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High-intensity functional training with an adequate and carbohydrate-restricted hypocaloric diet promotes weight loss and cardiometabolic improvements

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ABSTRACT

Introduction: Excess body weight and its comorbidities represent a major public health issue. Interventions based on diet and exercise have not only been shown to promote weight loss, but also improve overall health, including cardiovascular health. **Objective:** This study aimed to evaluate the effects of a 12-week hypocaloric low-carbohydrate (CHO) diet coupled with high-intensity functional training (HIFT) on the cardiometabolic risk of overweight adults. **Methods:** This is a randomized controlled trial. A total of 31 overweight adults participated in this study, divided into two groups based on the dietary intervention: reduced-CHO (R-CHO, ≤130 g/day; n=15) and adequate-CHO (A-CHO, >130 g/day; n=16). The cardiometabolic risk was assessed using lipidaemic, insulinemia, and glycaemic parameters. A two-way ANOVA with Bonferroni post-hoc test was utilized to evaluate the effects of the intervention. A p-value < 0.05 was considered statistically significant. **Results:** Participants from both groups displayed decreased low-density lipoprotein, very-low-density lipoprotein, total cholesterol, and triacylglycerol concentrations, as well as the number of risk factors for the metabolic disease after 12 weeks. The high-density lipoprotein (HDL) cholesterol concentration of both groups increased after 12 weeks, however, the result of the intragroup analysis revealed that a significant increase was only observed in the participants from the A-CHO group. **Conclusion:** Reduced or adequate CHO intake was both found to be effective in reducing cardiometabolic risk. However, improvements in HDL and final cardiometabolic classification risk indicated that CHO adequacy in the diet might be a better strategy associated with caloric restriction and HIFT.

Keywords: obesity; diet, high-protein low-carbohydrate; exercise; cardiometabolic risk factors; weight loss; healthy lifestyle.

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INTRODUCTION

Excess body weight is a public health problem that affects a large portion of the world population and is associated with an increased risk of cardiometabolic disease development[1]. Physical exercise coupled with a low-calorie diet has been pointed out as an effective strategy for weight loss and healthy weight maintenance[2] and is beneficial in improving the cardiovascular risk profile[3]. Thus, this strategy becomes useful for improving the overall health of individuals, being the most effective strategy for obesity prevention[2].

Food intake is an important factor related to body weight variations[4]. In addition to caloric restriction, macronutrient manipulation is a strategy being extensively studied[5-9]. In this context, low-carbohydrate (L-CHO) diets are highlighted as being interesting for weight loss and cardiovascular risk[1].

The minimum recommended daily intake of carbohydrates for adults defined by the Estimated Average Requirement (EAR) is 100 g/day or 45% of the total energy intake (TEI), so L-CHO diets are those with a carbohydrate contribution of less than 45% of TEI[10,11]. However, there are different levels in the spectrum of L-CHO diets which can reach the supply of 20 g/day or 4% of the TEI coming from this nutrient[12,13].

Studies have shown that carbohydrate-restricted diets had a satisfactory effect in improving the cardiometabolic condition of overweight subjects, being characterized by an increase in the concentration of high-density lipoprotein cholesterol (HDL-C) and adiponectin and C reactive protein reduction[13,14].

However, the results are controversial regarding the effect of the L-CHO diet on weight loss and cardiometabolic risk factors. Naude et al.[ten] demonstrated that the L-CHO diet was not superior to a balanced diet for weight loss at 3-6 months and 1-2 years. On the other hand, Mansoor et al.[15] observed that despite the greater weight loss obtained with the L-CHO diet and the increase in HDL-c, there was a concomitant increase in LDL-c. Severe restrictions can lead to unwanted effects[5,6,16,17], and it is necessary to identify effective and safe restriction levels, including when associated with physical training.

Studies have shown satisfactory cardioprotective effects from the association between restrictive diets and traditional physical training methods[2]. However, there is an absence in the scientific literature of clinical trials testing the interaction of this type of diet with modern programs such as high-intensity functional training (HIFT), which can prove to be a viable option because it is easy to apply and low cost[18].

HIFT is based on applying multisegmental exercises performed at maximum concentric speed and aims at the integrated development of physical valences (muscle strength and power, dynamic balance, motor coordination, agility, flexibility, and cardiovascular fitness) to promote multisystem adaptations and ensure autonomy in performing daily functions[19,20].

Furthermore, HIFT can lead to important neuromuscular changes, such as increased muscle cross-sectional area and reduced body fat[21], increased muscle strength and power[22]. Moreover, HIFT can increase cardiorespiratory resistance by increasing VO_2 max and the ability of a skeletal muscle to synthesize ATP by oxidative metabolism[23,24] from high-intensity interval exercises associated with the dynamic and circuit character of the main exercise blocks in its structure.

Although carbohydrate-restricted diets and HIFT alone are effective in generating positive results on weight reduction and metabolic health of individuals, the result regarding their association has still been poorly analyzed. The interventions developed to aid in body fat loss are generally based on moderate-intensity exercises, such as running and walking activities[25].

The recommendation and safe application of carbohydrate restriction and its effects on cardiovascular risk factors are still controversial. Therefore, the objective of this study was to compare the effect of low-calorie diets with carbohydrate restriction within the recommended minimum limits (100 g/day), associated with high-intensity functional training on the cardiovascular risk markers of overweight individuals in a 12-week intervention protocol.

METHODS

Participants

Potential participants aged between 18 and 59 years with a body mass index (BMI) of 25-39.9 kg/m², sedentary lifestyle, and stable weight within the three months before selection were recruited in this study through the university communication systems. The following exclusion criteria were used: ongoing specialized medical or nutritional follow-up, the existence of any eating disorder, diet adherence for weight loss within the last three months, presence of physical limitations and/or oscillation in weight equal to or greater than that aimed by the intervention (±10% body weight) and use of continuous medications which could interfere with the study results, such as anorectic or lipid-lowering agents or hormones. The participants were recruited from the university community, including students, staff, and professors. The sample calculation was performed, and it was observed that a minimum number of twenty-two volunteers would be necessary for a power of 0.8 and 82% detection probability of a difference between treatments[7]. Out of the 361 individuals who were interested in participating in the study, 250 did not meet the inclusion criteria, five left the study, and fifty-seven were redirected to other training programs (aerobic training). Finally, forty-nine overweight adults of all genders were included in the study.

The participants were randomly assigned to two groups according to the dietary intervention: reduced-CHO (R-CHO) and

adequate-CHO (A-CHO) groups. Randomization was performed in the SPSS software program according to the age, gender, and BMI of the participants so that there was no difference between groups for these variables. Figure 1 describes the distribution of the participants in the intervention groups.

The study protocol followed the principles of the Declaration of Helsinki and was approved by the Research Ethics Committee of the Federal University of Sergipe (Protocol No. 483.751) and registered under the Brazilian Clinical Trials Registry (Registration No. RBR-5n9g5f). All the participants provided informed consent.

Experimental design

This randomized controlled trial was designed to evaluate the effects of CHO reduction coupled with HIFT at baseline (M0) and after 12 weeks of intervention (M1). At M0, all participants answered a health and nutrition anamnesis from which demographic and health data were collected. The anthropometric data and dietary and lipid profiles of the participants were examined in both periods. The Research Ethics Committee of the Federal University of Sergipe (Protocol No. 483.751) approved the study protocol.

Individualized nutritional consultations with an average duration of 30–40 mins were performed once a month (weeks 1, 5, and 9) during the 12-week intervention period. Additionally, the weight and abdominal circumferences of the participants were measured, and a 24 h dietary recall was conducted. The participants subsequently attended training sessions (twice a week), and their body masses were also determined every week. Those participants who did not attend the nutritional consultations and/or had more than two consecutive or four sporadic absences during the 12 weeks were excluded from the study.

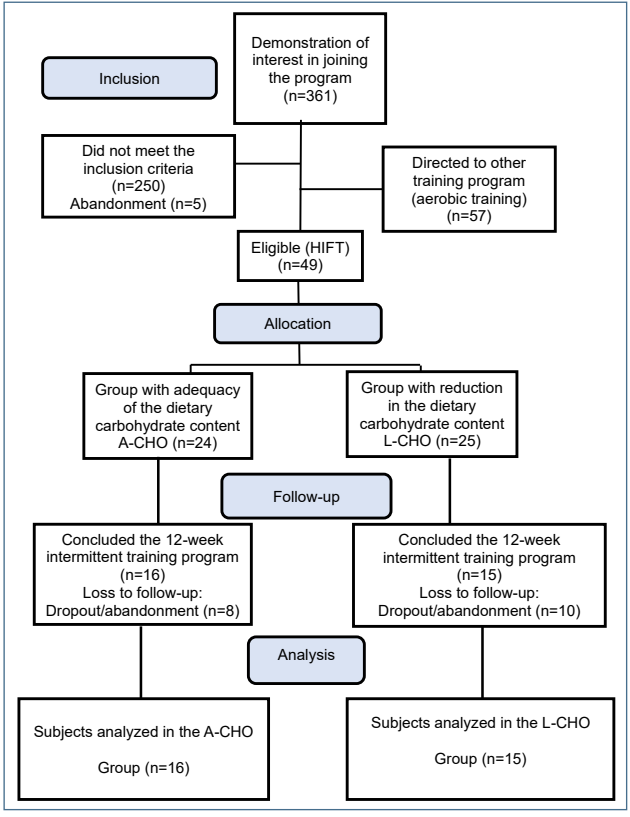

Figure 1: Consort fluxogram of participants.

Dietary intervention for weight loss

Two types of hypocaloric diets that differed in their CHO contents were planned. The R-CHO group had a CHO-reduced diet with an allowable CHO daily intake of around 100 g/day, which is the minimum daily amount required for this nutrient based on the Dietary Reference Intake guidelines[11]. On the other hand, the A-CHO group had an allowable intake of 250 g CHO daily. The caloric deficit was defined as a reduction in the consumption of 500–1000 kcal/day, leading to a target loss of approximately 10% of the body weight by the end of the 12-week intervention period.

The dietary intake of the participants was monitored through dietary records (DRs). The results of the DR analysis during the intervention showed that adherence to the eating plan did not occur as expected among some of the participants upon follow-up. Hence, the participants were further divided into groups for analysis based on their CHO intake (whether below or above the median ingestion of 130 g/day). Table 1 shows the characteristics of the participants' dietary intake during the intervention follow-up.

High-intensity functional training

The participants were put through HIFT three times a week (twice a week supervised by Physical Education professionals and students, and once a week guided but without direct supervision) for 12 weeks, with each session lasting approximately 40 min. Each HIFT session was conducted in three stages. The first stage corresponded to a standardized dynamic warm-up routine, whereas the second one referred to neuromuscular stimulation,

Table 1: Dietary intake characteristics of subjects during weight loss program according to diet group (A-CHO and R-CHO).

Diet component	A-CHO (n = 16)	R-CHO (n = 15)
	x (SD)	x (SD)
TEI (kcal/day)	1 673.9 (397.3)	1 181.6 (236.0)
Total Fiber (g/day)	23.6 (5.8)	16.7 (4.0)*[a]
CHO		
g/day	208.0 (44.3)	112.3 (18.8)*[a]
%TEI	50.6 (8.3)	39.2 (9.4)*
PTN		
g/day	92.6 (23.1)	88.7 (31.2)
%TEI	22.3 (3.6)	29.6 (6.3)*
LIP		
g/day	52.4 (22.8)	42.7 (15.6)[a]
%TEI	27.4 (5.4)	31.8 (6.7)

A-CHO: Group with adequate Carbohydrate content; R-CHO: Group with carbohydrate restriction; TEI: Total Energy Intake; CHO: Carbohydrate; PTN: Protein; LIP: Lipid. *p<0.05; a: Mann-Whitney.

which is further subdivided into two stages, neuromuscular I and II. The neuromuscular I session was characterized by performing push, pull, and squatting exercises in a circuit training routine, which is designed to enhance power, speed, agility, and coordination. On the other hand, the neuromuscular II session comprised strength exercises. The participants performed 5 min circuits twice for the neuromuscular sessions, which are composed of five different exercises, lasting 1 min each. The rest intervals between exercises decreased as the 12-week program progressed, and the training intensity was increased. Meanwhile, the third stage consisted of cardiorespiratory exercises lasting for 5 min and ludic games, which encourages cognitive stimulation.

Anthropometric and body composition evaluation

The body mass of the participants was measured using a 100 g digital scale (LIDER®, Araçatuba, SP, Brazil) during the baseline (M0) and final (M1) evaluations. Waist and hip circumferences were also determined using an inelastic tape measure (CESCORF®, Porto Alegre, RS, Brazil). Furthermore, the participants' body compositions were measured through electrical bio-impedance (BIA 310; Biodynamics® Co., Seattle, WA, USA). BMI was calculated by the mathematical formula weight/height² and classified according to the following cut-off points proposed by WHO[26]: <18.5 kg/m²: underweight; 18.5 - 24.9k kg/m²: eutrophic; 25.0 to 29.9 kg/m²: overweight/preobese; 30.0 - 34.9 kg/m²: class I obesity; 35.0 - 39.9 kg/m²: class II obesity; ≥40.0 kg/m²: class III obesity.

Biochemical and cardiometabolic risk profile evaluation

A venous blood sample was collected at M0 and M1 to evaluate the cardiometabolic markers. The concentrations of the lipid profile markers, which include the total serum cholesterol and its components (LDL-C, HDL-C, very-low-density lipoprotein cholesterol [VLDL-C]) and triacylglycerol, as well as the glucose, fasting insulin, and plasma uric acid levels were measured. The measurements were performed at the Laboratory of Clinical Analysis of the University Hospital using a CMD 800i device (Wiener Lab Group®, Rosario, Santa Fe, Argentina) for the glucose, uric acid, and lipid levels and an ARCHITECT i1000SR device (Abbott®, Lake Forest, IL, USA) for the serum insulin levels.

The participants' metabolic conditions were evaluated based on the criteria determined by the First Brazilian Guideline for Diagnosis and Treatment of Metabolic Syndrome[27]. This guideline consists of the following factors used to classify overweight individuals into metabolically healthy (MH) or metabolically unhealthy (MU) participants: abdominal circumference (>102 and >88 cm for men and women, respectively), triacylglycerol level (≥150 mg/dL), HDL-C level (<40 and <50 mg/dL for men and women, respectively), blood pressure (≥130 mmHg and/or ≥85 mmHg systolic and diastolic blood pressure, respectively), and fasting glucose level (≥110 mg/dL). A participant should present at least three of the metabolic syndrome determinants to be considered MU.

Statistical analysis

The data analysis was performed using the IBM SPSS Statistics software program (version 17.0; IBM Co., Armonk, NY, USA). Descriptive statistics were used to characterize the participants' data, which were presented as mean, standard deviation (SD), or relative and absolute frequencies. A two-way analysis of variance with the Bonferroni post-hoc test was used to compare the characteristics of the two groups (A-CHO and R-CHO) and evaluate the effects of the 12-week intervention based on the changes in the anthropometric, cardiovascular risk, and metabolic syndrome variables. A p-value<0.05 was considered statistically significant.

The effect size (ES) was also evaluated to verify the magnitude of the clinical effect of the intervention. The ES was calculated as follows: post-intervention mean − pre-intervention mean/pool of the pre-and post-intervention SD. The values obtained were classified based on the recommendations of Cohen[28].

RESULTS

A total of 31 (61.29% women) out of the 49 adult university community members who were overweight and initially assigned to the A-CHO and R-CHO groups completed the study. Table 2 displays the participants' characteristics. A significant improvement was observed in all anthropometric characteristics, body composition markers, and basal metabolic rates after the intervention (Table 3).

Furthermore, the participants showed an improvement in their lipid profiles, as evidenced by significant VLDL-C, total cholesterol, and triacylglycerol level reductions (Table 4), accompanied by a significant HDL-C increase as a function of time and LDL-C reduction (Figure 2). However, the analysis of the intragroup intervention effect revealed that only the A-CHO group showed a significant increase in HDL-C levels after the program (Figure 2).

Additionally, we observed that simultaneous glucose and insulin levels declined as a function of time, along with a significant homeostatic model assessment of insulin resistance (HOMA-IR) index reduction for both groups, which demonstrates an improvement in insulin resistance. However, the intragroup analysis showed that glucose concentration was significantly reduced only among the participants in the R-CHO group.

The prevalence of metabolic syndrome was analyzed using biochemical markers by the parameters defined by the First Brazilian Guideline for Diagnosis and Treatment of Metabolic Syndrome[27]. A reduction in the percentage of MU individuals after the 12-week intervention period was found in both groups (Δ=24.2% and 13.4%, for A-CHO and R-CHO groups, respectively).

Table 2: Characteristics of the subjects according to the type of diet (A-CHO and R-CHO).

Characteristics	A-CHO (n = 16)	R-CHO (n = 15)	P
	n (%)	n (%)	
Smoking	0 (0.0)	1 (6.7)	
Drinking alcohol	12 (75.0)	7 (46.7)	
Previous treatment for weight loss	10 (62.5)	7 (46.7)	
Diagnosed hypertension	3 (18.8)	1 (6.7)	
Diagnosed dyslipidemia	1 (6.3)	0 (0.0)	
Family history of CVD	6 (37.5)	3 (20.0)	
Variables	**x (SD)**	**x (SD)**	
Age (years)	32.3 (10.8)	30.4 (7.5)	0.569
Body weight (kg)	85.4 (14.9)	85.2 (13.6)	0.972
Height (m)	169.0 (9.3)	164.6 (7.8)	0.164
BMI (kg/m²)	29.7 (2.9)	31.3 (2.7)	0.133
Systolic Blood Pressure (mmHg)	122.1 (19.7)	119.5 (17.9)	0.621¥
Diastolic Blood Pressure (mmHg)	77.8 (11.6)	75.5 (9.3)	0.692¥
Total cholesterol (mg/dl)	204.4 (54.8)	201.9 (32.9)	0.879
LDL-c (mg/dl)	121.8 (42.0)	112.7 (29.2)	0.493
VLDL-c (mg/dl)	29.4 (14.7)	29.3 (19.0)	0.978
HDL-c (mg/dl)	53.3 (10.4)	60.0 (13.6)	0.129
Triacylglycerol (mg/dl)	146.9 (73.2)	146.4 (94.2)	0.988
Glucose (mg/dl)	88.1 (6.6)	91.6 (11.2)	0.290
Insulin (U/L)	12.2 (6.1)	10.4 (5.0)	0.373
HOMA-IR	2.5 (1.4)	2.4 (1.2)	0.557

A-CHO: Group with adequate Carbohydrate content; R-CHO: Group with carbohydrate restriction; CVD: Cardiovascular disease; BMI: Body Mass Index; ¥Mann-whitney

DISCUSSION

Despite the carbohydrate content (low or adequate), caloric restriction in conjunction with HIFT was effective in improving the cardiometabolic conditions of the overweight individuals who participated in the study, as evidenced by improvements in the lipid profile and insulin resistance markers, and the reductions in cardiovascular and metabolic syndrome risk factors. Furthermore, only the participants from the group with adequate ingestion of carbohydrates showed improvements in the concentrations of HDL-C after the 12-week intervention period, which is a protective factor for cardiovascular disease development.

The participants in this study had significant reductions in body mass, fat percentage, weight, and waist and hip circumferences at the end of the 12-week intervention. The reductions in these markers are key factors that have positive effects on improving the participants' cardiovascular risk profiles.

Caloric restriction is an effective strategy for weight loss than exercise alone[2]. However, HITF effectively contributes to achieving a negative energy balance, a gain of lean mass, and most importantly an improvement in cardiometabolic condition, because a sedentary lifestyle and low aerobic capacity are independent cardiovascular risk factors[29]. The applied exercise program can promote a high daily caloric expenditure and generate positive stimuli on the increase of hormonal release and protein synthesis rate, constituting favorable conditions for gaining muscle mass and reducing fat deposits[30]. Corroborating this finding, Neves et al.[31] found significant reductions in trunk fat, total fat, and body weight after eight weeks of functional training.

Lean mass preservation is a crucial factor that needs to be considered during weight loss. Although the participants had significant reductions in lean mass and basal metabolic rate at the end of the 12 weeks, the magnitude of the intervention's clinical effect on these variables was found to be small in this study. The association with interval exercises with high energy demand might be a factor that avoided the biggest reduction in lean mass in the participants [32]. In this sense, Sobrero et al.[24] found decreased fat percentage, and increased muscle mass, accompanied by better performance in agility, strength, and muscle power tests after 6 weeks of functional circuit training using a methodology similar to the HIFT proposal.

The effects of CHO restriction on the lipid profile remain controversial in the literature. A recent meta-analysis of 11 randomized clinical trials found that participants with low CHO intake (<20% of the TEI) experienced a significant increase in HDL-C concentration. In contrast, participants whose diets had CHO content <20% of the TEI within a period of 6–24 months displayed an increase in their LDL-C concentrations. These results highlight the negative cardiovascular effect of this type of dietary intervention because high LDL-C particle concentration is known to have high atherogenic potential[15,33].

In contrast with the results of the previously published studies, the present study showed an HDL-C concentration increase in the A-CHO group and LDL-C concentration reduction in both

Table 3: Variation of anthropometric after weight loss program according to gender and type of diet (A-CHO and R-CHO)

Variables	Group	Pre	Post	Group	Pre	Post	*p-value*
Body Mass (kg)	**A-CHO**			**R-CHO**			
	Male			**Male**			
	Mean ± SD	94.1 ± 4.6	86.8 ± 5.2*	Mean ± SD	101.1 ± 11.1	90.1 ± 12.8*	I p= 0.718
	CI 95%	83.7 – 104.4	75.2 – 98.3	CI 95%	86.5 – 115.7	73.8 – 106,4	Tp <0.001
	%Δ I ES		-8.01 I 0,50	%Δ I ES		-11.03 I 0.88	G p= 0.552
	Female			**Female**			
	Mean ± SD	76.7 ± 10.5	71.7 ± 10.5*	Mean ± SD	79.4 ± 9.1	73.4 ± 8.2*	I p= 0.711
	CI 95%	69.4 – 83.9	64.8 – 78.6	CI 95%	73.2 – 85.6	67.5 – 79.2	Tp <0.001
	%Δ I ES		-6.42 I 0,47	%Δ I ES		-6.20 I 0.67	G p= 0.623
	All			**All**			
	Mean ± SD	85.4 ± 14.9	79.2 ± 14.9*	Mean ± SD	85.2 ± 13.6	77.8 ± 11.9*	I p= 0.771
	CI 95%	78.1 – 92.7	72.3 – 86.2	CI 95%	77.6 – 92.7	70.7 – 85.0	Tp <0,001
	%Δ I ES		-7.22 I 0,41	%Δ I ES		-8.47 I 0,56	G p= 0.872
Abdominal Circumference (cm)	**A-CHO**			**R-CHO**			
	Male			**Male**			
	Mean ± SD	107.1 ± 11.9	98.4 ±12.7*	Mean ± SD	108.2 ± 8.2	97.5 ± 8.7*	I p= 0,902
	CI 95%	95.8 – 115.7	89.2 – 107.6	CI 95%	96.0 – 120.4	84.5 – 110.5	Tp <0.001
	%Δ I ES		-8.21 I 0,68	%Δ I ES		-9.95 I 1.10	G p= 0.988
	Female			**Female**			
	Mean ± SD	97.4 ± 7.0	89.5 ± 6.4*	Mean ± SD	97.0 ± 6.2	90.2 ± 7.3*	I p= 0,835
	CI 95%	92.5 – 102.2	84.2 – 94.7	CI 95%	92.9 – 101.2	85.7 – 94.6	Tp <0.001
	%Δ I ES		-8.04 I 1.03	%Δ I ES		-7.13 I 0,92	G p= 0.952
	All			**All**			
	Mean ± SD	102.2 ± 10.7	94.0 ± 10.8*	Mean ± SD	100.0 ± 8.2	92.1 ± 8.1*	I p= 0.601
	CI 95%	97.3 – 107.1	89.0 – 98.9	CI 95%	95.0 – 105.1	87.1 – 97.2	Tp <0.001
	%Δ I ES		-8.12 I 0.73	%Δ I ES		-7.88 I 0.88	G p= 0.557
% Fat (%)	**A-CHO**			**R-CHO**			
	Male			**Male**			
	Mean ± SD	29.9 ± 4.8	25.1 ± 4.2*	Mean ± SD	27.6 ± 3.3	21.8 ± 5.9*	I p= 0.293
	CI 95%	26.5 – 33.4	21.3 – 28.8	CI 95%	22.7 – 32.6	16.5 – 27.2	Tp <0.001
	%Δ I ES		-16.13 I 0.96	%Δ I ES		-21.99 I 1.07	G p= 0.325
	Female			**Female**			
	Mean ± SD	34.3 ± 3.4	31.8 ± 3.2*	Mean ± SD	37.0 ± 3.0	33.0 ± 2.6*	I p= 0.385
	CI 95%	32.0 – 36.7	29.7 – 34.0	CI 95%	35.0 – 39.0	31.2 – 35.0	Tp <0.001
	%Δ I ES		-7.18 I 0.72	%Δ I ES		-10.57 I 1.15	G p= 0.175
	All			**All**			
	Mean ± SD	32.1 ± 4.6	28.5 ± 5.1*	Mean ± SD	34.5 ± 5.2	30.0 ± 6.2*	I p= 0.440
	CI 95%	29.6 – 34.6	25.6 – 31.3	CI 95%	31.9 – 37.1	27.1 – 33.0	Tp <0,001
	%Δ I ES		-11.65 I 0.72	%Δ I ES		-13.61 I 0.73	G p= 0.297
Fat-free Mass (kg)	**A-CHO**			**R-CHO**			
	Male			**Male**			
	Mean ± SD	66.1 ± 7.3	64.6 ± 8.6	Mean ± SD	73.0 ± 6.6	70.0 ± 7.4*	I p= 0.309
	CI 95%	60.5 – 71.7	58.1 – 71.1	CI 95%	65.1 – 80.9	60.8 – 79.3	T p= 0.005
	%Δ I ES		-2.47 I 0.20	%Δ I ES		-4.17 I 0.45	G p= 0.217
	Female			**Female**			
	Mean ± SD	50.1 ± 5.2	48.7 ± 5.7*	Mean ± SD	49.9 ± 5.2	49.0 ± 4.7	I p= 0.894
	CI 95%	46.3 – 54.0	44.9 – 52.5	CI 95%	46.6 – 53.2	45.8 – 79.3	T p= 0.004
	%Δ I ES		-2.92 I 0.27	%Δ I ES		-1.73I 0.19	G p= 0.979
	All			**All**			
	Mean ± SD	58.1 ± 10.3	56.6 ± 10.8*	Mean ± SD	56.1 ± 11.8	54.6 ± 10.9*	I p= 0.609
	CI 95%	52.5 – 63.8	51.1 – 62.2	CI 95%	50.2 – 61.9	48.9 – 60.4	Tp <0,001
	%Δ I ES		-2.70 I 0.14	%Δ I ES		-2.38 I 0.13	G p= 0.609
BMR (kcal)	**A-CHO**			**R-CHO**			
	Male			**Male**			
	Mean ± SD	2010.4 ± 221.1	1964.0 ± 262.5	Mean ± SD	2219.3 ± 199.7	2129.3 ± 224.5*	I p= 0.309
	CI 95%	1841.0 – 2179.7	1765.7 – 2162.3	CI 95%	1979.7 – 2458.7	1848.8 – 2409.7	T p= 0.004
	%Δ I ES		-2.47 I 0.20	%Δ I ES		-4.15 I 0.20	G p= 0.217
	Female			**Female**			
	Mean ± SD	1524.1 ± 159.7	1480.5 ± 173.1*	Mean ± SD	1518.3 ± 157.1	1489.9 ± 141.8	I p= 0.898
	CI 95%	1406.1 – 1642.1	1364.5 – 1596.5	CI 95%	1417.6 – 1618.9	1391.0 – 1588.8	T p= 0.003
	%Δ I ES		-2.91 I 0.27	%Δ I ES		-1.76 I 0.19	G p= 0.981
	All			**All**			
	Mean ± SD	1767.3 ± 312.7	1722.3 ± 329.4*	Mean ± SD	1705.2 ± 359.4	1660.4 ± 332.9*	I p= 0.607
	CI 95%	1595.4 – 1939.1	1553.0 – 1891.5	CI 95%	1527.7 – 1882.7	1485.6 – 1835.2	Tp <0.001
	%Δ I ES		-2.69 I 0.14	%Δ I ES		-2.40 I 0.13	G p= 0.608

Notes: Data are presented as mean and standard deviation. BMI: Body Mass Index; % Fat: Fat percentage; BMR: Basal Metabolic Rate; CI –Confidence Interval; ES – Effect Size. *Significant intra-group variation.

Table 4: Cardiometabolic risk markers concentrations after weight loss program according to gender and type of diet (A-CHO and R-CHO)

Variables	Group	Pre	Post	Group	Pre	Post	p-value
VLDL-c (mg/dL)	**A-CHO**			**R-CHO**			
	Male			***Male***			
	Mean ± SD	35.88 ± 15,39	21.13 ± 10.12*	Mean ± SD	40.50 ± 30.45	14.75 ± 6.24*	I p = 0.281
	CI 95%	19.28 – 52.47	13.93 – 28.32	CI 95%	17.03 – 63.97	4.58 – 24.92	T p = 0.004
	%Δ I ES		-35.67 I -1.00	%Δ I ES		-50.15 I -1.05	G p = 0.918
	Female			***Female***			
	Mean ± SD	23.00 ± 11.36	19.38 ± 11.92	Mean ± SD	25.18 ± 12.47	17.36 ± 9.47*	I p = 0.687
	CI 95%	14.03 – 31.97	11.51 – 27.24	CI 95%	17.53 – 32.83	10.66 – 24.07	Tp <0.001
	%Δ I ES		14.71 I -0.32	%Δ I ES		-31.10 I -0.68	G p = 0.987
	All			***All***			
	Mean ± SD	29.44 ± 14.66	20.25 ± 10.72*	Mean ± SD	29.27 ± 18.96	16.67 ± 8.59*	I p = 0.315
	CI 95%	20.81 – 38.06	15.27 – 25.24	CI 95%	20.36 – 38.17	11.52 – 21.82	Tp < 0.001
	%Δ I ES		-25.19 I -0.68	%Δ I ES		-36.18 I -0.80	G p = 0.667
Total cholesterol (mg/dL)	**A-CHO**			**R-CHO**			
	Male			***Male***			
	Mean ± SD	208.13 ± 58.75	171.88 ± 45.10*	Mean ± SD	215.00 ± 19.71	175.50 ± 7.85*	I p = 0.879
	CI 95%	168.48 – 547.77	141.96 – 201.80	CI 95%	158.94 – 271.06	133.19 – 217.81	T p = 0.002
	%Δ I ES		-15.68 I -0.67	%Δ I ES		-18.02 I -1.56	G p = 0.843
	Female			***Female***			
	Mean ± SD	200.75 ± 54.25	183.75 ± 59.3	Mean ± SD	197.18 ± 36.12	174.91 ± 25.75	I p = 0.662
	CI 95%	167.57 – 233.93	151.80 – 215.70	CI 95%	168.88 ± 225.48	147.66 – 202.16	T p = 0.031
	%Δ I ES		-8.68 I -0.31	%Δ I ES		-7.36 I -0.68	G p = 0.741
	All			***All***			
	Mean ± SD	204.44 ± 54.76	177.81 ± 51.22*	Mean ± SD	201.93 ± 32.89	175.07 ± 22.07*	I p = 0.849
	CI 95%	181.16 ± 227.72	157.41 – 198.22	CI 95%	177.89 – 225.98	153.99 – 196.14	T p < 0.001
	%Δ I ES		-12.18 I -0.49	%Δ I ES		-10.20 I -0.87	G p = 0.854
Triacylglycerol (mg/dL)	**A-CHO**			**R-CHO**			
	Male			***Male***			
	Mean ± SD	178.63 ± 77.40	105.50 ± 51.54*	Mean ± SD	202.00 ± 151.95	73.00 ± 31.53*	I p = 0.280
	CI 95%	95.55 – 261.70	68.91 – 142.09	CI 95%	84.52 – 319.48	21.25 – 124.75	T p = 0.005
	%Δ I ES		-35.37 I -0.99	%Δ I ES		-50.56 I -1.05	G p = 0.915
	Female			***Female***			
	Mean ± SD	115.13 ± 56.49	96.50 ± 59.77	Mean ± SD	126.18 ± 61.74	87.36 ± 47.15*	I p = 0.714
	CI 95%	70.65 – 159.61	57.18 – 135.82	CI 95%	88.25 – 164.12	53.83 – 120.90	Tp < 0.001
	%Δ I ES		-15.22 I -0.33	%Δ I ES		-30.90 I -0.68	G p = 0.970
	All			***All***			
	Mean ± SD	146.88 ± 73.21	101.00 ± 54.11*	Mean ± SD	146.40 ± 94.20	83.53 ± 42.94*	I p = 0.330
	CI 95%	103.92 – 189.83	75.93 – 126.08	CI 95%	102.04 – 190.76	57.64 – 109.43	T p < 0.001
	%Δ I ES		-25.29 I -0.68	%Δ I ES		-36.15 I -0.80	G p = 0.680
Glucose (mg/dL)	**A-CHO**			**R-CHO**			
	Male			***Male***			
	Mean ± SD	91.50 ± 5.53	90.00 ± 5.42	Mean ± SD	94.25 ±12.63	85.00 ± 2.31*	I p = 0.114
	CI 95%	84.94 – 98.06	86.29 – 93.71	CI 95%	84.98 – 103.52	79.75 – 90.25	T p = 0.028
	%Δ I ES		-1.54 I -0.28	%Δ I ES		-8.87 I -0.95	G p = 0.759
	Female			***Female***			
	Mean ± SD	84.63 ± 6.00	84.00 ± 5.32	Mean ± SD	90.64 ± 11.17	88.00 ± 7.44	I p = 0.213
	CI 95%	77.62 – 91.63	79.04 – 88.96	CI 95%	84.66 – 96.61	83.77 – 92.23	T p = 0.281
	%Δ I ES		-0.54 I -0.11	%Δ I ES		-2.32 I -0.28	G p = 0.169
	All			***All***			
	Mean ± SD	88.06 ± 6.61	87.00 ± 6.04	Mean ± SD	91.60 ± 11.23	87.20 ± 6.53*	I p = 0.930
	CI 95%	83.39 – 92.73	83.79 – 90.21	CI 95%	86.78 – 96.43	83.88 – 90.52	T p = 0.029
	%Δ I ES		-1.04 I -0.17	%Δ I ES		-4,07 I -0.47	G p = 0.470
Insulin (mg/dL)	**A-CHO**			**R-CHO**			
	Male			***Male***			
	Mean ± SD	11.85 ± 5.71	7.74 ± 3.09	Mean ± SD	10.35 ± 4.27	7.53 ± 7.01	I p = 0.942
	CI 95%	7.66 – 16.04	4.09 – 11.38	CI 95%	4.43 – 16.27	2.37 – 12.68	T p = 0.083
	%Δ I ES		-25.59 I -0.84	%Δ I ES		-26.48 I -0.51	G p = 0.736
	Female			***Female***			
	Mean ± SD	12.52 ± 6.78	6.95 ± 2.73*	Mean ± SD	10.37 ± 5.46	6.46 ± 2.04*	I p = 0.662
	CI 95%	8.02 – 17.03	5.20 – 8.70	CI 95%	6.53 – 14.22	4.97 – 7.96	T p = 0.002
	%Δ I ES		-32.98 I -0.97	%Δ I ES		-27.94 I -0.87	G p = 0.448
	All			***All***			
	Mean ± SD	12.19 ± 6.07	7.34 ± 2.84*	Mean ± SD	10.37 ± 5.02	6.75 ± 3.71*	I p = 0.617
	CI 95%	9.33 – 15.04	5.66 – 9.03	CI 95%	7.42 – 13.32	5.01 – 8.48	Tp < 0.001
	%Δ I ES		-29.28 I -0.92	%Δ I ES		-27.55 I -0.77	G p = 0.366

Continue...

Table 4: Continued.

Variables	Group	Pre	Post	Group	Pre	Post	p-value
	A-CHO			**R-CHO**			
	Male			***Male***			
	Mean ± SD	2.66 ± 1.24	1.72 ± 0.72	Mean ± SD	2.46 ± 1.16	1.60 ± 1.52	I p = 0.843
	CI 95%	1.70 – 3.62	0.91 – 2.53	CI 95%	1.11 – 3.82	0.45 – 2.74	T p = 0.055
	%Δ I ES		-26.40 I -0.86	%Δ I ES		-31.81 I -0.65	G p = 0.771
	Female			***Female***			
HOMA-IR	Mean ± SD	2.63 ± 1.56	1.45 ± 0.58*	Mean ± SD	2.34 ± 1.24	1.42 ± 0.49*	I p = 0.919
	CI 95%	1.60 – 3.66	1.05 – 1.84	CI 95%	1.47- 3.22	1.08 – 1.76	T p = 0.002
	%Δ I ES		-32.38 I -0.92	%Δ I ES		-29.90 I -0.90	G p = 0.691
	All			***All***			
	Mean ± SD	2.65 ± 1.36	1.58 ± 0.65	Mean ± SD	2.38 ± 1.18	1.47 ± 0.82	I p = 0.660
	CI 95%	2.00 – 3.30	1.21 – 1.96	CI 95%	1.70 – 3.05	1.08 – 1.86	Tp < 0.001
	%Δ I ES		-29.39 I -0.90	%Δ I ES		-30.41 I -0.83	G p = 0.520

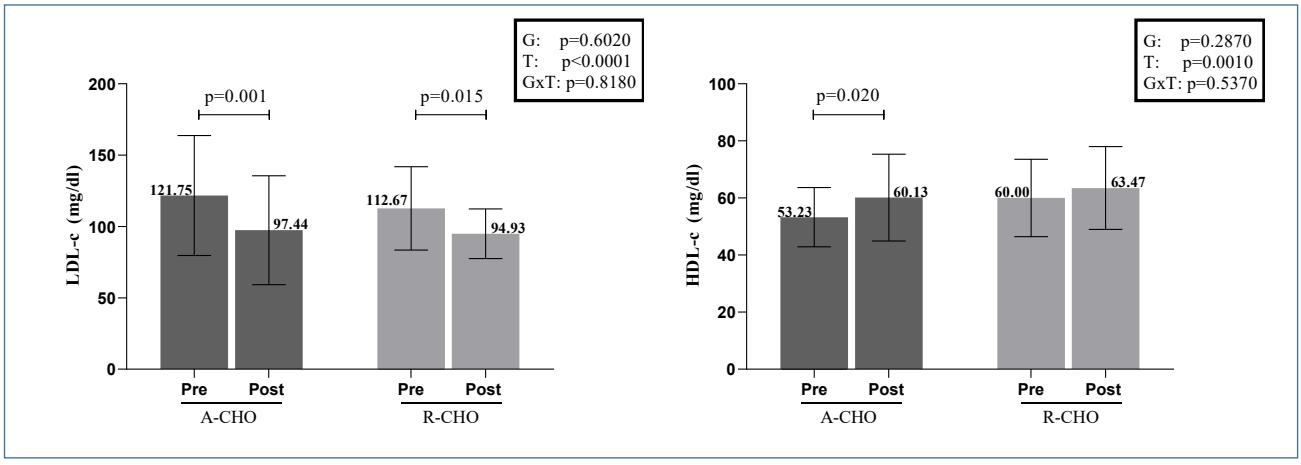

Figure 2: Variation of the concentration of LDL-c and HDL-c after 12 weeks of intervention, according to the type of diet (A-CHO and R-CHO)

groups. The differences in the findings between the present and previous studies are hypothesized to be caused by the following: (1) moderate CHO restriction, meaning the absence of drastic CHO reduction in the diet; and (2) HITF. Francois et al.[32] affirm the possibility of a synergetic effect promoted by the carbohydrate-restricted diet and practicing intense exercise in improving the cardiometabolic condition.

Maintaining the CHO amount within the minimum recommended intake (100–130 g) facilitates better macronutrient distribution without the need for consistently high lipid levels or saturated fat intake and provides adequate substrate supply, which is necessary for exercise tolerance. Furthermore, adequate CHO in conjunction with exercise is known to increase HDL-C concentration and LDL-C clearance through improvements and reductions in lipoprotein lipase and hepatic lipase activities, respectively[34]. Moreover, the importance of adequate CHO supply during HITF is also reflected in the findings of the present study.

Both intervention groups showed significant reductions in fasting insulin levels. However, only the participants from the R-CHO group displayed a significant decrease in glucose concentrations. The reduction in fasting plasma insulin concentration resulted in a decrease in the HOMA-IR index, which suggests an improvement in the insulin sensitivity of the participants from the two intervention groups.

It is essential to emphasize the contribution of the fourth block of HIFT (Cardiometabolic Activity - HIIT) in improving body composition and cardiovascular health[35]. As in our study, Racil et al.[36] also demonstrated a significant reduction in the fat percentage, total cholesterol, LDL-cholesterol, fasting insulin and insulin resistance, increased VO_2max and HDL cholesterol after 12 weeks of high-intensity interval training (100% to 110% of VO_2max) compared to the moderate intensity interval (70% to 80% VO_2max).

Adopting an adequate diet in conjunction with exercise leads to promoting a negative energy balance, which stimulates the mobilization of energy reserves and promotes weight loss[6]. Exercise enhances the muscle glucose uptake potential through insulin- and non-insulin-dependent pathways, as well as promotes fatty acid oxidation capacity through an increase in mitochondrial biogenesis[37]. This integrated effect promotes an improvement in the cardiometabolic condition of an individual, thus improving body composition, lipid profile, and insulin sensitivity. This finding is consistent with that of the present study, in which the participants, regardless of

the intervention group, showed improvements in their metabolic conditions following the 12-week intervention, as evidenced by significant reductions in the number of cardiovascular risk factors, in addition to the decrease in the number of MU participants. This result presents the integrated nature of the beneficial effects of the 12-week diet and HIFT interventions on the anthropometric and lipid profiles of the participants. The assessment of the integrated factors is crucial given the stronger association between the presence of risk factors and cardiovascular disease development and mortality than the presence of isolated risk factors[38,39].

The present study emphasizes the utilization of moderate CHO restriction and weekly monitoring, which may have contributed to the participant's adherence to the weight loss program, aside from ensuring a macronutrient-balanced food plan. Given the scarcity of studies evaluating the effects of dietary interventions in conjunction with HIFT, the addition of exercise to the intervention program in the present study is highly relevant in addressing this gap in the literature.

This study has some limitations to consider when interpreting the results. One of which is the inclusion of both men and women in the sample because responses to interventions may differ depending on gender, including the lipid profile. However, randomization was performed with gender control to minimize this difference, in addition to setting inclusion criteria for age and BMI. Additionally, several studies which evaluated the effect of this type of intervention also used samples composed of men and women[13,28]. For example, a study by Weiss et al.[29] utilized a sample consisting of 69%–79% women in the intervention groups. Additionally, Caudwell et al.[40] concluded that no difference exists between genders concerning weight loss when the energy expenditure is equivalent.

In conclusion, CHO reduction was found to be effective in the reduction of cardiometabolic risk. However, improvements in HDL and final cardiometabolic classification risk indicated that CHO adequacy in the diet might be a better strategy associated with caloric restriction and HIFT than CHO reduction.

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