The Effect of 12 Weeks of Different Exercise Training Modalities or Nutritional Guidance on Cardiometabolic Risk Factors, Vascular Parameters, and Physical Fitness in Overweight Adults: Cardiometabolic High-Intensity Interval Training-Resistance Training Randomized Controlled Study

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Abstract

Ramírez-Vélez, R, Castro-Astudillo, K, Correa-Bautista, JE, González-Ruiz, K, Izquierdo, M, García-Hermoso, A, Álvarez, C, Ramírez-Campillo, R, and Correa-Rodríguez, M. The effect of 12 weeks of different exercise training modalities or nutritional guidance on cardiometabolic risk factors, vascular parameters and physical fitness in overweight adults: cardiometabolic high-intensity interval training-resistance training randomized controlled study. J Strength Cond Res XX(X): 000–000, 2020—Evidence suggests that exercise training improves cardiometabolic risk factors. The aim of this study was to investigate whether 12 weeks of high-intensity interval training (HIIT), resistance training (RT), concurrent training (CT = HIIT + RT), or nutritional guidance (NG) induced improvements in cardiometabolic risk factors, vascular parameters, and physical fitness in overweight adults, and to compare the responses between the 4 intervention groups. Twelve-weeks factorial randomized design examining the effects of different exercise regimes and/or NG on anthropometric and body composition (fat and lean mass at whole body, trunk fat, fat mass index, appendicular muscle mass, and waist circumference); cardiometabolic risk factors and vascular parameters (blood lipids, fasting glucose, blood pressure, flow-mediated dilation [FMD%], aortic pulse wave velocity (PWV), and augmentation index); and physical fitness (cardiorespiratory fitness and handgrip strength). Adjusted mixed linear models revealed a significant improvement in cardiorespiratory fitness (mL·kg⁻¹·min⁻¹): HIIT +8.3, RT +4.1, and CT +6.3 (all p < 0.001). The improvement difference between the groups was statistically significant between the HIIT and NG group (p = 0.014), (time × group interaction F(23,964); p < 0.001; η² partial = 0.365). In addition, the RT and CT groups have a significant positive impact on PWV (m·s⁻¹) (d = 0.391 and 0.229 respectively, p < 0.001, (time × group interaction F(18,457); p = 0.003; η² partial = 0.280). Hereafter, the RT group has a significant positive impact on the FMD (%) in comparison to HIIT, CT, or NG group (time × group interaction F(23,942); p = 0.044; η² partial = 0.174). The main findings of this study are that 12 weeks of HIIT leads to significant improvements in cardiorespiratory fitness, whereas RT resulted in improvements in the vascular profile, supporting the positive effect of both training programs for cardiometabolic risk factors in sedentary and overweight adults.

Key Words: high-intensity interval training, resistance training, concurrent training, vascular function, metabolic syndrome

Introduction

Obesity is a major public health problem worldwide. The prevalence of overweight/obesity is rapidly increasing and, in the Latin-American population, it is estimated that more than 19% of adults are obese (26). Excess body weight is an independent risk predictor for cardiometabolic disease. In addition, excessive accumulation of body fat has been related to the metabolic syndrome (MetS), a clustering of central obesity, hyperglycemia or hyperinsulinemia, dyslipidemia, and elevated blood pressure, thus increasing cardiovascular risk (42). Note that a recent estimation of the prevalence of MetS among U.S. adults is 34.3% (36). Also, endothelial dysfunction, considered a precursor to the atherosclerotic cascade, has been reported to increase susceptibility to several cardiovascular events (38).
Regular physical activity and nutritional guidance (NG) are among the therapeutic actions used to reduce MetS in adults. According to the World Health Organization (WHO) and the American College of Sports Medicine, the recommended exercise prescription for improving and maintaining health is at least 150 minutes of moderate-intensity physical activity (40–60% maximum oxygen uptake, V\textsubscript{O\textsubscript{2max}}) or 75 minutes of vigorous-intensity physical activity (60–85% V\textsubscript{O\textsubscript{2max}}) per week for healthy adults (39). Despite the importance of engaging in regular exercise, most adults fail to meet these recommendations, reporting lack of time as a major barrier for being physically active. Therefore, identifying more time-efficient modes of exercise training is a major area of interest.

High-intensity interval training (HIIT) defined by Gibala et al. as a brief, intermittent burst of vigorous activity interspersed by periods of low-intensity exercise, has become a popular and more time-efficient alternative to traditional exercise strategies (11). The impact of HIIT on cardiometabolic risk factors such as body composition, metabolic parameters, vascular function, and physical fitness has been investigated extensively in overweight-obese populations (13,21,31,33). Compared with moderate-intensity continuous exercise, HIIT may result in a superior or equal improvement in body composition, cardiovascular health (CVH), and cardiorespiratory fitness (2,4,17). Regarding vascular function, although HIIT was reported to be more effective at improving brachial artery vascular function than moderate-intensity continuous training (MICT) (31), Sawyer et al. (33) reported that HIIT and MICT produced different brachial artery vascular adaptations in sedentary and obese adults.

However, resistance training (RT), has also been shown to be effective in improving several cardiometabolic risk factors including insulin resistance/hyperglycemia, dyslipidemia, hypertension, and obesity (44). However, whether a concurrent training (CT) including HIIT and RT may be more effective and provide additive improvements in cardiometabolic parameters remains to be determined, because previous studies investigating the effects of concurrent aerobic and RT on cardiometabolic health have produced inconclusive findings (13,44). For example, Ho et al. (13) showed that 12 weeks of combination exercise training yielded greater benefits for body composition and cardiorespiratory fitness than moderate-intensity aerobic and RT modalities in overweight/obese adults. By contrast, Willis et al. (44) reported that a program of concurrent aerobic training and RT in middle-aged overweight/obese adults failed to significantly reduce fat or body mass over aerobic training alone, suggesting that aerobic training is the optimal mode of exercise for reducing these parameters. They also found that a program including RT was needed to increase lean mass in this group. Interestingly, Kemmler et al. (18) reported that a high-intensity aerobic and resistance exercise program affected MetS risk factors and significantly lowered the severity of MetS in 32 elderly women (69.5 ± 4.3 years), supporting that high intensity is more strongly inversely related to the MetS than low-intensity exercise. However, the potential greater benefits of specific concurrent HIIT and RT across cardiometabolic markers over these modalities alone has not been widely investigated.

In addition to exercise training, NG has been postulated as an effective intervention for promoting cardiometabolic health. Indeed, NG with adequate nutrition has been shown to improve insulin resistance, reduce oxidative stress and lipid profile and prevent excess weight, hypertension, type 2 diabetes, and low-grade chronic inflammation (1), supporting that dietary habits influence multiple risk factors for cardiometabolic health. Nevertheless, the potential effects of NG on cardiometabolic health when directly compared with different training modalities remain to be determined.

To the best of our knowledge, although exercise training has been reported to be a therapeutic strategy toward CVH improvement, the effect of different exercise intervention programs on parameters related to CVH such as endothelial function of arterial fitness in sedentary and overweight subjects has been scarcely investigated. Limited studies have produced inconsistent or even contradictory results (23). Moreover, no previous studies have compared the effect of different training modalities and NG on cardiometabolic risk factors in a cohort of overweight subjects. Against this background, the aim of the present study was to investigate whether 12 weeks of HIIT, RT, CT, or an NG plan induced improvement on MetS risk factors, vascular function, and physical fitness in sedentary and overweight adults, and to compare the responses between the 4 intervention groups. For daily practice, this research will provide insight to practitioners/clinicians or trainers working with overweight inactive populations how different exercise training modalities (HIIT, RT, and CT) and NG may produce different cardiovascular adaptations.

Methods

Experimental Approach to the Problem

The Cardiometabolic HIIT-RT study is a single blind, randomized controlled 2 x 2 factorial trial (ClinicalTrials.gov ID: NCT02715063) conducted from March 2016 to June 2017 in Bogotá, Colombia. The study was approved by the Research Ethics Committee of The University of Manuela Beltran (ID 06-1006-2014) and complied with the revised ethical guidelines of the Declaration of Helsinki (revision of 2013). Randomization was performed by a third party using variable permuted block sizes with computer-generated random numbers. Details of sample calculation, randomization, characteristics of participants, design, methods, and measurements of the Cardiometabolic HIIT-RT study have been published elsewhere (30); however, the most relevant information is briefly described below.

Subjects

The study included a total of 57 sedentary subjects (no participation in exercise more than once a week for the previous 6 months), aged 30–50 years, with abdominal obesity (waist circumference [WC] ≥90 cm [men] ≥80 cm [women]) or excess weight, body mass index ≥25 and ≤30 kg/m\textsuperscript{2}, identified as being willing and with almost immediate availability. Subjects were recruited from a private health care institution (Clinica Rangel Pereira, IPS) and the Rosario University in Bogotá. Before being enrolled in the study, all subjects were informed about the experimental procedures and risks before they signed an informed consent.

Interventions. We determined the sample size for each group by power calculations using G\textsuperscript{Power} 3. It was assumed that vascular function (flow mediated dilation) would increase by approximately 2% over 12 weeks (30). Each participant met with the study dietician for nutrition assessment and counselling, and an individualized nutrition intervention plan. Dietary intake was assessed using 24-hour dietary recalls performed on one randomly selected
day each month. Total energy (kcal), carbohydrates (%), proteins (%), fat (%), and saturated fat (%) were obtained.

Nutritional Guidance. Without exercise training. Participants received usual clinical care according to the consensus recommendations of the national goals for CVH promotion and disease reduction of the American Heart Association and Colombian guidelines (6). All participants received NG 4 times during the program: twice in individual sessions (baseline and after 12 weeks) and twice in groups (fourth and eighth weeks). Diets were monitored by means of 3-day dietary recall, in accordance with the standards of the food-based dietary guidelines, Colombia. The focus of this counseling was on changing the quality of the diet with changing the total energy intake to encourage weight loss. The prescribed NG was based on an exchange list, by reducing ~250 kcal·wk⁻¹ from the calorie total to decrease energy intake by ~5–10%, to promote a decrease of ~0.5–1.0% of baseline body weight/month, without changing physical activity levels. Nutritional guidance advice also included recommendations for macronutrient intake to be within the recommended ranges (percentages of total energy: carbohydrate, 45–65%; fat, 20–35%; and protein, 10–35%). The assessment was carried out by trained registered clinical dietitians (C.A.H.-B), and the scoring was controlled by one researcher (R.R.-V.).

High-Intensity Interval Training Group. All HIIT sessions were preceded with a 5-minute warm-up and ended with a 4-minute cool-down at 65% heart rate maximum (HRmax) until the subject expended between 400 and 500 kcal at a frequency of 3 times per week on a treadmill ergometer (Pecor TRM 885, Italy). The HIIT protocol consisted of 4 bouts of 4-minute intervals at 85–95% HRmax interspersed with 4 minutes of active recovery at 65% HRmax. Participants were instructed to reach their target HR for each interval within the first 2 minutes of the 4-minute interval. We calculated the training energy expenditure with the consensus public health recommendations from WHO (43) and the US Department of Health and Human Services (28). HR monitors (A3; Polar Electro OY, Finland) were used to adjust workload to achieve the target HR. In addition, a rating of perceived exertion was also measured during each exercise session (15–17 during high intensity and 11–13 during recovery).

Resistance Training Group. The RT session was initiated with ~12–15 repetitions per set of 6 exercises that targeted all the major muscle groups at high intensity. A 60-second recovery was permitted as many times as needed according to the subject’s weight until the subject expended between 400 and 500 kcal at 50–70% of one-repetition maximum (1RM). The entire workout will last approximately 30–40 minutes at a frequency of 3 times per week. Each session is preceded and followed by a gradual warm-up and cool-down period (both of 10-minute duration and consisting of walking and light, static stretching (avoiding muscle pain) in most muscle groups). The cool-down period also includes relaxation and stretching exercises.

Concurrent training = high-intensity interval training + resistance training Group. The CT group did the aerobic training program (200–250 kcal) plus the RT program (200–250 kcal) during each session at a frequency of 3 times per week. The energy expenditure associated with the physical training prescribed for the CT group was therefore ~400–500 kcal/session. During 3 protocols, standardized verbal stimuli were offered.

Procedures

Training intensity and energy expenditure during the exercise session. In exercise intensity, the actual intensity values were reported as the mean of HR measured in the HIIT and CT groups and as the average value of workload and repetitions determined in the acute session in the RT group. The intensity of the HIIT or CT group was based on the percentage of each individual’s HRmax derived from a maximal treadmill test. In RT, we applied average energy expenditure values during exercise calculated using the traditional method of 1 L O₂ to 5.0 kcal, whereas the average energy expenditure during recovery (nontraditional method) was calculated using the Scott (34) conversion of 1 L O₂ to 4.7 kcal in relative intensity (70% of IRM). The total energy expenditure (TEE) for RT + recovery-energy expenditure was estimated using the equation (TEE = 19.751 + [0.08933 × Work ([J]). Here, “work” corresponded to ~342.2 ± 53.3 J in ~12–15 repetitions per set of 6 exercises as constant. Research staff monitored and recorded compliance with target HR and energy expenditure during the sessions.

Venous Blood Sampling. Participants arrived at the Rosario University CEMA-Laboratory between 6:00 and 9:00 following a 10- to 12-hour overnight fast. Participants were reminded to maintain standardized conditions (i.e., a hydrated state and abstaining from caffeine and alcohol consumption for 36 hours). The following blood parameters were measured: (a) high-density lipoprotein cholesterol (HDL-C), (b) triglycerides, (c) total cholesterol, (d) fasting glucose, and (e) the metabolic regulators glucose and hemoglobin A1C (HbA1c) (by enzymatic colorimetric methods). All determinants were measured using Cardiocheck (Polymer Technology Systems, Pts, Indianapolis, IN) and A1CNow+ (Bayer Diabetes care, Sunnyvale, CA).

Blood Pressure and Heart Rate. Systolic (SBP) and diastolic blood pressure (DBP) were recorded using an automated monitor (Omrorn M2, HEM-7117-E; Omron Healthcare Corporation, Kyoto, Japan) in duplicate after 15 minutes of rest, with the subjects in a seated position and with both feet resting on the floor. The mean arterial pressure (MAP) was calculated using the following formula: MAP = SBP + [(2 × DBP)/3], where DBP and SBP are diastolic and systolic blood pressure, respectively. Resting HR was measured using a chest monitor (V-800; Polar Electro, Inc., Kempele, Finland) after subjects had rested in the supine position for at least 15 minutes.

Anthropometry and Body Composition. Body mass (Tanita BC-418, Tokyo, Japan) and height (Seca 274, Hamburg, Germany) were measured in duplicate using standard protocols. Body mass index (BMI) was calculated with the following formula: BMI = body mass (kg)/height squared (m²). Waist circumference was measured to the nearest 1 mm with a flexible steel tape measure (Lufkin W606PM, Parsippany, NJ). Waist circumference was measured to the nearest 1 mm with a flexible steel tape measure (Lufkin W606PM, Parsippany, NJ) placed midway between the lowest rib and the iliac crest while participants were in a standing position at the end of an exhalation, in accordance with the International Society for the Advancement of Kainthropometry guidelines. BMI was classified using WHO criteria (normal: 18.5–24.9 kg/m²; overweight: 25.0–29.9 kg/m²; and obese: ≥30 kg/m²). The technical error of measurement values was less than 2% for all anthropometric variables. Whole body fat and lean mass, trunk fat mass index, muscle index, and appendicular muscle mass were measured by dual-energy X-ray absorptiometry (QDR-1500, Hologic Corp., Quirugil, Software version 7.10, Waltham, MA).
Cardiorespiratory Fitness and Muscular Strength. At 48 hours after the start of the training period, the VO2max of inactive subjects was determined 24 hours before the acute intervention using a maximum treadmill exercise test (Precor TRM 885). Exercise capacity was evaluated according to treadmill exercise test duration, which was used to estimate aerobic consumption expressed in VO2max (ml·kg⁻¹·min⁻¹), based on well-characterized regression equations recommended by the American College of Sports Medicine. In addition, a previous study demonstrated that treadmill test time correlates well (r = 0.92) with VO2max (15). Blood pressure was recorded at rest, at each stage change, at peak exercise, and during recovery using a standardized cuff sphygmomanometer. The corresponding metabolic equivalent (METs) was also calculated by dividing VO2max by 3.5 ml·kg⁻¹·min⁻¹. Details of cardiorespiratory fitness assessment have been published elsewhere (30). Regarding muscular strength, 1RM was measured for 6 different exercises: bicep screw curl, triceps extension, dumbbell side lateral raise, military press, dumbbell squat, and dumbbell front lunge, which were implemented based on similar procedures (30). The 1RM was performed in 6 resistance exercises and was conducted between 09:00 and 11:00 AM; the highest load of 3 attempts per exercise was reported. The 50–70% value of the 1RM was used to determine the workload during the sessions for the RT and CT groups.

Endothelial Function Measures. Endothelial function was measured by flow mediated-dilation (FMD), aortic pulse wave velocity (PWV), and the augmentation index (AIx). Details of endothelial function measures have been published elsewhere (29). Pulse wave velocity was measured by analyzing the oscillometric pressure curves registered from the upper arm with an arteriographic computer program (Arteriograph Software v.1.9.9.2; TensoMed, Budapest, Hungary). The R value as an estimate of the measurement errors for the repeat measurements between 2 sessions (n = 6) was low for the arteriograph (0.18 m/s⁻¹).

Cardiometabolic Parameters. We calculated a composite cardiometabolic z-score that reflects a continuous score of the 5 metabolic abnormalities. The cardiometabolic z-score was calculated from subjects’ data, based on the International Diabetes Federation and standard deviations using data from the entire subject cohort at baseline. The equation used was: MetScore = ([HDL-C: ♂ ≤40 or ♀ ≤50 mg·dl⁻¹]/SD*[-1]) + ([TG: 150 mg·dl⁻¹]/SD) + ([fasting glucose: 100 mg·dl⁻¹]/SD) + ([WC: ♂ ≥94 or ♀ ≥80 cm]/SD) + ([MAP: 100 mm Hg]/SD). The mean of this continuously distributed cardiometabolic z-score was therefore zero by definition.

Statistical Analyses
The Shapiro-Wilk test was used to determine whether parametric tests were appropriate. A nonparametric test equivalent was applied if the assumption of normality was still violated after log transformation of data when necessary. To aid interpretation, data were back-transformed from the log scale for presentation in the results. Baseline demographics were described using frequency and percentage for categorical variables, mean, and SD

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**Figure 1.** Consolidated standards of reporting trials (CONSORT) flow diagram. *They started a structured exercise program.

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for continuous data. The mean change in each group was reported as the estimated margin of the mean, as assessed by 95% confidence intervals (CI) with adjustment for kcal for diet, sex, and baseline values as covariates using a linear-mixed effects model. Within-group differences were considered significant when the 95% CI did not include zero. In the per-protocol mixed model analyses, we used 95% CI and p values ≤ 0.05 for the intergroup comparisons, for each outcome measure across group × time interaction factors. In addition to repeated measures analysis of variance, Bonferroni-Holm corrections were performed. Within-group effect size of the interventions was calculated using “Cohen’s d” for one-way analysis of covariance (regression) and interpreted as follows: “small” effect (0.01–0.10), “small-to-medium” (0.10–0.25), “medium-to-large” effect (0.25–0.40), and “large” effect (≥0.40). Partial eta-squared (η²) group × time interaction was calculated as the between-group sum of squares divided by the total sum of squares and interpreted as follows: “small” effect (0.01), “small-to-medium” effect (0.02–0.13), “medium-to-large” (0.13–0.26), and “large” effect (≥0.26). All statistical tests were 2 tailed, and significance was accepted at p < 0.05. All analyses were performed using the SPSS software package (Version 24, IBM, NY).

Results

Characteristics of the Subjects

Figure 1 shows the CONSORT flow diagram of study progression. A total of 80 participants were eligible after assessment. Reasons for eligible subjects declining to participate included “lack of time” (n = 5), and “personal reasons” (n = 3). Of the remaining 72 participants, 18 were randomized into each of the following intervention groups: (a) NG; (b) HIIT; (c) RT; and (d) CT (HIIT and RT protocol).

Baseline parameters are shown in Table 1. The mean (SD) values were 40.7 (7.0) years of age, body fat 39.0 (5.8) %, and VO2max 37.8 (8.4) ml·kg⁻¹·min⁻¹. Regarding vascular function parameters, the mean (SD) values of FMD, PWV, AIx (aortic), and Alx (brachial) were 9.8 (6.6)%, 7.3 (1.0) m·s⁻¹, 24.5 (18.5)%), and −19.8 (27.0)%, respectively. Other details of vascular function, exercise, and diet parameters are shown in Table 1.

Training Adherence

Training adherence (% of total sessions completed; mean) for each training group was the following: HIIT, 95%; RT, 96%; and CT, 88%. There were no differences in training adherence between intervention groups (p = 0.671). No physical limitations or health problems were found during the training intervention.

Changes in Body Composition Parameters

The results of the analysis in body composition are shown in Figure 2. We found a decrease in total body fat (% from PRE to POST intervention both in HIIT (−3.0, CI 95% = −4.2 to −1.9; d = 0.429; p < 0.001) and RT (−3.2, CI 95% = −5.3 to −1.1; d = 0.319; p < 0.001), and for trunk fat mass (kg) both in HIIT (−2.0, CI 95% = −3.2 to −0.7; d = 0.392; p < 0.001) and RT (−2.0, CI 95% = −3.7 to −0.2; d = 0.258; p < 0.001). However, after the Bonferroni-Holm correction, it did not show significant differences for time × group interaction effect in body fat (F(2,746); p = 0.055; η² partial = 0.171), or trunk fat mass (F(1,989); p = 0.131; η² = 0.130).

Changes in Metabolic Parameters

Regarding metabolic parameters (Figure 3), we found a decrease in total cholesterol (−16.8, CI 95% = −29.5 to −4.1; d = 0.289) levels from PRE to POST in HIIT, and in triglyceride levels in the NG group (−45.2, CI 95% = −72.9 to −17.5; d = 0.294), (p all < 0.001). All significant effects can be classified as medium-to-large. There were statistically significant decreases for cardiometabolic z-score in the 4 groups after the intervention (d = range 0.365–0.468; all p values < 0.001); however, the training response (mean changes)

Table 1

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Sex, men n (%)</th>
<th>Morphological parameters, mean (SD)</th>
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<tr>
<td>Age, y</td>
<td>40.78 (7.06)</td>
<td>Age, y</td>
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<tr>
<td>Mass, kg</td>
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<td>Mass, kg</td>
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<tr>
<td>Height, cm</td>
<td>162.51 (7.94)</td>
<td>Height, cm</td>
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<td>BMI, kg/m²</td>
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<td>Waist circumference, cm</td>
<td>92.68 (8.49)</td>
<td>Waist circumference, cm</td>
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<tr>
<td>Total body fat, %</td>
<td>39.03 (5.87)</td>
<td>Total body fat, %</td>
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<tr>
<td>Trunk fat mass, kg</td>
<td>16.42 (4.30)</td>
<td>Trunk fat mass, kg</td>
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<td>23 (40.9)</td>
<td>High HbA1c, n (%)</td>
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<tr>
<td>Cardiometabolic z-score</td>
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<td>Cardiometabolic z-score</td>
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<td>Systolic blood pressure, mm Hg</td>
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<td>Mean arterial pressure, mm Hg</td>
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<td>Vascular function parameters, mean (SD)</td>
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<tr>
<td>Dmax, mm</td>
<td>9.81 (6.62)</td>
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<td>FMDn, %</td>
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<td>Alx (aortic), %</td>
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<td>AIx (brachial), %</td>
<td>−19.89 (27.03)</td>
<td>AIx (brachial), %</td>
</tr>
</tbody>
</table>

*PVW = Pulse wave velocity; AIx = augmentation index; HDL-C = high-density lipoprotein cholesterol; HR = heart rate.
†Data are reported as mean values (SD) or percentages (%).

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difference between the 4 groups was not statistically significant \( (\text{time} \times \text{group interaction} F(0.250); p = 0.951; \eta^2 \text{ partial} = 0.008) \).

**Changes in Vascular Function Parameters**

The exercise effort test results for the 4 intervention groups are shown in Figure 4. After 12 weeks of supervised training, all 3 exercise programs significantly increased FMD (%), in the following increasing order: HIIT group (+2.7%, CI 95% = 1.4 to 7.0; \( d = 0.384 \)), CT group (+5.3, CI 95% = 0.2 to 10.5; \( d = 0.579 \)), and RT group (+10.5%, CI 95% = 3.9 to 17.1; \( d = 1.015 \)). However, after the Bonferroni-Holm correction, only one significant \( \text{time} \times \text{group effect} \) remained (NG vs. RT group, \( p = 0.049 \)). Hereafter, RT group has a significant positive impact on the FMD (%) in comparison to the HIIT, CT, or NG group (time \times \text{group interaction} F(2.942); p = 0.044; \( \eta^2 \text{ partial} = 0.174 \)).

In addition, the RT and CT groups have a significant positive impact on PWV (m·s\(^{-1}\)) \( (d = 0.391 \text{ and } 0.229, \text{ respectively}; p < 0.001, \text{ time} \times \text{group interaction} F(3.457); p = 0.003; \eta^2 \text{ partial} = 0.280, \text{ “large” effect} \)). However, after the Bonferroni-Holm correction, 2 significant \( \text{time} \times \text{group effect} \) remained (NG vs. RT group, \( p = 0.012 \) and NG vs. CT group \( p = 0.007 \)). Similarly, aortic AIx shown a “medium-to-large” effect (time \times \text{group interaction} F(12.759); \( p = 0.001; \eta^2 \text{ partial} = 0.233 \)). There were no significant treatment effects on other vascular parameters.

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**Figure 2.** Training response in body composition parameters between intervention groups. NG = nutritional guidance; HIIT = high-intensity interval training; RT = resistance training; Concurrent training (HIIT + RT) group; data shown are mean changes and individual participant responses. The effect sizes (mostly Cohen’s \( d \)) were also calculated to determine within-group effect of the interventions.
Changes in Exercise Parameters

Figure 5 shows the results for HR rest (b·min⁻¹), VO₂max (ml·kg⁻¹·min⁻¹) and handgrip strength (kg) for the 4 groups. Regarding the HR rest after the intervention, the only significant result was observed in the RT group (PRE 62.3 (11.2) vs. POST 57.0 (8.3); mean difference 5.3, CI 95% = -10.2 to -0.5; d = 0.243; p < 0.001). Adjusted mixed linear models revealed a significant improvement in cardiorespiratory fitness (ml·kg⁻¹·min⁻¹): HIIT +8.3; d = 0.579, RT +4.1; d = 0.579, and CT +6.3; d = 0.579; (all p < 0.001). The improvement difference between the groups was statistically significant between the HIIT and NG groups (p = 0.014), (time x group effect F(3,826) = p = 0.017; η² partial = 0.219 and time x group interaction F(23,564) = p < 0.001; η² partial = 0.365). These significant effects can be classified as large. There were also significant differences in handgrip strength between PRE- and POST-training measures: HIIT +3.1; d = 0.129, RT +6.3; d = 0.156, and CT +3.1; d = 0.140; all p < 0.001. The improvement difference between the groups was not statistically significant (F(0.071) = p = 0.975; η² partial = 0.005).

Discussion

Our aim was to compare the effects of 12 weeks of HIIT, RT, CT (HIIT + RT), or NG on MetS risk factors, physical fitness, and vascular function in a cohort of sedentary and overweight adults. The main findings of this study are that 12 weeks of HIIT leads to significant improvements in cardiorespiratory fitness, whereas the RT resulted in improvements in the vascular profile, supporting the positive effect of both training programs for cardiometabolic risk factors in sedentary and overweight adults.

Exercise training is a well-established means of enhancing vascular health. Consistent with previous studies (25,31), our data reveal that all 3 exercise regimens improve FMD. Furthermore,
both RT and CT intervention improve PWV (m·s⁻¹), supporting the concept that different types of exercise training may produce diverse adaptations of arterial stiffness in obese and sedentary adults (12). Indeed, we observed that FMD (%) was higher in the RT than in the CT group. This is of particular interest because lower PWV values, a measure of pulse wave reflections influencing the central blood pressure, predict mortality and cardiovascular events (16). Although RT programs have shown beneficial effects on vascular parameters (24,45), a recent study found that a 8-week period of RT did not change arterial stiffness in individuals with MetS or in healthy controls (7). Considering that the aforementioned study used a shorter training period, it could be hypothesized that only longer RT interventions have a substantial effect on arterial stiffness. It has been suggested that the role of different exercise training interventions on vascular function may be mediated by the synthesis of molecular mediators, changes in neurohormonal release, and/or oxidant/antioxidant balance (9). Accordingly, these findings raise the question of whether regular exercise training (i.e., RT) directly reduces arterial stiffness or reduces blood pressure and consequently increases FMD, especially in adults with cardiovascular risk factors. Nevertheless, the specific role of RT in arterial stiffness in overweight and sedentary adults is unclear and warrants further investigation.

Regarding body composition parameters, although no significant difference in training response was found between HIIT, RT, CT, and NG, we found decrease in total body fat and trunk fat mass after the HIIT and RT interventions. The fact that the CT group may have experienced lesser changes in body weight may be

**Figure 4.** Training response in vascular function parameters between intervention groups. NG = nutritional guidance; HIIT = high-intensity interval training; RT = resistance training; Concurrent training (HIIT + RT) group; data shown are mean changes and individual participant responses.
explained by a higher dietary intake in this group. However, it should be noted that each participant met with the study dietician for nutrition assessment and counselling, and an individualized nutrition intervention plan. In contrast to our findings, Tremblay et al. (41) reported that a 15-week HIIT program induced a more pronounced reduction in subcutaneous adiposity compared with a 20-week endurance training program. The differences in period training between both studies may account for the discordance in results and point to the possibility that longer training period could be necessary to determine what training modalities are more advantageous for inducing body composition improvements (19).

All 4 regimens led to reductions in WC (NG = -1.69 cm, HIIT = -4.39 cm, RT = -3.95 cm, and CT = -2.86 cm), (data not shown). It has been suggested that WC reduction is an important component that influences adult MetS, because it reflects abdominal fat excess and is closely related to cardiovascular diseases. The potential mechanisms underlying the HIIT-induced fat loss effect are unknown, but may include increased exercise and postexercise fatty acid oxidation and suppressed appetite (4). Therefore, the data of the present study strongly suggest that the response of overweight adults to a program of exercise training consists of a change in visceral obesity and a decrease in the risk factors for MetS.

No changes in metabolic parameters were observed between the 4 intervention groups; however, we found significant decreases in total cholesterol from baseline to postexercise in the HIIT group. Previous studies examining HIIT protocols for blood lipids have also demonstrated positive changes (3,8,20,38). In agreement with previous research (8,21), we failed to find any favorable change in HDL-c levels in overweight and sedentary adults. By contrast, Tjonna et al. (40) reported that HDL-c increased in middle-aged adults in response to 16 weeks of aerobic interval training. It is relevant to consider, however, that this study was conducted in a cohort of adults with MetS and very low baseline HDL-c values. The lack of consistent results may also be explained by differences in HIIT programs, and it is possible that only long-term training has a substantial effect on HDL-c response.

Regarding cardiometabolic health, decreases in the cardiometabolic z-score were identified in the 4 groups after the intervention, although the training response difference between the groups was not statistically significant. Considering that HIIT yielded the improvement in cardiometabolic z-score ($d = 0.468$), it seems that HIIT could be a more effective intervention for improving cardiometabolic risk in overweight and sedentary adults. Existing research has indeed shown that high-intensity exercise is more strongly inversely related with MetS when compared with low-intensity exercise (10,18).

Despite the similarity in volume and duration of the HIIT and RT interventions with the CT program, we saw a greater $\dot{V}O_{2\text{max}}$, ($d = 0.579$) improvement with HIIT than with RT ($d = 0.263$), CT ($d = 0.326$), except in NG ($d = 0.001$). Nevertheless, as expected, the improvement difference between the groups was statistically significant only between HIIT and NG groups ($p = 0.014$). This is consistent with previous studies (4,17,21,23). Moreover, our results overall are in line with other studies (3,21,37,44) in that all groups responded positively to exercise and presented an increase in $\dot{V}O_{2\text{max}}$ or METs and a decrease in HR rest. Improvements in CRF parameters were also demonstrated through a decrease in HR rest and the use of more intense workloads. Better heart and muscle function likely played a role in this improved performance (22).

We found an inverse relationship between aerobic fitness and fat content, and both were significantly related to the lipid profile. This reinforces the importance of supervised exercise training as a non-pharmacologic strategy for reversing the adverse effects of lack of exercise among overweight adults, thereby preserving fat-free mass in sedentary and overweight men. In this context, previous work have reported a pivotal role of adipokines and myokines derived from adipose tissue and skeletal muscle in metabolic and cardiovascular disorders, because they may modulate the cross-talk between both adipose tissue and skeletal muscle (5,27). Recently, Huh et al. reported that exercise including high-intensity interval exercise, continuous moderate-intensity exercise, and resistance exercise is able to increase circulating irisin levels in individuals with MetS and...
healthy subjects (14). However, further research is required to investigate the role of novel myokines that has been reported to mediate the effect of exercise at systemic level in patients with MetS and CVD.

While our findings have clinical relevance, there are acknowledged limitations to this study. First, because endothelial function is well known to be affected by age and training status, and our study cohort comprised overweight and sedentary middle-aged adults, this could imply that our findings may not be generalizable to other populations with different characteristics. In addition, although most modifiable CVD risk factors are assessed routinely in clinical practice (blood pressure, glucose and lipid profiles, obesity, and smoking), physical activity is typically not assessed, with the exception of a few health care systems (26). Although the importance of physical activity has been recognized in surveillance efforts, the CRF level of adults is an important indicator of current and future health, independent of physical activity levels. Findings from exercise-based intervention studies (ideally in 10-minute bouts of at least vigorous intensity physical activity) indicate that CRF levels can be improved in adults through exercise training without necessarily complying with the component of the physical activity guidelines (150 min·wk$^{-1}$ of moderate-intensity physical activity, 75 min·wk$^{-1}$ of vigorous-intensity physical activity, or an equivalent combination). In addition, Ross et al. (32) recently published an American Heart Association statement summarizing the evidence on the importance of assessing cardiorespiratory fitness as a “vital sign” in clinical practice. In the sense, we suggest that inclusion of CRF as a measure for national and international health surveillance efforts in sedentary individuals is important and should be validated in the future. Another limitation is that the potential role of exercise-induced myokines was not assessed. Finally, it should be noted that in the NG group, diets were monitored by means of a 24-hour dietary recall. Although the 24-hour diet recall has been recognized as a reliable method to collect a variety of detailed information about food consumed over a specific period, this tool has inherent limitations (35).

However, the main strength of our study is that it is the first study, to our knowledge, on the effect of 12 weeks of HIIT, RT, CT, or NG on MetS risk factors, physical fitness, and vascular function in adults from the Latin-American population. Second, there was high exercise adherence and we used state-of-the-art techniques to assess cardiorespiratory fitness (e.g., dual-energy X-ray absorptiometry, considered the current gold standard). In addition, body composition parameters were assessed by dual-energy X-ray absorptiometry, considered the current gold standard for body composition measurement; therefore, it is our opinion that it may be suitable to access the changes induced by an intervention on markers of body fatness.

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### References


