston, MA. Participants were asked to refrain from other food or non diet beverages. All subjects met with an investigator weekly and were questioned about their medical condition and their compliance to the dietary protocol. Only 1 week worth of supplement was given at a time requiring subjects to be present at the weekly weigh-in and meeting sessions. Adherence to the diet was questioned if weight loss was less then 2 lbs per week. Each subject was asked to give a verbal declaration of adherence to the diet at each weekly meeting. Self-reported compliance was excellent.

Exercise Training Protocols

Resistance Training plus Diet. The Resistance Training (R+D) group performed resistance exercises 3 days/week at 10 stations which included four lower body and six upper body exercises for 12 weeks. The initial 2 week were used to familiarize subjects to the resistance training apparatus and to determine the maximum weight that could be lifted either once (1RM) or eight times (8RM). The 1RM was determined as follows: Subjects performed one set of six to eight repetitions with a weight that could be lifted 12 to 15 times. A second set of two to three repetitions with a slightly heavier weight was performed. The weight was then increased to a cautious estimate of the 1RM at which time subjects attempted a single lift. If successful, the weight was gradually increased until the subject could not complete the one repetition lift. The 1RM test was conducted during week 2 and again at the end of week 12.

The training protocol was as follows: During the initial training session, subjects exercised by lifting a weight that was considered light for one set of approximately 15 repetitions per station. For the second workout, subjects performed two sets using the same weight as the first workout for each station. A gradual increase in weight was used until subjects were lifting a weight that could be lifted at least eight times but no more than 12 times as determined by the 8RM for two sets by the end of week 2 of training. Three sets were done at week 6 and four sets at week 9 all utilizing the same intensity and number of repetitions as described previously. Rest periods of approximately 1 minute were given between each exercise throughout the training session in a circuit-type workout. Careful monitoring of subjects was done to insure that once an individual was able to lift a weight 12 times on the final set, additional weight was added on the next training session. In addition, heart rate was monitored during the 1-minute resting periods periodically throughout the exercise session by radial artery palpation. This procedure was used throughout the 12-week training period to maintain a consistent level of training intensity. Training sessions were scheduled three times per week with a mandatory 1-day rest between visits to eliminate soreness and insure full recovery due to the aggressive nature of the protocol. Very few subjects complained of fatigue or soreness throughout the entire 12-week period.

Standard Treatment Control plus Diet. The Standard Treatment Control (C+D) group exercised 4 days/week by walking, biking, or stair climbing. Exercise duration began at 20 minutes/day and increased 10 minutes/day/week until subjects were exercising 50 to 60 minutes each session. A self-paced protocol was used to simulate the HMR program in which exercise intensity is not prescribed but exercise is encouraged. In addition, heart rate was monitored approximately every 10 minutes during exercise by radial artery palpation. All participants were individually monitored at each exercise session to assure compliance with both the resistance and aerobic training protocols.

Data Analysis

A series of independent repeated measures analysis of variance (ANOVA) calculations were used to assess the degree to which exercise training (resistance vs. standard treatment control) produced changes in cardiovascular fitness, metabolic, and weight variables over two time points (pre-post training). Because of the low number of male subjects, data were analyzed both with males included and excluded. Results were similar, therefore the following results reflect the entire subject pool. A probability level of 0.05 was selected as the criterion for statistical significance.

RESULTS

No differences were observed between groups at the start of the study for body weight, percent fat, LBW, Max VO_2, or RMR (Table 1). Compliance to exercise sessions was excellent in both groups during the 12-week study, averaging 92.5%±17.9% and 91.4%±21.8% for the C+D and R+D groups, respectively with no difference between groups. The C+D exercised at a greater ($p<0.01$) heart rate intensity compare to R+D during the daily training sessions (78.4%±5.9% vs. 69.0%±7.7%; mean±SD percent of max HR)

Maximum VO_2 and treadmill time to fatigue was measured during the pretest and immediately after the 12-week study period (Table 2). There was a significant increase ($p<0.05$) in peak VO_2 for both of the C+D and R+D groups (C+D: 21.2±2.6 to 27.6±3.4 ml/kg/minute; R+D: 21.1±4.2 to 27.4±5.5 ml/kg/minute, mean±SD) which was of similar magnitude. There was a significant group by test interaction ($p<0.05$) for the treadmill time to fatigue. (C+D: 12.0±3.7 to 17.5±2.8 minutes; R+D: 10.9±2.7 to 13.8±6.1 minutes, mean±SD). The C+D group had a significantly greater improvement than did R+D.

Body weight, body fat, LBM, BMI, and percentage of fat measured during the pretest and post test can be found in Table 2. Although both groups lost a significant amount of weight ($p<0.05$) there was a significant group by test interaction ($p<0.01$) for body weight. As can be seen in Table 2, C+D experienced a significantly greater decrease in body weight than did R+D, (19.4 vs. 14.7%). Each group experienced a similar reduction ($p<0.05$) in body fat (C+D: 40.8±9.1 to

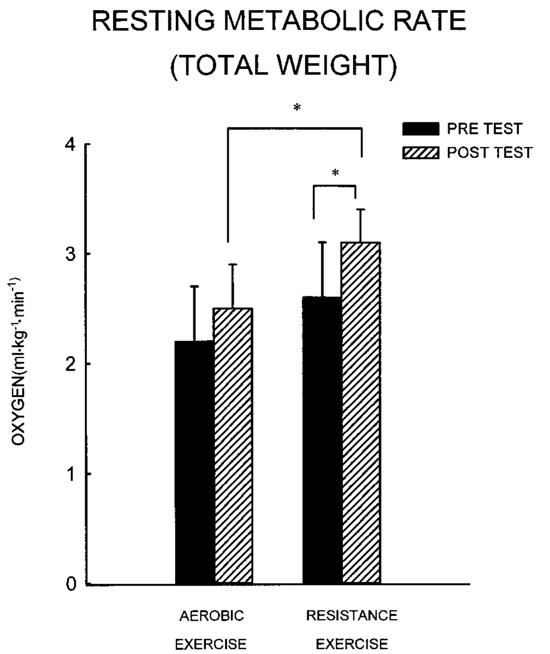

Fig. 1 Resting metabolic rate (RMR, mean±SD) expressed as ml/kg/minute for the resistance plus diet (R+D) and standard treatment control aerobic plus diet (C+D) groups. RMR increased significantly ($p<0.05$) pre to post in R+D. It was also significantly greater ($p<0.05$) in the R+D than in the C+D group after 12 weeks. No change was observed in the C+D group pre to post.

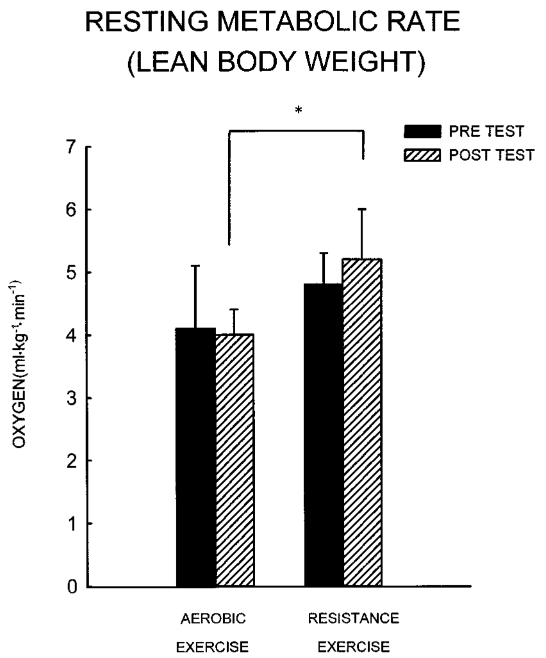

Fig. 2 Resting metabolic rate (RMR, mean±SD) expressed as ml/kg LBW/minute for the resistance plus diet (R+D) and standard treatment control aerobic plus diet (C+D) groups. RMR was significantly greater ($p<0.05$) in the R+D than in the C+D group after 12 weeks. No change was observed in the C+D group pre to post.

28.0±6.5 kg, R+D: 44.9±10.9 to 30.4±5.3, kg), fat percentage (C+D: 44.5±7.0 to 37.1±6.0, R+D: 46.2±6.8 to 37.6±4.8), and BMI (C+D: 35.2±3.9 to 28.6±2.8, R+D: 35.5±2.0 to 29.7±1.7). There was also a significant ($p<0.05$) group by test interaction for LBW. Lean body weight decreased ($p<0.05$) in the C+D group (51.3±10.7 to 47.3±7.0 kg, mean±SD). No reduction in LBW was observed in the R+D group (51.6±7.8 to 50.7±9.0 kg, mean±SD).

There was a significant group by test interaction for the RMR expressed either as ml/kg/minute total weight (Fig. 1) or ml/kg LBW/minute (Fig. 2). As can be seen in Fig. 1, RMR increased ($p<0.05$) in the R+D group and was greater after 12 weeks compared with C+D. The RMR was also significantly greater ($p<0.05$) in the R+D versus the C+D group after 12-weeks expressed as ml/kg LBW/minute (Fig. 2) or 24-hour RMR (Table 2). The 24-hour RMR (Table 2) decreased significantly ($p<0.05$) in the C+D group (1569.2±202.4 to 1358.5±297.1 kcal/day, mean±SD).

The 1RM test results for leg press (LPRM), leg extension (LERM), bench press (BPRM), and shoulder press (SPRM) determined for R+D can be found in Table 3. There was a significant ($p<.01$) increase in strength in all four measures pre to post. The increases in strength ranged from 23.0±3.7% for SPRM to 48.0±30.1% for LERM. The average intensity during

Table 2. Changes in Body Composition Data, RMR and Peak VO_2 (Mean±SD)

	C+D (N=10)		R+D (N=10)	
	Pre	Post	Pre	Post
Body weight (kg)	93.8±15.1	75.7±10.6*	97.7±15.2	83.3±12.6*†
BMI	35.2±3.9	28.6±2.8*	35.5±2.0	29.7±1.7*
Fat (%)	44.5±7.0	37.1±6.0*	46.2±6.8	37.6±4.9*
LBW (kg)	51.4±10.6	47.3±7.0*	51.6±7.9	50.8±9.0
Fat (kg)	40.8±9.1	28.0±6.47	44.9±19.9	30.4±5.3
Peak VO_2 (ml/kg/minute)	21.2±2.6	27.6±3.4*	21.1±4.2	27.4±5.5*
Treadmill time (minutes) to fatigue	12.0±3.7	17.5±2.8*	10.9±2.7	13.8±6.1*†
RMR (kcal/day)	1569.2±202.4	1358.5±297.1*	1737.1±393.4	1800.4±362.0†

C+D, standard treatment control plus VLCD; R+D, resistance treatment plus VLCD.
BMI, body mass index (kg/m^2); LBW, lean body weight; VO_2, oxygen consumption; RMR, resting metabolic rate. * $p<0.05$, significantly different from pre test values; † $p<0.05$, significant differences between groups.

Table 3. Changes in Strength after 12 Weeks of Resistance Training in the R+D Group (Mean±SD)

	R+D (N=10)		
	Pre	Post	% Change
SPRM (lbs)	62.7±16.3	76.5±22.0*	23.0±3.7
BPRM (lbs)	67.9±16.5	95.0±25.5*	42.4±23.4
LPRM (lbs)	333.0±70.4	468.5±72.7*	38.7±22.4
LERM (lbs)	94.2±35.0	135.7±32.6*	48.0±30.1

R+D, resistance treatment plus VLCD.
SPRM=shoulder press one repetition maximum; BPRM=bench press one repetition maximum; LPRM=leg press one repetition maximum; LERM=leg extension one repetition maximum.
* $p<0.05$, significantly different from pretest values.

the final week of training for the R+D group for these four measures was 75.9±8.3% of the maximum 1RMs.

DISCUSSION

The results from the present study indicate that the addition of a high intensity high volume resistance training program to a VLCD can attenuate the loss of LBM and increase RMR while still producing a significant weight loss. Combining aerobic exercise and a VLCD resulted in a significant decrease in body weight, LBM, and RMR. Resistance exercise was also associated with an increase in peak VO_2 similar to changes seen in the standard treatment control aerobic group.

Other studies have reported that weight loss through the combination of diet and aerobic exercise results in significant loss of both body fat and LBM [9–12] similar to the present findings. The percentages of fat and lean body mass lost on VLCDs has been reported to be approximately 75% and 25%, respectively [22]. These percentages can fluctuate and may be affected by the amount of protein intake [23] and the amount of physical activity performed during the VLCD period. The diet used in the present study was composed of 40% protein or approximately 80 g/day. Froidevaux and others [23] reported that a low-energy diet supplemented with protein (77±4 g protein/day) resulted in a body fat mass decrease of 11±4 kg corresponding to 83±19% of weight loss. This would indicate that a diet supplemented with protein may contribute to the maintenance of LBM during periods of severe energy restriction. However, although diet composition can potentially affect the type of tissue lost during conditions of negative energy balance, such effects are usually very small given the short duration of most obesity treatment programs and therefore of minimal significance during the weight loss period [24]. Some evidence indicates that aerobic training concurrent with VLCD can cause greater loss in FFM than occurs with a VLCD alone [13,14]. Resistance training may be more advantageous to use during periods of severe energy restriction as it has been shown to have a low metabolic cost and to create a smaller energy deficit then aerobic training. This ultimately could help preserve FFM.

The relative percent change in weight after 12 weeks of VLCD was significantly greater in the standard treatment control aerobic training versus resistance training group. The scheduled exercise sessions per week for the C+D and R+D groups were four and three sessions, respectively. Subject compliance to exercise was excellent for both groups and did not differ. The resistance training group only exercised three times weekly because the aggressive program necessitated a day of rest between workouts. The C+D group exercised 4 days per week because this has been the experimental design used in past studies with VLCD [12,17] and because the purpose of this group was to serve as a standard treatment control. In addition, subjects in C+D exercised at a greater intensity per session (higher percent of maximum HR) as compared with the resistance trained subjects. Therefore, it is likely that these subjects expended more energy throughout the 12-week training program compared with R+D contributing to the greater weight loss. It is also possible that subjects in C+D were under a greater influence of catabolic hormones such as epinephrine during and immediately following each workout. Previous studies have reported that exercise can stimulate the sympathetic nervous system and that the release of catecholamines, especially epinephrine, during exercise is an intensity dependent process [25,26]. There is a possibility that subjects in R+D would have lost more weight had they exercised four times per week as opposed to three. However, what is known is that resistance training three times per week while consuming a VLCD was associated with a significant large loss of clinically relevant body weight and that this loss was almost entirely fat weight.

Few studies have been conducted that combine resistance training with weight loss and even fewer have examined this type of exercise in combination with a VLCD. Ballor and others [27] reported that resistance training can increase fat free mass in subjects consuming a diet of approximately 1200 kcal/day. However, most studies that have combined a VLCD (800 kcals or less) have reported that resistance training does not attenuate the loss of LBM or decrease in RMR. Resistance training combined with severe energy restriction (approximately 520 kcal/day) showed no greater retention of FFM than when severe energy restriction was used by itself [12]. In a similar study, Donnelly et al [17] reported that resistance training alone or in combination with aerobic training showed no greater effects in increasing weight loss or decreasing the loss of FFM or RMR compared to VLCD alone. The same study also reported no differences between aerobic and resistance training for any of the aforementioned parameters. Comparisons with these and the present study are difficult due to the different experimental designs used in each study, especially the resistance training protocols. The present study incorporated a progressive intensive resistance training protocol of high volume designed to not only prevent the decline in FFM with weight loss but enhance it if possible. Maintaining FFM and RMR may be very important during periods of weight loss.

Previous research has shown that significant muscle hypertrophy is possible in an individual undergoing severe energy restriction. Both slow twitch and fast twitch cross-sectional fiber area increased significantly in muscles that were resistive trained for 90 days in individuals who were consuming a VLCD [18]. Similar to the present study, dietary intake was approximately 800 kcals/day. However, hypertrophy was only seen in exercised muscles and the resistance training was unable to prevent the loss of overall FFM any better then diet alone. Muscular activity during severe energy restriction may decrease protein catabolism by decreasing the sensitivity of working muscles to catabolic hormones [28]. However, it is possible that some baseline level of dietary intake (i.e., 800 to 1200 kcals) is necessary for significant muscle hypertrophy to occur with resistance training. Studies have reported that a dietary intake of 1,000 to 1,500 kcals is needed to see the positive benefits that exercise training can have on RMR and FFM [29,30]. Alternatively, it is also possible that a more aggressive resistance training protocol which incorporates more muscle groups could attenuate this loss of FFM so often seen during severe energy restriction. Results from the present study showed, in fact, that this type of protocol was able to maintain FFM in individuals who were consuming a VLCD and losing a significant amount of weight.

A significant increase in peak VO_2 was observed in both the aerobic and resistance trained individuals. Previous studies combining resistance training only with a VLCD have not reported increases in peak VO_2 [12,17]. The present protocol required that the subject not only be challenged to lift more weight but also to maintain a minimal rest period between sets to incorporate a circuit type workout. This approach most likely contributed to the increased oxygen consumption noted in the resistance training group and may have contributed to the maintenance of FFM.

Subjects in the R+D also experienced a significant increase in both upper body and lower body strength as measured by the four 1RM tests. The 1RM testing was conducted at the end of the second week of training. This was done to allow for the initial strength gains so often seen at the beginning of a resistance training program, particularly in previously untrained individuals. The causes of these increases have been associated with the optimization of motor unit recruitment patterns or the so called "neurological training" [31]. Subjects in the C+D were instructed not to participate in any resistance training during the course of the study. For this reason, 1RM testing was not performed on these subjects because a single lifting measurement would most likely have been invalid and not comparable to those obtained from the R+D group.

In summary, the addition of high volume aggressive resistance training to a VLCD was associated with a significant weight loss while preserving LBW and RMR. The preservation of LBW and RMR during the consumption of a VLCD did not occur with a standard treatment control aerobic training program. These results indicate that high volume resistance training may be beneficial for patients who use a VLCD to lose large amounts of weight at least for periods up to 12 weeks. Future clinical studies need to determine its efficacy in long term weight loss programs and the maintenance of this weight loss for extended periods of time.

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