


Effect of circuit training with low-carbohydrate diet on body composition, cardiometabolic indices, and exercise capacity in adults with mild to moderate obesity in Saudi Arabia

A randomized control trial

Mohamed K. Seyam, PhD^{a,*}, Mazen Alqahtani, PhD^a, Mohamed Sherif Sirajudeen, PhD^a , Hariraja Muthusamy, MPT^a, Faizan Z. Kashoo, MPT^a, Mukhtar M. Salah, PhD^b

Abstract

Background: Circuit training that combines aerobic and resisted training is reported to reduce body fat, weight, and improve exercise capacity than performing either type of exercise independently. There is no study evaluating the combined effect of circuit training exercise (CTE) and dietary intervention (low-carbohydrate [LC] diet) among young males with obesity.

Methods: A randomized control trial was conducted to explore the effects of a combined program of CTE and a LC diet for adults with mild or moderate obesity. Seventy adults with obesity were allocated randomly into 2 groups. The experimental group (group 1) received circuit training with LC diet intervention, whereas the control (group 2) received only circuit training. The study variables such as exercise capacity, body composition, and cardiometabolic indices were measured at the baseline and the end of 60 days of intervention.

Results: The participants of group 1 showed significant improvements in body composition (body weight, body mass index, waist circumference, waist hip circumference, and body fat percentage), exercise capacity (maximal oxygen consumption), and cardiometabolic indices (high-density lipoprotein, low-density lipoprotein, triglycerides, and total cholesterol) with a $P < .05$ for all the variables, when compared with group 2.

Conclusions: The combined structured CTE with controlled LC diet intervention in obese adults caused significant reduction in body composition and cardiometabolic indices variables and an increase in exercise capacity.

Abbreviations: BMI = body mass index, CTE = circuit training exercise, HR = heart rate, LC = low carbohydrate.

Keywords: aerobic exercise, body composition, cardiometabolic indices, circuit training, low-carbohydrate diet, obesity, resistance training

1. Introduction

The prevalence of obesity across the globe has almost tripled from 4% in 1975 to 18% at present. According to the World Health Organization, the worldwide obesity represents 13% of the world adults account for more than 650 million adults, 18 years and older, were obese.^[1,2] More than one-third of adults in Kingdom of Saudi Arabia (KSA) are considered to be obese.

The overall prevalence of obesity in KSA is 3.6 million, and Saudis 15 years old or older were found to be obese.^[3] In the KSA, the overall estimate percentage of the population of obesity or with risk of obesity is 69%.^[4] Obesity seems to be popular among adults, but now it appear among young adults as its prevalence is rising every year.^[5] Obesity is predisposing factor for multisystem disorders such as diabetes mellitus, coronary artery diseases, some neoplasms, renal diseases, sleep disorders,

This work was supported by the Deanship of Scientific Research at Majmaah University (project no. R-2022-141).

The authors have no conflicts of interest to disclose.

The funding source did not participate in planning, collection, analysis, or interpretation of data. However the funder contribute financially to the publication of the study.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

The research protocol was registered with ClinicalTrials.gov (Identifier: NCT04794309). The full trial protocol is available and can be accessed in the website of (<https://clinicaltrials.gov/>).

^a Department of Physical Therapy & Health Rehabilitation, College of Applied Medical Sciences, Majmaah University, Majmaah, Saudi Arabia,

^b Mathematics Department, College of Science, Majmaah University, Majmaah, Saudi Arabia.

*Correspondence: Mohamed K. Seyam, Department of Physical Therapy & Health Rehabilitation, College of Applied Medical Sciences, Majmaah University, Majmaah 11952, Saudi Arabia (e-mail: m.seyam@mu.edu.sa).

Copyright © 2022 the Author(s). Published by Wolters Kluwer Health, Inc. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial License 4.0 (CCBY-NC), where it is permissible to download, share, remix, transform, and build up the work provided it is properly cited. The work cannot be used commercially without permission from the journal.

How to cite this article: Seyam MK, Alqahtani M, Sirajudeen MS, Muthusamy H, Kashoo FZ, Salah MM. Effect of circuit training with low-carbohydrate diet on body composition, cardiometabolic indices, and exercise capacity in adults with mild to moderate obesity in Saudi Arabia. A randomized control trial. *Medicine* 2022;101:33(e30054).

Received: 10 August 2021 / Received in final form: 24 March 2022 / Accepted: 25 April 2022

<http://dx.doi.org/10.1097/MD.0000000000030054>

joint degeneration, and gouty arthritis.^[6] Thus, obesity is one of the leading causes of mortality and short lifespan.^[7] The epidemiology of obesity continues to increase^[8,9] due to mismatch between energy consumed and expended. Research reports that an obese individual is in a constant state of inflammation due to steady release of adipokines into the circulation.^[10] A well-balanced exercise routine with dietary intervention is required to normalize the body composition, glycemic control, and restore hormonal balance.^[11]

Resistance training and aerobic exercises are customized to help control obesity and the associated risk factors.^[12] Both types of exercise have been prescribed to sedentary and obese individuals and have resulted in improved blood pressure (BP), heart rate (HR), body composition, biochemical markers, and strength.^[13,14] Combined training (i.e., aerobic and resistance training combined) is reported to improve BP, arterial stiffness, body composition, and maximal oxygen consumption (VO_{2max}) than performing either type of exercise independently.^[15,16] Thus, combined training may be a more optimal mode of exercise prescription for the obese population. Even though aerobic exercise is reported beneficial, it has its own limitations. The routine aerobic exercises sometimes become repetitive and demotivating. Repetitive nature of these exercises are not suitable for people with arthritis or morbid obesity. Resistance exercise training are reported to consume calories during and after the exercise due to muscle repair and recovery.^[17]

One weight loss method that has gained popularity in the face of modest supportive scientific evidence is the low-carbohydrate (LC) diet. A popular version of LC diet recommends the extreme restriction of carbohydrate intake to less than 20 g/d initially. This level of carbohydrate restriction can induce serum and urinary ketones and weight loss.^[18,19] LC diet has a positive effect in reducing body weight (BW) and the risk factors that are associated with diseases of other systems, which are predisposed by obesity. The acute LC diet is recommended for its safety and therapeutic effect.^[20] The diet plan of LC diet includes high-fiber content of vegetables, fruit, low-glycemic-index carbohydrates, and healthier fat sources.^[21] Thus, the combined effects of LC diet and circuit training exercise (CTE) would help reduce the risks among obese adults.

This study aimed to investigate the effect of the combined program of CTE (aerobic and resistance exercises) and LC diet in the obese sedentary adults in KSA.

2. Materials and Methods

2.1. Research design

This study was conducted at King Khalid General Hospital, Al Majmaah, KSA. This study followed the Declaration of Helsinki principles. The Majmaah University Institutional Review Board of the Basic and Health Science Research Center provided ethical approval for this study. The approval number was MUREC-Apr. 11/COM-2017/15. All the participants signed a written informed consent form before participation.

2.2. Participants

Seventy mildly (obesity class I 30–34.99 kg/m²) and moderately (obesity class II 35–39.99 kg/m²) obese,^[22,23] previously untrained males were recruited from the Sudair region of Riyadh province. To ensure maximum recruitment of potential participants, distribution of pamphlets and advertisement in the hospital, and community awareness program was conducted before the commencement of recruitment process. None of them had received any exercise program prior to participation in the study. They were randomly assigned into 2 groups. Group 1 was receiving circuit training with diet recommendations. Group 2 was the control group, which received diet

recommendations. The randomization process was carried out by a research assistant who was not involved in the process of randomized control trial, using a randomization scheme. The scheme was generated using the randomization function of Microsoft Excel, Microsoft corporation, Redmond, Washington, USA

2.3. Inclusion and exclusion criteria

Inclusion criteria were: being between 20 and 39 years old; previously sedentary; defined as no strength training and less than 150 minutes of brisk walking or moderate exercise per week and less than 60 minutes of vigorous exercise per week in the preceding 6 months,^[24,25] having a body mass index (BMI) between 30 and 40 kg/m².^[23] Exclusion criteria were having pacemakers, implanted defibrillators, a history of heart problems, chronic respiratory condition, stroke, diabetes, recent cancer, other life-threatening illness, or any condition that limited their ability to engage in moderate-intensity exercise.

2.4. Procedure and measures

2.4.1. Experimental measurements. Body composition and anthropometric assessment, BW, height, BMI, skinfolds (3 sites), and waist circumference (WC)/hip circumference (HC) were measured before and after the 60 days program. BMI was calculated as BW in kilograms divided by the square of height in meters (kg/m²).^[23] Participants' weight was measured in kilograms (kg) (to the nearest 0.1 kg), height was measured in centimeters (cm) (to the nearest 0.5 cm). Skinfold thickness measurements were performed by skin fold calipers on the right side of the body. The 3 measurement sites were the chest, abdominal, and thigh skinfolds. The calculation of the body density (BD) was based on the sum of the skin fold thickness in the 3 sites (S3SF) using a specific equation. $BD = (1.10938 - [0.0008267 \times S3SF]) + (0.0000016 \times [S3SF]^2) - (0.0002574 \times \text{age})$. After calculating BD, body fat percentage (BF%) was determined as follows. $BF\% = (495/BD) - 450$.^[26] The assessment of central obesity was based on WC, HC, and waist hip ratio (WHR). The standardized measurement procedure was followed for the measurement of WC and HC. The participants were instructed to stand erect, relaxed, arms at the side and feet close together. The WC was measured by using measuring inch tape at the midway between the inferior border of the rib cage and iliac crest. The reading was taken at the end of a normal expiration. The HC was measured at the level of greater trochanter of femur (widest part of the hip). The measuring tape was positioned parallel to floor while measuring WC and HC. The WHR is an index of abdominal to lower body fat distribution. The WHR was obtained by dividing WC by HC.

2.4.2. Assessment of exercise capacity. The renowned-modified sub-maximal treadmill exercise test, which is the leading indicator of exercise capacity (EC), was done to calculate VO_{2max} . The test began with a warm-up at a speed of 2.7 km/h for 5 minutes, and the speed was increased every 3 minutes, until the participant exerted the maximum effort and stopped upon exhaustion. The HR and BP were monitored throughout the test using Polar Electro Oy (Karnily, Italy) and Sphygmomanometer, respectively, and were recorded at the end of each level of the test. The brief period of 3 to 5 minutes of cooling down was done upon the completion of the final stage of the test. Verbal encouragement was provided throughout the test to ensure that the maximal effort was achieved. The prediction of the peak VO_{2max} was done using the specific equation. $Oxygen\ consumption\ VO_{2max}\ (mL/kg/min) = 14.76 - (1.379 \times T) + (0.451 \times T^2) - (0.012 \times T^3)$.^[27,28]

2.4.3. Cardiometabolic indices. Blood samples were collected to analyze the concentrations of total cholesterol (Tot. Chol), high-density lipoprotein (HDL), low-density lipoprotein (LDL), and triglycerides (TGs). Serum specimens for the measurements of lipids and lipoproteins were obtained in the mornings after at least 8 hours of fasting blood samples before and after the program. Blood was centrifuged for 15 minutes at 520 × g and 4°C to separate plasma from blood cells, and it was stored at -20°C until the analysis. The analysis of plasma Tot. Chol, HDL, and TG concentrations were done using enzymatic kits, standardized reagents, and VP Auto-analyzer (Abbott Laboratories, North Chicago, IL). The LDL concentrations were calculated using Friedewald equation ($LDL-c [mg/dL] = TC [mg/dL] - HDL-c [mg/dL] - TG [mg/dL]/5$). The within-run CVs were 2.1% for Tot. Chol concentrations, 1.9% for HDL concentrations, and 3.2% for TG concentrations.^[29,30]

2.4.4. Training protocols. The participants randomized to group 1 began the CTE with the following parameters for the first 30 days, 10 minutes of warming-up followed by 30–45 minutes of conditioning protocol at an intensity of 70% of maximum HR. The circuit training was customized as 10 minutes of aerobic exercise and 5 minutes of resistance exercise. This cycle was repeated 3 times upon completion, with a frequency of 5 days per week for the first stage (first 30 days) of

the program. The cool-down period in the form of walking on a treadmill was done at low intensity for 5 minutes. The mode of aerobic exercise used was the electronic braked cycle ergometer, treadmill walking, rowing on row-ergometer, hand cycling on arm-ergometer. Resistance exercise training was tailored in the form of 8 different exercises as follows: military press, leg extension, bench press, standing leg curl (ankle weights), lateral pull-down, dumbbell triceps push-down, dumbbell seated biceps curl, and sit-ups (abdominal curls). In the second stage of the study (i.e., the next 30 days), the duration of resistance exercises was increased from 5 minutes to 10 minutes in each cycle along with the same aerobic exercise protocols performed in stage 1. Hence, the total time of CTE increased from 30–45 minutes to 60–75 minutes in stage 2.^[27,31]

2.4.5. Low-carbohydrate diet. Participants of both groups received the same regulations and instructions on LC diet. Experienced staff in nutrition was consulted and additional handouts were used to instruct the practitioner of both groups to reduce carbohydrate intake to less than 20g per day. There was no strict dietary plan observed among participants; however, participants in both groups (1 and 2) were allowed to eat healthy animal products (chicken, fish, and fat-free meat), green leaves vegetable salad, and 1 cup of LC vegetables (broccoli, squash, or cauliflower). The participants of both

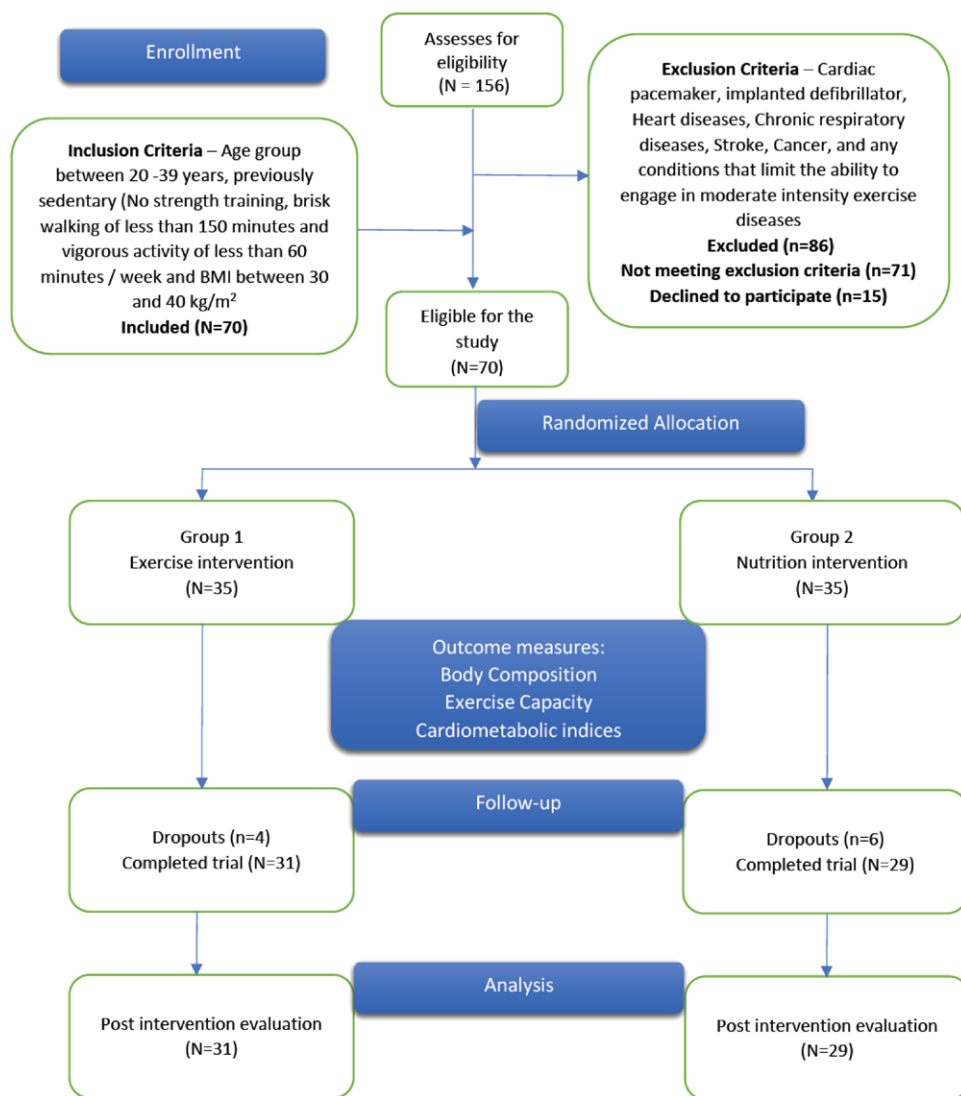


Figure 1. Flowchart representation of the study. BMI = body mass index.

Table 1
Baseline characteristics of participants of group 1 and group 2.

Variables	Group	Preintervention		Significance
		X ± SD	P	
Weight (kg)	Group 1	109.9 ± 11.2	.826	NS
	Group 2	111.1 ± 9.7		
BMI (kg/m ²)	Group 1	35.4 ± 2.5	.617	NS
	Group 2	34.9 ± 3.1		
WC (cm)	Group 1	114.1 ± 5.8	.888	NS
	Group 2	114.2 ± 5.9		
WHR (%)	Group 1	0.96 ± 0.01	.759	NS
	Group 2	0.96 ± 0.02		
BF%	Group 1	27.7 ± 1.5	.803	NS
	Group 2	27.6 ± 1.6		
HDL (mg/dL)	Group 1	49.5 ± 5.8	.851	NS
	Group 2	49.9 ± 5.6		
LDL (mg/dL)	Group 1	107.9 ± 18.9	.764	NS
	Group 2	109 ± 16.6		
TG (mg/dL)	Group 1	113.6 ± 23.7	.996	NS
	Group 2	112.4 ± 21		
Chol. (mg/dL)	Group 1	183.5 ± 22.3	.897	NS
	Group 2	182.6 ± 21.1		
VO _{2max} (mL/kg/min)	Group 1	30.3 ± 4.5	.635	NS
	Group 2	29.6 ± 4.9		

BF% = body fat percent, BMI = body mass index, Chol. = total cholesterol, HDL = high-density lipoprotein, LDL = low-density lipoprotein, NS = non significant, P = probability level, SD = standard deviation, TG = triglyceride, VO_{2max} = maximum oxygen consumption, WC = waist circumference, WHR = waist hip ratio, X = mean.

groups were instructed to increase their fluid intake (i.e., at least 3 liters of water every day).^[32]

2.5. Data analysis

Sample size was calculated based on the mean and standard deviation (7.9% ± 1.6%) obtained from the earlier research on met-analysis using the same variables.^[33] The required sample size was determined as 30 participants in each group using the formula, sample size (n) = z²σ²/d² (z² = square of z-score, σ² = variance of population, d² = margin error).^[34] The data obtained from both the group showed Gaussian distribution. The data measured at the baseline and after the intervention (after the 60th day of intervention) included anthropological data, plasma lipid profile, and EC. The data collection procedure and sequence were the same for all the participants in both groups. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSSv1.0.0.1406). Parametric analysis was done using the paired-sample *t* test, and 2-way

analysis of variances to determine the significance of pre- and post-intervention outcome measurements among the intra-groups. The comparison between group 1 and group 2 was made using the statistical test independent sample *t* test. Comparisons were considered significant at a *P* of .05 or less.

3. Results

Seventy participants with a mean age of 30.3 ± 5.23 years were participated in the study, 35 participants in each group.

In group 1, from the 35 obese men who were recruited, 4 dropped out after the baseline assessment (2 lost interest in the study and 2 moved away). Therefore, the data for 35 participants were available for the initial assessment but 31 participants were included in the final analysis. In group 2, from the 35 participants, 6 dropped out after the baseline assessment as they lost interest in the study (Fig. 1).

Our findings were classified as follows: combined effects of CTE and LC diet on cardiorespiratory fitness, anthropometric body properties, central obesity, peripheral obesity, and serum lipid profile. For group 2, the same measurements were done.

All the baseline assessment comparisons between participants in the 2 groups (pre-intervention) were performed using the independent sample *t* test (Table 1). The results revealed that there was no significant difference between groups in anthropometric body properties, central obesity, peripheral obesity, cardiorespiratory fitness, and serum lipid profile as shown in Table 1.

The within-group (pre-post testing) comparison for group 1 showed statistical significant difference in weight (*P* = .001), BMI (*P* = .001), WC (*P* = .001), WHR (*P* = .002), BF% (*P* = .001), HDL (*P* = .001), LDL (*P* = .013), TG (*P* = .001), cholesterol (*P* = .001), and VO_{2max} (*P* = .028) (see Table 2). However, group 2 showed statistical significant difference in weight (*P* = .001), BMI (*P* = .001), WC (*P* = .009), WHR (*P* = .029), BF% (*P* = .012), VO_{2max} (*P* = .001), but not for HDL (*P* = .977), LDL (*P* = .058), TG (*P* = .218), and cholesterol (*P* = .051) (see Table 3).

A between-group comparison between the post-mean values of group 1 and group 2 showed a significant difference for weight (*P* = .044), BMI (*P* = .015), BF% (*P* = .025) HDL (*P* = .033) and VO_{2max} (*P* = .028) but not for WC (*P* = .613), WHR (*P* = .553), LDL (*P* = .244), TG (*P* = .456), and cholesterol (*P* = .297) (see Table 4).

4. Discussion

Our present study shows that combining the CTE program (aerobic and resistance training) and LC diet significantly reduces the BF%, BW, LDL, and TGs concentration in the blood plasma and has greater incremental effects on the EC/CV fitness and

Table 2
The preintervention and postintervention comparison of characteristics of group 1.

Variables	Preintervention		Postintervention		CR (%)	Significance
	X ± SD	P	X ± SD	P		
Weight (kg)	109.9 ± 11.2	.000	96.6 ± 14.4	.000	12.1%	*
BMI (kg/m ²)	35.4 ± 2.5		32.1 ± 2.2		9.3%	
WC (cm)	114.1 ± 5.8	.001	109.4 ± 4.8	.001	4.1%	*
WHR (%)	0.96 ± 0.01		0.95 ± 0.02		1.0%	
BF%	27.7 ± 1.5	.001	23.9 ± 2.3	.001	13.7%	*
HDL (mg/dL)	49.5 ± 5.8		52.3 ± 5.3		5.7%	
LDL (mg/dL)	107.9 ± 18.9	.013	103.8 ± 16.5	.013	3.8%	*
TG (mg/dL)	113.6 ± 23.7		104.5 ± 22.7		8.01%	
Chol. (mg/dL)	183.5 ± 22.3	.001	165.8 ± 22.1	.001	4.2%	*
VO _{2max} (mL/kg/min)	30.3 ± 4.5		33.6 ± 6.0		10.9%	

BF% = body fat percent, BMI = body mass index, Chol. = total cholesterol, CR = change ratio, HDL = high-density lipoprotein, LDL = low-density lipoprotein, P = probability level, SD = standard deviation, TG = triglyceride, VO_{2max} = maximum oxygen consumption, WC = waist circumference, WHR = waist hip ratio, X = mean.

*Significant.

NS nonsignificant.

Table 3
The preintervention and postintervention comparison of characteristics of group 2.

Variables	Preintervention	Postintervention	P	CR (%)	Significance
	X ± SD	X ± SD			
Weight (kg)	111.1 ± 9.7	106.1 ± 9.6	.001	4.5%	*
BMI (kg/m ²)	34.9 ± 3.1	33.3 ± 3.2	.001	4.6%	*
WC (cm)	114.2 ± 5.9	109.6 ± 4.9	.009	4%	*
WHR (%)	0.96 ± 0.02	0.95 ± 0.01	.029	1%	*
BF%	27.6 ± 1.6	25.2 ± 1.5	.012	8.7%	*
HDL (mg/dL)	49.9 ± 5.6	50.1 ± 4.9	.977	0.4%	NS
LDL (mg/dL)	108 ± 16.6	104.7 ± 16.2	.058	3.1%	NS
TG (mg/dL)	112.4 ± 21	108.2 ± 22.8	.218	3.6%	NS
Chol. (mg/dL)	182.6 ± 21.1	169.7 ± 23.5	.051	7.1%	NS
VO _{2max} (mL/kg/min)	29.6 ± 4.9	32.2 ± 4.8	.001	8.8%	*

BF% = body fat percent, BMI = body mass index, Chol. = total cholesterol, CR = change ratio, HDL= high-density lipoprotein, LDL = low-density lipoprotein, NS = nonsignificant, P = probability level, SD = standard deviation, TG = triglyceride, VO_{2max} = maximum oxygen consumption, WC = waist circumference, WHR = waist hip ratio, X = mean.
*Significant.

Table 4
The preintervention and postintervention comparison of characteristics between group 1 and 2.

Variables	Group	Postintervention	P	Significance
		X ± SD		
Weight (kg)	Group 1	96.6 ± 14.4	.044	*
	Group 2	106.1 ± 9.6		
BMI (kg/m ²)	Group 1	32.1 ± 2.2	.015	*
	Group 2	33.3 ± 3.2		
WC (cm)	Group 1	109.4 ± 4.8	.613	NS
	Group 2	109.6 ± 4.9		
WHR (%)	Group 1	0.95 ± .02	.553	NS
	Group 2	0.95 ± 0.01		
BF%	Group 1	23.9 ± 2.3	.025	*
	Group 2	25.2 ± 1.5		
HDL (mg/dL)	Group 1	52.3 ± 5.3	.033	*
	Group 2	50.1 ± 4.8		
LDL (mg/dL)	Group 1	103.8 ± 16.5	.244	NS
	Group 2	104.7 ± 16.2		
TG (mg/dL)	Group 1	104.5 ± 22.7	.456	NS
	Group 2	108.2 ± 22.8		
Chol. (mg/dL)	Group 1	165.8 ± 22.1	.297	NS
	Group 2	169.7 ± 23.5		
VO _{2max} (mL/kg/min)	Group 1	33.6 ± 6.0	.028	*
	Group 2	32.2 ± 4.8		

BF% = body fat percent, BMI = body mass index, Chol. = total cholesterol, CR = change ratio, HDL= high-density lipoprotein, LDL = low-density lipoprotein, NS = nonsignificant, P = probability level, SD = standard deviation, TG = triglyceride, VO_{2max} = maximum oxygen consumption, WC = waist circumference, WHR = waist hip ratio, X = mean.
*Significant.

HDL concentrations in the blood plasma compared with the group 2 participants with regard to LC diet only.

4.1. Body composition

In the current randomized trial, the examined body fat indicators such as BMI, BF% (P < .05), WC, and WHR decreased significantly in the group 1 participants compared with group 2, which agrees with the previous studies that investigated the combination of exercise programs and LC diet.^[35] The mean of BF% decreased from 27.7 ± 1.5 to 23.9 ± 2.3 for group 1 and from 27.6 ± 1.6 to 25.2 ± 1.5 for group 2 after 60 days of intervention, respectively. In agreement with the previous systematic review and meta-analysis that compared the effects of low-fat diet and LC diet on body composition insinuates that LC diet is more significantly effective in inducing weight loss than low-fat diets.^[36] Group 1 participants more significantly reduced the BF% and BD than group 2 participants. This implies that there

is a greater decrease in visceral adipose tissue in the abdomen, as visceral adiposity is associated with the prevalence of metabolic syndrome and cardiovascular disease (CVD).^[37] In addition, the fat deposition in the abdominal area increases the risk of atherosclerosis, as it discharges free fatty acids into hepatic circulation, thereby increasing the lipoprotein level in the blood plasma.^[38] Hence, group 1 participants exhibited a significant reduction in BF%, which reduces the risk of metabolic syndrome and CVD.^[39,40] The results of the current study support that the combined CTE and LC diet (group 1) significantly reduces BW which is in accordance with previous studies.^[41]

4.2. Exercise capacity

Previous studies have found that the CTE program can increase the VO_{2max} (mL/kg/min) (EC) up to 18% from the baseline values.^[42] Another study has reported that the resistance circuit training causes changes in the mechanism of oxygen transport and utilization and the utilization of energy by the muscles.^[43] As the muscle work during the resistance training degrades the levels of phosphagen and glycogen, there will be greater utilization of the intramuscular TGs. All these changes in the mechanisms of energy utilization will improve the consumption of oxygen during the resistance training. Group 1 in the current trials showed that there is a greater increase in the VO_{2max} when compared with group 2 participants. Therefore, the application of CTE and aerobic training among the obese population increases EC.^[44]

4.3. Cardiometabolic indices (blood biochemistry)

Previous study reported that the combined exercises such as circuit training and aerobic training increases the activity of the extracellular enzyme, lipoprotein lipase, which is responsible for the breakdown of TG. This, in turn causes, molecular increase in HDL.^[45] Our current findings showed significant improvement in the lipid profile values (HDL, LDL, TG, and Tot. Chol) in group 1 (P < .05), whereas group 2 participants exhibited insignificant lipid profile variables (P > .05), which is in accordance with Azarmehr et al,^[40] who displayed a greater reduction in TG, a significant increase in HDL, and no significant effect on the LDL after 8 weeks of circuit resistant training in women over the age of 50 with type 2 diabetes mellitus. In contrast, Watts et al^[46] found no differences in plasma lipids in 19 adolescent obese participants after 8 weeks of circuit training. This may be because the age of the participants was 14.3 ± 1.5 years and the exercise training frequency was only 1 hour per week. There will be an increase in the process of mitochondrial biogenesis due to the adaptation to the exercise

training, which will have a positive effect over the lipid profiles and the intake of glucose. This will, in turn, reduce the risk of CVD.^[47] On the other hand, in addition to CTE, the LC diet has the advantage of increasing the sensitivity of insulin, reducing the concentration of serum insulin, and decreasing hunger hormones, leptin and ghrelin, which increases the energy expenditure during the exercise/activity.^[36,48,49] Therefore, it is important to combine the LC diet with CTE or aerobic exercises to achieve a maximal incremental effect in the levels of HDL, Tot. Chol level and to reduce the levels of LDL and TG in the body.

5. Limitations

There are limitations in our study. The sample size is relatively small and lack long-term follow-up. There could be attrition bias due to drop-out rate in our study. Our study might suffer from sampling bias because participants were recruited from one province of Saudi Arabia.

6. Summary and Conclusion

A combined CTE and nutritional intervention for obesity in adults resulted in favorable weight loss, reduced BMI, decreased BF%, and improved exercise fitness. The intervention focused mainly on CTE training and dietary education. The rationale of our program design of 5 guided training sessions and emphasis on nutritional education was to make it more motivating and challenging to the participants. The future researches are recommended by including nondiabetic overweight individuals.

Author contributions

Mohamed K. Seyam and Mukhtar M. Salah: Formal analysis. All authors: conceptualization, methodology, writing—original draft preparation and writing—review and editing.

References

- 1] <https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight>. [access date June 9, 2021].
- 2] Di Cesare M, Soric M, Bovet P, et al. The epidemiological burden of obesity in childhood: a worldwide epidemic requiring urgent action. *BMC Med*. 2019;17:1–20.
- 3] Memish ZA, El Bcheraoui C, Tuffaha M, et al. Obesity and associated factors—Kingdom of Saudi Arabia, 2013. *Prev Chronic Dis*. 2014;11:E174.
- 4] Enani S, Bahijri S, Malibary M, et al. The association between dyslipidemia, dietary habits and other lifestyle indicators among non-diabetic attendees of primary health care centers in Jeddah, Saudi Arabia. *Nutrients*. 2020;12:2441.
- 5] Wyatt SB, Winters KP, Dubbert PM. Overweight and obesity: prevalence, consequences, and causes of a growing public health problem. *Am J Med Sci*. 2006;331:166–74.
- 6] Litwin M, Kulaga Z. Obesity, metabolic syndrome, and primary hypertension. *Pediatr Nephrol*. 2021;36:825–37.
- 7] Bray GA, Heisel WE, Afshin A, et al. The science of obesity management: an endocrine society scientific statement. *Endocr Rev*. 2018;39:79–132.
- 8] Ogden CL, Carroll MD, Kit BK, et al. Prevalence of obesity among adults: United States. *NCHS Data Brief*. 2012;2013:1–8.
- 9] O'Leary CB, Hackney AC. Acute and chronic effects of resistance exercise on the testosterone and cortisol responses in obese males: a systematic review. *Physiol Res*. 2014;63:693–704.
- 10] Johnson AR, Justin Milner J, Makowski L. The inflammation highway: metabolism accelerates inflammatory traffic in obesity. *Immunol Rev*. 2012;249:218–38.
- 11] Strasser B, Arvandi M, Siebert U. Resistance training, visceral obesity and inflammatory response: a review of the evidence. *Obes Rev*. 2012;13:578–91.
- 12] Strasser B, Schobersberger W. Evidence for resistance training as a treatment therapy in obesity. *J Obes*. 2011;2011:482564.
- 13] Chaudhary S, Kang MK, Sandhu JS. The effects of aerobic versus resistance training on cardiovascular fitness in obese sedentary females. *Asian J Sports Med*. 2010;1:177–84.
- 14] Donnelly JE, Blair SN, Jakicic JM, et al. Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults. *Med Sci Sports Exerc*. 2009;41:459–71.
- 15] Ho SS, Dhaliwal SS, Hills AP, et al. The effect of 12 weeks of aerobic, resistance or combination exercise training on cardiovascular risk factors in the overweight and obese in a randomized trial. *BMC Public Health*. 2012;12:704.
- 16] Ho SS, Radavelli-Bagatini S, Dhaliwal SS, et al. Resistance, aerobic, and combination training on vascular function in overweight and obese adults. *J Clin Hypertens*. 2012;14:848–54.
- 17] Ivy J. Exercise physiology and adaptations to training. In: Devlin J, Schneider S, eds. *Handbook of Exercise in Diabetes*. 2nd ed. Alexandria, VA: American Diabetes Association; 2002:23–62.
- 18] Westman EC. A review of very low carbohydrate diets for weight loss. *J Clin Outcomes Manag*. 1999;6:36–40.
- 19] Westman EC, Yancy WS, Edman JS, et al. Effect of 6-month adherence to a very low carbohydrate diet program. *Am J Med*. 2002;113:30–6.
- 20] Yancy WS Jr, Olsen MK, Guyton JR, et al. A low-carbohydrate, ketogenic diet versus a low-fat diet to treat obesity and hyperlipidemia: a randomized, controlled trial. *Ann Intern Med*. 2004;140:769–77.
- 21] Bray GA, Ryan DH, Gordon D, et al. A double-blind randomized placebo-controlled trial of sibutramine. *Obes Res*. 1996;4:263–70.
- 22] Denis EO, Conor DJ, Katherine AW, et al. Respiratory consequences of mild-to-moderate obesity: impact on exercise performance in health and in chronic obstructive pulmonary disease. *Pulmonary Med*. 2012;2012:818925.
- 23] Louis JA. Classification of obesity and assessment of obesity-related health risks. *Obesity Res*. 2002;10:105S–15S.
- 24] Catrine TL, Cora LC, John PT, et al. A step-defined sedentary lifestyle index: <5000 steps/day. *Appl Physiol Nutr Metab*. 2012;38:100–14.
- 25] World Health Organization. *WHO Guidelines on Physical Activity and Sedentary Behaviour*. Geneva, Switzerland: World Health Organization; 2020.
- 26] Andrew SJ, Michael LP. Practical assessment of body composition. *Phys Sportsmed*. 1985;13:76–90.
- 27] American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. 9th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2014:114–26.
- 28] George JD, Vehrs PR, Allsen PE, et al. $\dot{V}_{O_{2max}}$ estimation from a submaximal 1-mile track jog for fit college-age individuals. *Med Sci Sports Exerc*. 1993;25:401–6.
- 29] Bansal E, Kaur N. Does friedewald formula underestimate the risk of ischemic heart disease? *Indian J Clin Biochem*. 2014;29:496–500.
- 30] Kim S, Kim JY, Lee DC, et al. Combined impact of cardiorespiratory fitness and visceral adiposity on metabolic syndrome in overweight and obese adults in Korea. *PLoS One*. 2014;9:e85742.
- 31] Garber CE, Blissmer B, Deschenes MR, et al; American College of Sports Medicine. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011;43:1334–59.
- 32] Crowe TC. Safety of low-carbohydrate diets. *Obes Rev*. 2005;6:235–45.
- 33] Miller WC, Koceja DM, Hamilton EJ. A meta-analysis of the past 25 years of weight loss research using diet, exercise or diet plus exercise intervention. *Int J Obes*. 1997;21:941–7.
- 34] Daniel WW, Cross CL. *Biostatistics: A Foundation for Analysis in the Health Sciences*. 10th ed. New York, NY: John Wiley & Sons; 2013:189.
- 35] Perissiou M, Borkoles E, Kobayashi K, et al. The effect of an 8 week prescribed exercise and low-carbohydrate diet on cardiorespiratory fitness, body composition and cardiometabolic risk factors in obese individuals: a randomised controlled trial. *Nutrients*. 2020;12:482.
- 36] Chawla S, Tassarolo Silva F, Amaral Medeiros S, et al. The effect of low-fat and low-carbohydrate diets on weight loss and lipid levels: a systematic review and meta-analysis. *Nutrients*. 2020;12:3774.
- 37] Ritchie SA, Connell JM. The link between abdominal obesity, metabolic syndrome and cardiovascular disease. *Nutr Metab Cardiovasc Dis*. 2007;17:319–26.
- 38] Macor C, Ruggeri A, Mazzonetto P, et al. Visceral adipose tissue impairs insulin secretion and insulin sensitivity but not energy expenditure in obesity. *Metabolism*. 1997;46:123–9.

- [39] Cornier MA, Draznin B. Low-carbohydrate diets in the treatment of the metabolic syndrome. In: Nielsen. H ed. *The Metabolic Syndrome*. Vienna, Austria: Springer; 2013:87–98.
- [40] Azarmehr SA, Toloe MRE, Akbari E. The effect of 8 weeks of Circuit Resistance Training on metabolic syndrome risk factors and body composition in women over age 50 with diabetes mellitus type 2. *Int J Appl Exerc Physiol*. 2017;6:103–10.
- [41] Paoli A, Pacelli QF, Moro T, et al. Effects of high-intensity circuit training, low-intensity circuit training and endurance training on blood pressure and lipoproteins in middle-aged overweight men. *Lipids Health Dis*. 2013;12:1–8.
- [42] Brentano MA, Cadore EL, Da Silva EM, et al. Physiological adaptations to strength and circuit training in postmenopausal women with bone loss. *J Strength Cond Res*. 2008;22:1816–25.
- [43] Romero-Arenas S, Martínez-Pascual M, Alcaraz PE. Impact of resistance circuit training on neuromuscular, cardiorespiratory and body composition adaptations in the elderly. *Aging Dis*. 2013;4:256.
- [44] Takeshima N, Rogers ME, Islam MM, et al. Effect of concurrent aerobic and resistance circuit exercise training on fitness in older adults. *Eur J Appl Physiol*. 2004;93:173–82.
- [45] Jane ML, Ho CC, Chen SC, et al. A simple method for increasing high-density lipoprotein cholesterol levels: a pilot study of combination aerobic and resistance exercise training. *Int J Sport Nutr Exerc Metab*. 2012;23:271–81.
- [46] Watts K, Beye P, Siafarikas A, et al. Exercise training normalizes vascular dysfunction and improves central adiposity in obese adolescents. *J Am Coll Cardiol*. 2004;43:1823–7.
- [47] Burgomaster KA, Howarth KR, Phillips SM, et al. Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. *J Physiol*. 2008;586:151–60.
- [48] Samaha FF, Iqbal N, Seshadri P, et al. A low-carbohydrate as compared with a low-fat diet in severe obesity. *N Engl J Med*. 2003;348:2074–81.
- [49] Ebbeling CB, Feldman HA, Klein GL, et al. Effects of a low carbohydrate diet on energy expenditure during weight loss maintenance: randomized trial. *BMJ*. 2018;14:363.