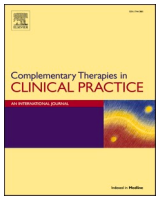
Complementary Therapies in Clinical Practice 59 (2025) 101960

Contents lists available at ScienceDirect

Complementary Therapies in Clinical Practice

journal homepage: www.elsevier.com/locate/ctcp



Moderate intensity continuous training, combined moderate-intensity continuous training vs combined high-intensity interval training in adults with hypertension: Randomized controlled trial

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ARTICLE INFO

Keywords:
High blood pressure
Strength training
Load-speed ratio
Concurrent training
MICT
HIIT

ABSTRACT

Background and purpose: Despite all efforts to treat hypertension, it is still responsible for 10.8 million deaths annually. The aim of this study was to compare the effects of continuous moderate-intensity training, strength training combined with continuous moderate-intensity training and strength training combined with high-intensity interval training in adults with high blood pressure.
Methods: A 12-week randomized control trial was performed. A total of 100 volunteers, 51 women and 49 men with hypertension participated. The sample was randomly assigned into three intervention groups and one control group.
Results: All intervention groups significantly improved their hemodynamic parameters, body composition, lipid profile, glucose, and physical fitness as compared to the control group. Both combined training groups showed greater improvements than the moderate-intensity continuous training group. However, the strength group combined with the moderate-intensity continuous group showed the greatest benefits in systolic, diastolic and mean arterial pressure, of −13.4 mmHg, −6.8 mmHg and −8.9 mmHg respectively, abdominal circumference, upper and lower limb strength and VO_2peak, versus the continuous moderate-intensity group; it also achieved greater reductions in systolic and mean blood pressure, up to −6.8 mmHg and 4.3 mmHg respectively, than the strength group combined with the high intensity interval group.
Conclusion: Performing a strength training program combined with continuous moderate intensity training, 2 days per week for 12 weeks, produces significant improvements in cardiometabolic biomarkers, body composition, and physical condition of adults with hypertension, with these adaptations being superior to those produced by continuous moderate-intensity training and strength training combined with high-intensity intervallic training.

1. Introduction

Hypertension is a chronic, virtually asymptomatic disorder that deteriorates the quality of blood vessels and can lead to target organ damage if not diagnosed early and properly controlled. It remains the most prevalent modifiable risk factor worldwide, and is responsible for more than 10 million deaths per year from cardiovascular disease [1,2]. In this sense, hypertension is considered at 140 mmHg systolic blood pressure (SBP) and 90 mmHg diastolic blood pressure (DBP); although an optimal control is below 130 mmHg and 85 mmHg respectively [3].

An active lifestyle is essential to address this disorder, as exercise acts as a drug that can prevent and treat many non-communicable diseases, including hypertension [4,5]. Moderate-intensity continuous training (MICT) is a priority for this population, according to the main clinical guidelines in cardiology and hypertension, with a minimum of 3 days/week and with a volume of 150–300 min/week at moderate intensity or 75–150 min/week at vigorous intensity [6–8], to achieve reductions in SBP from −4.9 to −12 mmHg and DBP from −3.4 to −5.8 mmHg [8,

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https://doi.org/10.1016/j.ctcp.2025.101960
Received 7 November 2024; Received in revised form 1 February 2025; Accepted 11 February 2025
Available online 13 February 2025

9]. Furthermore, the inclusion of strength training at least 2 days/week is recommended to benefit from the health improvements provided by this modality [10], including reductions in SBP from −3.0 to −4.7 mmHg and DBP from −3.2 to −3.8 mmHg [6,7]; Some of these guidelines also specify a total of 8–10 exercises per session involving large muscle groups and performing 8–12 repetitions per exercise [8]. These exercise guidelines do not include strength training combined with MICT in the same training session. However, different scientific publications have shown significant improvements in SBP and DBP levels with these training modalities [11–15]; Nevertheless, despite the benefits of combined training, further research is needed to establish dose-response relationships [16,17]. Another training modality that has also been shown to improve blood pressure levels is high-intensity interval training (HIIT) [18–21]. Recently, this training modality, because of its time efficiency and the growing evidence available, has been proposed as an alternative to MICT [18–20]. While this modality alone has shown similar improvements in blood pressure levels [19,20,22], even higher in diurnal SBP or vascular function than MICT for the control of hypertension, according to recent meta-analyses [18–22], little research has combined strength work with HIIT in this population group [23,24], even though this tool may provide greater cardiometabolic health benefits.

On the other hand, the programming of training is a complicated task, and even more so when it comes to programming the degree of effort for strength improvement. In the literature that can be found on strength training and hypertension, strength has been assessed by performing 1RM (one-repetition maximum) tests, a method considered the gold standard, but which involves an excessive, inaccurate and even harmful effort [25,26]; and for the volume of work, a fixed number of repetitions has been determined for all participants, resulting in a different degree of effort for each of them, as has been shown in previous work [25–27]. Until recently, it was difficult to truly know the relative intensity at which one was working, and thus the intensity at which a certain effect was produced. This was solved when the speed of execution emerged, a tool that represents a paradigm shift in the field of training by providing accurate information on the programmed load and the effects produced by it [28–30]. Currently, a large number of studies can be found with different population groups, in which the speed of execution has been used for the dosage of the training load; young men [29], multiple sclerosis patients [31], older women [32], or cancer survivors [33]. However, there are no contributions from the measurement of movement velocity in cardiovascular pathology, and more specifically in hypertension. One of the main problems with previous works is the lack of rigor in training programming; intensity and volume were not measured as accurately as possible, and it is therefore not possible to know whether the participants underwent the same amount of training, with the same relative intensity and the same degree of fatigue.

Therefore, the aim of the present study was to compare the effects of different individualized training programs: continuous moderate-intensity training, strength training combined with continuous moderate-intensity training, and strength training combined with high-intensity interval training, in adults with arterial hypertension.

2. Methodology

2.1. Study design

A randomized controlled clinical trial with several simultaneous study branches was conducted; the study was single-blind, longitudinal, and prospective. To distribute subjects into experimental group 1 (EG1), experimental group 2 (EG2), experimental group 3 (EG3), and control group (CG) a simple randomization method with the Microsoft Excel software (version 2016) was used. Four group were established based on blood pressure values, after which a randomized sequence was generated using simple randomization. The group assignment was blinded to the examiner and staff who performed the statistical analysis. This research followed the guidelines from the Consolidated Standards of Reporting Trials (CONSORT) statement, and the Template for Intervention Description and Replication (TIDieR) checklist. The trial design was registered at ClinicalTrial.gov (Code: NCT05914870).

In accordance with de Declaration of Helsinki, this randomized control trial obtained the approval of the Research Ethics Committee of the Universidad Católica de Murcia (CE062107). The Informed Consent

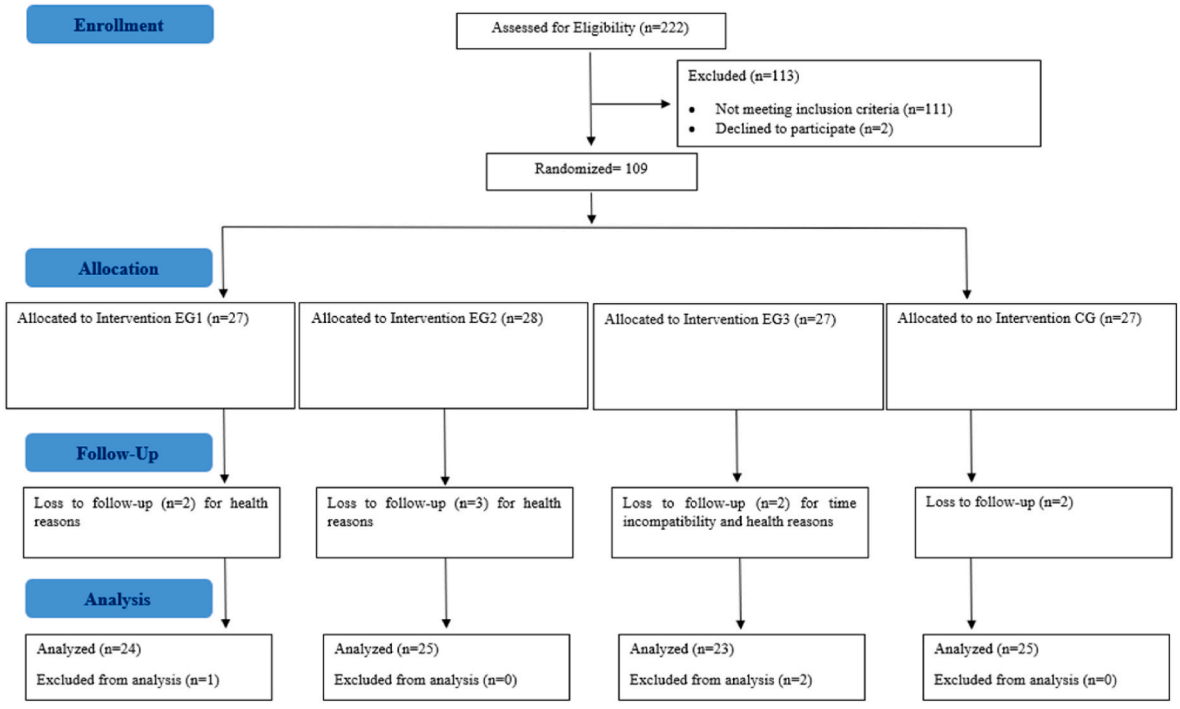

Fig. 1. Flow diagram.

document was signed by all participants prior to the start of the study.

2.2. Participants

A total of 100 volunteers participated, 51 women and 49 men, all of them with hypertension, a mean age 54 years, and previously sedentary. The sample was randomly assigned into three experimental and one control group: EG1, moderate-intensity continuous training or MICT, (n = 24); EG2, strength training combined with MICT, (n = 25); EG3, strength training combined with HIIT, (n = 23); and CG, control group, (n = 25) (see Fig.1).

The inclusion criteria were: a) adults with diagnosed hypertension and with follow-up by their primary care physician; b) age range 40–65 years; (c) not engaged in at least 150 min of moderate physical activity per week or 75 min of vigorous physical activity per week or a combination of both during the past 12 months. The exclusion criteria were: a) subjects with osteoarticular or musculoskeletal problems that conditioned the development of the intervention; b) uncontrolled or training-limiting cardiometabolic diseases such as heart disease, unstable coronary artery disease, heart failure, renal failure, diabetes, or morbid obesity; c) neurological problems; d) cognitive impairment that hinders the understanding and performance of the training; e) subjects who are dependent in the performance of daily activities; or f) pregnant women. Participants were instructed not to change their eating habits. The sample size and power calculations were performed using Rstudio 3.15.0 software. The significance level was set at $\alpha = 0.05$ and the power to 95 % ($1\text{-}\beta = 0.95$). The standard deviation used was according to the standard deviation for blood pressure found in previous studies [34]. A minimum clinically significant change of a total of 10 mmHg in SBP and 5 mmHg in DBP was considered [35]. With a dropout rate of up to 9.57 % [36], the aim was to enroll at least 26 participants in each group. The final sample provided a power of 95 % if found between and within a variance of 4.6 mmHg of DBP and 3.2 mmHg in DBP.

2.3. Assessment tools and protocols

The pre-post intervention measurements were carried out in the morning, between 8:00 and 13:00 h, by two researchers. They were carried out in a laboratory at a temperature of 24 °C, in two different assessment sessions, with a difference of 48–72 h between them and always under the same conditions. The height of the participants was measured with a SECA 217 stadiometer (SECA, Germany). Body Composition was assessed with the InBody 770 analyzer using the DSM-BIA measurement method (Multifrequency and Direct Segmental Bioelectrical Impedance) [37,38]. The analysis was performed on an empty stomach, without drinking liquids 30 min before the test, without drinking alcohol 48 h before the test and without wearing metallic elements in contact with the skin such as chokers, rings, belts, etc. For the assessment, the subject wiped their hands and feet with the InBody tissue, then climbed forwards onto the equipment, placing their feet on the plates, and grasping the electrodes with their hands with arms extended away from the sides of the body, without speaking and without moving until the end of the test.

Abdominal girth was measured with a non-elastic tape measure (SECA 200; SECA) according to the ISAK protocol [39]; standing with feet together, arms crossed on the chest and abdomen relaxed. The measurement was taken at the narrowest part of the waist after a normal exhalation.

The evaluation of the hemodynamic parameters, SBP (systolic blood pressure), DBP (diastolic blood pressure), MAP (mean arterial pressure), PP (pulse pressure) and RPP (rate pressure product), was performed with the BPBIO-750 sphygmomanometer [40]. For the test, the participants, after sitting for 5 min before the measurement, placed the left arm relaxed and supported on the blood pressure monitor, with the cuff at the level of the heart, their back supported, legs parallel without crossing and in silence during the test. Three measurements were taken 3 min apart, and the average of the last two measurements was taken as the reference value [41].

Blood chemistry analyses were performed from 8:00 to 9:00 a.m., after a minimum fasting period of 10 h. Samples were stored in sterile tubes under refrigeration (4–8 °C) for a maximum of 4 h, and then analyzed according to standardized procedures. Total cholesterol (TC), high-density lipoproteins (HDL), and low-density lipoproteins (LDL), were measured by a homogeneous enzymatic colorimetric assay, while triglycerides (TG) were measured by an enzymatic assay. (Cobas 8000C702, Roche, Mannheim, Germany); and glucose by an ultraviolet hexokinase assay (Cobas 8000C702, Roche, Mannheim, Germany).

The manual hydraulic dynamometer Baseline was used to assess the manual gripping force. The test was performed with the participant seated on a chair, back supported, feet on the floor, right elbow flexed at 90°, and holding the dynamometer with the wrist in neutral position with the thumb upwards; on command, the subject squeezed the grip as hard as possible for 3 s. The same procedure was repeated with the left hand. Two measurements were made with both hands and the highest maximum force (kg) of the two attempts was considered [42].

For the assessment of the maximum upper and lower body strength and the programming of the training, different tests were carried out using the speed of execution in the concentric motion with the Velowin optoelectronic encoder (Velowin v.1.7.232, Instruments and Sports Technology; Murcia, Spain) [28,29]. Two tests were carried out per body region on the Multipower BH TR machine, one of progressive loads, and the other of velocity loss in the set (%VL); the exercises performed were the squat and the bench press [28–30,43]. The tests were carried out in different sessions, 24 h apart, and before starting the tests, the participant underwent a standardized general warm-up.

For the technical execution of the progressive load test in the squat exercise, the protocol described in previous studies was followed [44,45]. The initial external load for the squat exercise was set at 15 kg for women and was progressively increased individually with 5 kg, 2.5 kg and 1.25 kg discs until a mean propulsive velocity (MPV) between 0.76 and 0.68 m s^{-1} was reached, which corresponds to 75%–80 % 1RM in this exercise; for men, the initial weight was set at 25 kg and progressively increased individually with 10 kg, 5 kg and 2.5 kg discs until an MPV between 0.76 and 0.68 m s^{-1} was reached, which corresponds to 75%–80 % 1RM in this exercise. During the test, 5 sets were performed; in the first set, the participants performed 3 reps with a very light load that allowed them to move the bar at a speed <1.28 m s^{-1} (<40 % 1RM); in the second set, they performed 3 reps with a light load that allowed them to move the bar between 1.28 and 1.21 m s^{-1} (40%–45 % 1RM); in the third set, they performed 3 reps with a medium load that allowed them to move the bar between 1.14 and 1.00 m s^{-1} (50%–60 % 1RM); in the fourth set, they performed 2 reps with a medium-high load that allowed them to move the bar between 0.92 and 0.84 m s^{-1} (65%–70 % 1RM); and in the fifth set, they performed 1 rep with a high load that allowed them to move the bar between 0.76 and 0.68 m s^{-1} (75%–80 % 1RM) [28,31–33,46]. The velocity loss test was performed 24 h after the progressive load test. For this test, a workload was defined that allowed the participant to move the bar at 0.99 ± 0.02 m s^{-1}, assuming 60 % of 1RM, and a velocity loss magnitude of 10 % was established. The test ended when the subject reached the prescribed %VL limit, regardless of the number of repetitions performed in the series [47,48].

For the technical execution of the progressive load test in the bench press exercise, the protocol described in previous studies was followed [31,32]. The initial external load for the bench press exercise was set at 10 kg for the women and was progressively increased individually with 5 kg, 2.5 kg and 1.25 kg discs until a MPV between 0.55 and 0.47 m s^{-1} was reached, which corresponds to 75%–80 % 1RM in this exercise; for men, the initial weight was set at 20 kg and progressively increased individually with 10 kg, 5 kg and 2.5 kg discs until an MPV between 0.55 and 0.47 m s^{-1} was reached, which corresponds to 75%–80 % 1RM in this exercise. For the test, 5 sets were performed; in the first set, the participants performed 3 reps with a very light load that allowed them to

move the bar at a speed <1.13 m s^{-1} (<40 %); in the second set, they performed 3 reps with a light load that allowed them to move the bar between 1.13 and 1.04 m s^{-1} (40%–45 % 1RM); in the third set, they performed 3 reps with a medium load that allowed them to move the bar between 0.95 and 0.87 m s^{-1} (50%–60 % 1RM); in the fourth set, they performed 2 reps with a medium-high load that allowed them to move the bar between 0.70 and 0.62 m s^{-1} (65%–70 % 1RM); and in the fifth set they performed 1 rep with a high load that allowed them to move the bar between 0.55 and 0.47 m s^{-1} (75%–80 % 1RM) [28,31,32]. The velocity loss test was performed 24 h after the progressive load test. A workload was defined that allowed the participant to move the bar at 0.97 ± 0.03 m s^{-1}, assuming 50 % 1RM, and a magnitude of velocity loss of 15 % was established. The test ended when the subject reached the prescribed %VL limit, regardless of the number of repetitions performed in the series [29,43].

Cardiorespiratory fitness was assessed with the IC7 cycloergometer, with a high-precision potentiometer with a direct WattRate measurement and an accurate magnetic resistance of 300°. For the adjustment of the bicycle, the protocol described in previous studies was followed [49]**. The test consisted of a** clinical step test with progressive loads; the steps lasted 2 min and the pedaling cadence was between 70 and 80 bpm. In the first 2 min, the subject pedaled at 50 W, then the load was increased by 25 W every 2 min; the test ended when the participant decided to stop voluntarily due to fatigue [50]. The maximum working power was established as the last 2 min step that the subject was able to complete. The VO_2max was estimated using the formula described by the ACSM [51]: VO_2max = (1.8 *workload (kg.m.min-1))/body weight (kg) + 3.5 + 3.5 (where 1 W = 6.12 kg m.min-1).

2.4. Procedure

The intervention period lasted 12 weeks, the training frequency was 2 days/week (24 sessions) and the length of time per session was 60 min.

EG1 performed a MICT session starting with 10 min of standardized general warm-up, 5 min of Nordic walking on an elliptical trainer, joint mobility exercises, and dynamic stretching. In the main phase, they performed 40 min of continuous aerobic endurance training on a cycloergometer, without breaks, maintaining the same intensity range throughout the session; the intensity was increased every 4 weeks, from weeks 1–4 they worked at 55%–60 % heart rate reserve (HRR), from weeks 5–8 at 60%–65 % HRR, and from weeks 9–12 at 65%–70 % HRR. Finally, a 10 min post-workout phase with a cool down and static stretching took place.

EG2 performed strength training, based on an individual load-velocity ratio assessment, combined with MICT. The session started with 10 min of standardized general warm-up, 5 min of Nordic walking on the elliptical machine, joint mobility exercises, and dynamic stretching. Finally, a more specific warm-up was performed. The participants performed 2 sets of each exercise, squat and bench press, only with the weight of the bar (5 kg); the first set consisted of 8–10 reps and the second set of 6–8 reps; the rest between sets was 2 min. The main training phase was divided into two 20-min blocks. During the first 20 min, they performed 2 strength exercises that reproduced basic motor actions. The first exercise was a lower hemisphere push (squat) with an intensity of 60 % of their 1RM; 3 sets were performed with the number of repetitions individualized for each subject using the initial speed loss test, and the rest between sets and between exercises was 3 min. The second exercise was a bench press at an intensity of 50 % of their 1RM. Regarding the selection of volume, the analysis of previous studies indicated a %VL of 25–30 % in squat and 35–40 % in bench press, as a medium-high effort value above which the degree of fatigue begins to increase, causing a significant decrease in performance [27,29,43]**. Following a minimum stimulus criterion, in order to guarantee a low training volume, and considering the intensities proposed in this study, a 10 % %VL was established for the squat exercise and 15 % for the bench press. In the last 20 min of the main phase, the participants performed continuous moderate-intensity training on a cycloergometer; the intensity of the training increased every 4 weeks. Thus, from weeks 1 to 4, they trained at 55%-60 %** HRR**, from weeks 5 to 8, at 60%-65 %** HRR**, and from weeks 9 to 12, at 65%-70 %** HRR**. Finally, a 10 min post-training phase with cool down and static stretching took place.**

EG3 performed strength training, based on an individual load-velocity ratio assessment, combined with HIIT. This group performed the same warm-up protocol and the first 20 min of the main phase as EG2. In the last 20 min of the main phase, they performed high-intensity interval training on a cycloergometer. Following the review of previous studies, and the lack of a standardized protocol for this training modality in adults with hypertension [19,20], a work-recovery ratio of 1:1, 2 min work: 2 min active recovery was established following previous work in cardiac rehabilitation and cardiovascular pathology [52–54]. In addition, based on the European Society of Cardiology (ESC) classification of aerobic training intensity from maximal ergometry [6], an intensity of 80–85 % HRR was determined for the training time, and 55%–60 % HRR for the active recovery time. The review of the latest ESC documents allowed for the following ranges of intensity: <40 % low intensity HRR, 40–69 % moderate intensity HRR, 70–85 % high intensity HRR, and >85 % very high intensity HRR [6,55]. Training intensities were not modified during the intervention. Finally, a 10 min post-training phase with a return to calm and static stretching took place. The heart rate was monitored using the MyZone MZ-3 Heart Rate Monitor, which allowed the HR to be monitored at all times. In addition, the subjective rate of perceived exertion (RPE) was recorded simultaneously [56], as well as the training in watts, with the WattRate direct measurement potentiometer [57], by means of a computer integrated in the cycloergometer.

2.5. Statistical analysis

The Kolmogorov–Smirnov test and Mauchly's W-test were used to evaluate the normality and the sphericity of the data. The mean and standard deviation were calculated from the quantitative variables, and frequency and percent were used for the qualitative variables. A two-way analysis of variance (ANOVA) with repeated measurements and Bonferroni's correction will be used to compare the changes from the baseline between groups, the evaluation time interaction, and evaluation time. To protect against a Type I error, Bonferroni's correction was used to achieve $p < 0.005$ for statistical significance. The effect size was calculated using partial eta-squared (η2p) for analysis of variance, and will be defined as small: ES ≥ 0.10; moderate: ES ≥ 0.30, large: ES ≥ 1.2; or very large: ES ≥ 2.0. Lastly, an error of $p \leq 0.05$ was used [58]. All analyses were based on intention-to-treat with an error of $p < 0.05$. The statistical analysis was performed using the statistical package SPSS 24.0 for Windows.

3. Results

Table 1 shows the characteristics of the sample, and Tables 2 and 3 show the pre-post intervention results of EG1, EG2, EG3, and CG. In addition, group * time interaction is also presented.

On the one hand, EG1, EG2, and EG3 showed significant improvements in SBP, DBP, MAP, RHrest, lean mass, waist circumference, TC, LDL, glucose, handgrip strength, 1RM upper body, upper limb MPV (m/s 50 %), 1RM lower body, lower limb MPV (m/s 60 %), and VO_2peak, with these changes being significantly greater than those of the CG. On the other hand, EG2 obtained greater changes in SBP, DBP, MAP, PP, RPP, waist circumference, 1RM upper body, upper limb MPV (m/s 50 %), 1RM lower body, and lower limb MPV (m/s 60 %) than EG1.

EG2 also showed further improvements in SBP, MAP, RPP, 1RM upper limb, upper limb MPV (m/s 50 %), and VO_2peak than EG3.

Finally, the EG3 achieved major improvements in SBP, MAP, and RPP than EG1. Furthermore, it was the only intervention group that significantly reduced BFP (body fat percentage) with respect to the CG.

Table 1
Characteristics of the sample.

Variable		% (n) or M±SD
Sex	Female	51.54 [50]
	Male	48.45 [47]
Age		54.17 ± 6.70
Marital Status	Married	87.00 [59]
	Single	11.00 [11]
	Widow	2.00 [2]
Occupation	Full-Time Worker	49.00 [49]
	Part-Time Worker	4.00 [4]
	Unemployed	16.00 [16]
	Self-Employed	10.00 [10]
	Retired	21.00 [21]
Level of Education	No Education	9.00 [9]
	Elementary School	32.00 [32]
	Secondary School	16.00 [16]
	High School	25.00 [25]
	University Education	18.00 [18]
Living Status	Living with Someone	87.00 [59]
	Living Alone	13.00 [13]

4. Discussion

The aim of the present study was to compare the effects of different individualized training programs, i.e., MICT, strength training combined with MITC, and strength training combined with HIIT, in adults with high blood pressure. The results showed that EG1, EG2, and EG3 significantly improved blood pressure levels, while the CG showed no change. One of the main findings of this research was that both groups with combined training showed greater improvements in these variables, with strength training combined with MICT showing the greatest benefits. It can be observed that the reductions in blood pressure levels obtained in this study were significantly greater than the results obtained in previous work with this same modality, despite the fact that the frequency of training was lower [16]. These improvements could be linked to the rigorousness with which the intensity and volume of strength training was quantified, which provided the same training for all participants and a similar degree of exertion [25,26,28–30]. The greater changes in the combined training groups can be attributed to an improvement in endothelial function induced by strength training. Endothelial dysfunction is associated with several cardiovascular risk factors, including hypertension. The endothelium plays an important role in vascular contractile modulation that is largely dependent on the bioavailability of nitric oxide (NO) [60–62]. When the endothelium is damaged, it neutralizes NO production and stimulates the production of vasoconstrictive substances, leading to an increase in blood pressure [63,64]. Strength training can stimulate NO production by increasing vascular AMPK/PPARδ and suppressing endoplasmic reticulum stress, thereby improving endothelial function [65–68]. Furthermore, although the two combined training groups had the same dose of strength training, the group that performed MICT showed greater improvements than the group that performed HIIT. This may be because aerobic exercise, performed over a prolonged period of time and at a moderate intensity, has been widely shown to have beneficial effects on endothelial function [69,70].

In terms of body composition variables, lean mass and waist circumference, the intervention groups showed significant improvements, while the CG showed no change. Physical exercise induces changes in body composition because during muscle contraction, hundreds of exerkines with autocrine, paracrine or endocrine effects are released into the bloodstream, with major health benefits [4,71,72]. Training can increase muscle mass and reduce fat percentage [68,72], as the secretion of some of these exerkines promotes muscle hypertrophy and myogenesis, lipolysis, and fatty acid oxidation, and induces the browning of white adipose tissue [68,72–74]. Likewise, the participants in the strength training groups showed the most improvement in these variables, with the combined MICT group again showing the most improvement. These results can be attributed to strength training, which promotes visceral fat loss by promoting metabolic adaptations in the abdominal subcutaneous adipose tissue, with a significant increase in lipolysis in this area, both during and after training [72,75,76]. With regard to improvements in body composition, it is known that muscle is an important modifiable risk factor for the development of cardiovascular disease, also for cardiovascular disease mortality and for all-cause mortality; lean mass appears to have a protective effect against cardiovascular and metabolic disease [77]. On the other hand, recent studies have compared improvements in body composition with MICT vs HIIT training, showing that the changes brought about by both types of training are similar and even favor MICT in reducing body fat [78–80].

In line with these changes, it can be observed that participants in the intervention groups also significantly reduced their total cholesterol, LDL and glucose values, with these reductions being significantly different from the CG, which did not change. These improvements can be brought about by the release of IL-6 during exercise, among other exerkines, as its signaling within muscle leads to an increase in basal glucose uptake and translocation of its transporter GLUT-4 [68,72,81], in addition to increasing intramyocellular or whole-body fatty acid oxidation through activation of AMPK [68,72,81].

In relation to physical fitness, the results showed significant improvements in all three training groups in both strength and cardiorespiratory fitness as compared to the CG. Regarding the strength gains of the three intervention groups, it is known that the practice of exercise, regardless of the modality performed, is capable of provoking structural (peripheral) and neural (central) physiological adaptations, as muscular action is necessary to overcome a load [25,26]. The central adaptations of these groups were determined by the type of activity performed, the intensity of the work, and the duration of the action [25]. The combined strength training group with MICT showed greater improvements in manual pressure strength and maximal upper and lower limb strength than the continuous moderate-intensity group. These results may be a response to strength training, which achieves greater neural adaptations through increased recruitment and synchronization of motor units and stimulus frequency, as previously demonstrated in the literature [82–84]. These adaptations of the central nervous system as a whole contribute to gains and improvements in maximal strength. In terms of aerobic endurance, the results revealed significant changes in the function of the cardiovascular and respiratory systems, with an improvement observed in maximal oxygen consumption and an increase in stroke volume and cardiac output. Exercise can lead to important adaptations in skeletal muscle, such as increased mitochondrial biogenesis and capillary density, with these responses to exercise reflected in an improved ability to transport and use oxygen to generate energy [85–87]. Many studies support the important role of PGC-1α (peroxisome proliferator-activated receptor gamma 1α coactivator) in these muscle adaptations induced by aerobic endurance exercise, including its possible role in the complex regulation of mitochondrial quality [86,59,88]. Despite the controversy that combined training may interfere with the adaptations induced by the different metabolic pathways AMPK and m-TOR, activated by aerobic and strength training respectively, in the present study, it can be observed that EG2, strength training combined with MICT, obtained greater improvements in VO_2peak than EG1, which performed a single modality of continuous moderate-intensity training, showing the compatibility of the two modalities in the same session and showing a similarity with previous studies [89,90]. These results can be justified by the large adaptive reserve that sedentary subjects have at the start of any exercise program. Previous studies have shown that sedentary subjects who begin a combined strength and endurance training program achieve a positive and additive response to the two exercise modalities, favoring a generic adaptation in the absence of a true specificity of the training effect [91]. Another important factor to consider is the low degree of fatigue in strength training, which could explain the possible interference of this training modality, thus achieving a greater maintenance of the MHC IIX

Table 2
Effect of multicomponent training and cardiovascular training on blood biomarkers and body composition.

Outcome	Group	Pre-test (M±SD)	Post-test (M±SD)	No Adjusted			Group[a] time interaction		
				Difference post-pre (M± SD)	p	95 % CI (Mpost-Mpre)	F	Sig	ES
SBP (mmHg)	EG1	144.46 ± 8.83	136.17 ± 7.86	−8.29 ± 1.46[a,c,d]	<0.001	−11.20; −5.38	36.00	<0.001	0.54
	EG2	143.44 ± 7.53	121.76 ± 8.52	−21.68 ± 1.43[a,b,d]	<0.001	−24.53; −18.82			
	EG3	143.87 ± 8.49	128.96 ± 10.40	−14.91 ± 1.49[a,b,c]	<0.001	−17.88; −11.94			
	CG	147.92 ± 11.83	146.56 ± 11.52	−1.36 ± 1.43[b,c,d]	0.346	−4.21; 1.49			
DBP (mmHg)	EG1	90.00 ± 6.90	82.92 ± 6.12	−7.08 ± 1.10[a,c]	<0.001	−9.27; −4.89	19.46	<0.001	0.38
	EG2	88.28 ± 5.72	74.36 ± 5.09	−13.92 ± 1.08[a,b]	<0.001	−16.06; −11.77			
	EG3	88.30 ± 6.98	77.61 ± 7.91	−10.69 ± 1.12[a]	<0.001	−12.93; −8.45			
	CG	92.16 ± 7.28	89.32 ± 6.95	−2.84 ± 1.08[b,c,d]	0.01	−4.98; −0.69			
MAP (mmHg)	EG1	108.17 ± 5.96	100.67 ± 5.87	−7.50 ± 1.00[a,c,d]	<0.001	−9.49; −5.50	37.06	<0.001	0.54
	EG2	106.52 ± 5.27	90.12 ± 5.34	−16.40 ± 0.98[a,b,d]	<0.001	−18.35; −14.44			
	EG3	106.78 ± 6.90	94.74 ± 7.85	−12.04 ± 1.02[a,b,c]	<0.001	−14.08; −10.00			
	CG	110.60 ± 7.25	108.28 ± 7.80	−2.32 ± 0.98[b,c,d]	0.021	−4.27; −0.36			
PP (mmHg)	EG1	54.46 ± 10.29	53.25 ± 6.72	−1.20 ± 1.49[c]	0.419	−4.16; 1.75	7.84	<0.001	0.20
	EG2	55.16 ± 7.48	47.40 ± 7.68	−7.76 ± 1.46[a,b]	<0.001	−10.65; −4.86			
	EG3	55.54 ± 6.17	50.83 ± 9.58	−4.73 ± 1.52[a]	0.002	−7.76;-1.71			
	CG	55.76 ± 11.32	57.20 ± 8.51	1.44 ± 1.46[c,d]	0.327	−1.45; 4.33			
RPP	EG1	11379.67 ± 1442.92	10005.00 ± 1365.80	−1374.66 ± 251.81[c,d]	<0.001	−1874.71; −874.61	22.88	<0.001	0.42
	EG2	11254.00 ± 1735.96	8507.64 ± 1309.88	−2746.36 ± 246.72[b,d]	<0.001	−3236.30; −2256.41			
	EG3	11545.13 ± 1554.06	9528.30 ± 1474.82	−2016.82 ± 257.23[a,b,c]	<0.001	−2527.63; −1506.01			
	CG	11827.56 ± 1474.97	11875.68 ± 1132.23	48.12 ± 246.72[cc]	0.846	−441.82; 538.06			
RHR	EG1	79.04 ± 11.20	73.54 ± 9.51	−5.50 ± 1.64[a]	0.001	−8.77; −2.23	7.02	<0.001	0.18
	EG2	78.40 ± 11.05	69.72 ± 8.49	−8.68 ± 1.61[a]	<0.001	−11.88; −5.47			
	EG3	80.17 ± 8.95	73.57 ± 9.38	−6.60 ± 1.68[a]	<0.001	−9.94; −3.26			
	CG	80.00 ± 8.23	81.28 ± 8.06	1.28 ± 1.61[b,c,d]	0.430	−1.92; 4.48			
Weight (Kg)	EG1	91.45 ± 16.59	91.32 ± 16.45	−0.20 ± 0.16	0.212	−0.53; 0.12	0.73	0.531	0.24
	EG2	78.11 ± 14.18	77.75 ± 13.89	−0.17 ± 0.16	0.282	−0.49; 0.14			
	EG3	87.88 ± 16.01	86.98 ± 16.62	−0.40 ± 0.16	0.019	−0.74; −0.68			
	CG	88.94 ± 15.94	88.86 ± 16.28	−0.04 ± 0.16	0.806	−0.36; 0.28			
LBM (Kg)	EG1	30.28 ± 6.34	30.77 ± 6.31	−0.12 ± 0.38[a]	0.756	−0.89; 0.64	0.76	0.514	0.24
	EG2	28.98 ± 6.73	29.56 ± 6.77	−0.35 ± 0.37[a]	0.351	−1.11; 0.39			
	GE3	29.93 ± 5.77	30.38 ± 6.21	−0.89 ± 0.39[a]	0.026	−1.68; −0.11			
	CG	30.56 ± 5.98	30.38 ± 5.92	−0.08 ± 0.37[b,c,d]	0.825	−0.83; 0.67			
BFP (%)	EG1	39.70 ± 8.09	38.73 ± 8.20	−0.96 ± 0.33	0.004	−1.62; −0.30	3.78	0.013	0.11
	EG2	32.62 ± 10.27	31.55 ± 9.75	−1.07 ± 0.32	0.001	−1.71; −0.42			
	EG3	38.00 ± 9.08	36.83 ± 9.15	−1.17 ± 0.33[a]	0.001	−1.84; −0.49			
	CG	37.69 ± 8.44	37.89 ± 8.70	0.19 ± 0.32[d]	0.547	−0.44; 0.84			
BMI (Kg/m^2)	EG1	32.61 ± 5.14	32.40 ± 5.11	−0.90 ± 0.39	0.024	−1.68; −0.12	3.23	0.026	0.09
	EG2	27.43 ± 4.87	27.25 ± 4.56	−1.09 ± 0.38	0.006	−1.85; −0.32			
	EG3	31.85 ± 5.59	31.44 ± 5.56	−1.46 ± 0.40	<0.001	−2.26, −0.66			
	EG	31.90 ± 4.99	31.86 ± 5.09	0.18 ± 0.38	0.628	−0.57; 0.95			
VF (cm^2)	EG1	183.60 ± 59.58	178.39 ± 59.24	−5.21 ± 2.12	0.016	−9.42; −0.99	3.32	0.023	0.09
	EG2	125.19 ± 58.83	119.74 ± 54.32	−5.44 ± 2.07	0.010	−9.57; −1.31			
	EG3	165.07 ± 56.86	156.66 ± 56.29	−8.41 ± 2.16[a]	<0.001	−12.71; −4.10			
	CG	165.25 ± 54.58	166.10 ± 55.82	0.84 ± 2.07[d]	0.684	−3.28; 4.97			
Waist circumference (cm)	EG1	110.08 ± 13.26	106.83 ± 15.27	−3.25 ± 0.88[a,c]	<0.001	−5.00; −1.49	12.66	<0.001	0.29
	EG2	98.76 ± 10.54	92.16 ± 10.58	−6.60 ± 0.86[a,b]	<0.001	−8.32; −4.87			
	EG3	106.60 ± 14.32	102.26 ± 16.12	−4.34 ± 0.90[a]	<0.001	−6.14; −2.55			
	CG	105.80 ± 12.33	106.52 ± 12.64	0.72 ± 0.86[b,c,d]	0.409	−1.00; 2.44			

Legend: SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; MAP: Mean Arterial Pressure; PP: Pulse Pressure: RPP: Rate Pressure Product; RHR: Resting Heart Rate; BMI: Body Mass Index; LBM: Lean Body Mass; BFP: Body Fat Percentage; VF: Visceral Fat.

[a] Significantly different from corresponding CG value at the $p < 0.05$ level.
[b] Significantly different from corresponding EG1 value at the $p < 0.05$ level.
[c] Significantly different from corresponding EG2 value at the $p < 0.05$ level.
[d] Significantly different from corresponding EG3 value at the $p < 0.05$ level.

fibers [92].

This study has some limitations that should be taken into account for future research, such as the total intervention time. It is possible that longer periods of time training will lead to more significant results in some of the variables. Another point to consider is an intervention group with only strength training that could have been compared with the other modalities, and the effects on blood pressure as compared to the other modalities could have been known more precisely. Finally, another limitation was the daily intake of the participants, as the diet could have been controlled by making a daily dietary record.

Despite these limitations, this would be the first study in a hypertensive population comparing different strength training modalities, based on an individual assessment of the load-velocity relationship, combined with MICT and HIIT, versus continuous moderate-high intensity training. Another contribution and strength of this study is the precision with which the effort was dosed through the speed of execution, which allowed the workload to be individualized for each participant, ensuring that the stimulus programmed for strength training was truly the one applied and executed by each of them. More importantly, this quantification of load allowed all hypertensive participants to perform the same training and reach a similar degree of fatigue.

Table 3
Effect of multicomponent training and cardiovascular training on metabolic biomarkers, and physical fitness.

Outcome	Group	Pre-test (M ± ED)	Post-test (M ± ED)	No Adjusted			Group[a] time interaction		
				Difference post-pre (M± ED)	p	95 % CI (Mpost-Mpre)	F	Sig	ES
TC (mg/dl)	EG1	192.25 ± 40.54	185.04 ± 23.10	−7.20 ± 5.43[a]	0.18	−18.00; 3.58	7.34	<0.001	0.19
	EG2	199.72 ± 30.11	192.08 ± 29.20	−7.64 ± 5.32[a]	0.15	−18.21; 2.93			
	EG3	195.73 ± 38.36	177.16 ± 35.48	−18.47 ± 5.54[a]	0.001	−29.50; −7.45			
	CG	191.76 ± 28.50	208.00 ± 29.89	16.24 ± 5.32[b,c,d]	0.003	5.66; 26.81			
HDL (mg/dl)	EG1	48.21 ± 7.15	50.00 ± 10.37	1.79 ± 1.00	0.078	−0.20; 3.79	0.89	0.447	0.02
	EG2	54.44 ± 9.92	55.32 ± 11.29	0.88 ± 0.98	0.375	−1.07; 2.83			
	EG3	48.17 ± 11.63	49.17 ± 12.30	1.00 ± 1.02	0.333	−1.04; 3.04			
	CG	48.76 ± 11.09	48.48 ± 12.48	−0.28 ± 0.98	0.777	−2.23; 1.67			
LDL (mg/dl)	EG1	118.27 ± 36.36	110.45 ± 21.58	−7.82 ± 4.71[a]	0.100	−17.18; 1.53	6.65	<0.001	0.17
	EG2	120.61 ± 24.77	114.14 ± 24.54	−6.47 ± 4.61[a]	0.164	−15.64; 2.70			
	EG3	118.15 ± 36.26	105.30 ± 32.60	−12.85 ± 4.81[a]	0.009	−22.41; −3.29			
	CG	116.82 ± 23.25	131.34 ± 31.29	14.52 ± 4.61[b,c,d]	0.002	5.34; 23.69			
TG (mg/dl)	EG1	126.08 ± 52.16	121.91 ± 36.94	−4.16 ± 7.42	0.576	−18.91; 10.58	3.01	0.034	0.09
	EG2	122.32 ± 59.16	113.72 ± 43.21	−8.60 ± 7.27	0.240	−23.05; 5.85			
	EG3	137.21 ± 55.82	121.43 ± 65.24	−15.78 ± 7.58[a]	0.040	−30.84; −0.71			
	CG	133.44 ± 64.33	147.96 ± 79.97	14.52 ± 7.27[d]	0.049	0.70; 28.97			
Glucose (mg/dl)	EG1	107.33 ± 13.49	99.91 ± 14.06	−7.41 ± 1.60[a]	<0.001	−10.60; −4.22	11.73	<0.001	0.27
	EG2	98.16 ± 14.69	91.36 ± 10.77	−6.80 ± 1.57[a]	<0.001	−9.92; −3.67			
	EG3	97.60 ± 13.05	87.65 ± 13.14	−9.95 ± 1.64[a]	<0.001	−13.21; −6.69			
	CG	97.24 ± 22.48	99.80 ± 19.94	2.56 ± 1.57[b,c,d]	0.107	−0.56; 5.68			
Handgrip RA	EG1	32.85 ± 7.61	35.56 ± 10.23	2.70 ± 0.59[a]	<0.001	1.53; 3.88	7.91	<0.001	0.20
	EG2	31.18 ± 9.80	33.24 ± 11.18	2.06 ± 0.57	0.001	0.91; 3.20			
	EG3	31.80 ± 7.79	35.45 ± 8.26	3.65 ± 0.60[a]	0.80	2.45; 4.84			
	CG	31.42 ± 8.73	31.56 ± 8.81	0.14 ± 0.57[b,d]	<0.001	−1.00; 1.28			
1RM (Kg UL)	EG1	51.33 ± 21.18	59.87 ± 24.99	8.54 ± 1.58[a,c]	<0.001	5.40; 11.68	41.34	<0.001	0.57
	EG2	46.24 ± 23.68	65.12 ± 30.34	18.88 ± 1.54[a,b,d]	<0.001	15.80; 21.95			
	EG3	51.09 ± 20.52	62.78 ± 26.91	11.69 ± 1.61[a,c]	<0.001	8.48; 14.90			
	CG	54.24 ± 24.26	52.20 ± 23.20	−2.04 ± 1.54[b,c,d]	0.191	−5.11; 1.03			
MPV (m/s 50 %)	EG1	0.97 ± 0.02	1.08 ± 0.07	0.10 ± 0.01[a,c]	<0.001	0.08; 0.13	78.17	<0.001	0.71
	EG2	0.96 ± 0.03	1.20 ± 0.06	0.23 ± 0.01[a,b,d]	<0.001	0.20; 0.26			
	EG3	0.96 ± 0.03	1.10 ± 0.06	0.13 ± 0.01[a,c]	<0.001	0.10; 0.16			
	CG	0.97 ± 0.02	0.92 ± 0.04	−0.05 ± 0.01[b,c,d]	<0.001	−0.07; −0.02			
1RM (Kg LL)	EG1	70.75 ± 34.09	87.96 ± 38.71	17.20 ± 1.92[a,c]	<0.001	13.38; 21.03	49.49	<0.001	0.61
	EG2	73.08 ± 35.11	98.32 ± 41.42	25.24 ± 1.88[a,b]	<0.001	21.49; 28.98			
	EG3	79.26 ± 32.24	97.65 ± 37.24	18.39 ± 1.96[a]	<0.001	14.48; 22.29			
	CG	79.92 ± 32.17	76.44 ± 30.72	−3.48 ± 1.88[b,c,d]	0.068	−7.22; 0.26			
MPV (m/s 60 %)	EG1	0.99 ± 0.02	1.15 ± 0.08	0.16 ± 0.01[a,c]	<0.001	0.13; 0.19	76.50	<0.001	0.71
	EG2	0.99 ± 0.02	1.21 ± 0.05	0.22 ± 0.01[a,b]	<0.001	0.19; 0.25			
	EG3	0.98 ± 0.02	1.16 ± 0.06	0.17 ± 0.01[a]	<0.001	0.14; 0.20			
	CG	0.99 ± 0.02	0.95 ± 0.05	−0.03 ± 0.01[b,c,d]	0.006	−0.06; −0.01			
VO2p (ml/kg/min)	EG1	22.01 ± 4.34	26.71 ± 5.38	4.69 ± 0.34[a]	<0.001	4.00; 5.38	57.55	<0.001	0.65
	EG2	25.08 ± 3.82	30.86 ± 4.40	5.78 ± 0.33[a,d]	<0.001	5.10; 6.45			
	EG3	21.13 ± 3.64	24.56 ± 4.56	3.43 ± 0.35[a,c]	<0.001	2.73, 4.13			
	CG	21.61 ± 3.58	21.43 ± 3.57	−0.18 ± 0.33[b,c,d]	0.588	−0.85; 0.49			

Legend: TC: Total Cholesterol; HDL: High Density Lipoprotein; LDL: Low Density Lipoprotein; TG: Triglycerides; RA: right arm; LA: left arm; 1RM: One-Repetition Maximum; UL: Upper Limb; LL: Lower Limb; MPV: mean propulsive velocity; VO2p: Peak oxygen consumption.

[a] Significantly different from corresponding CG value at the $p < 0.05$ level.
[b] Significantly different from corresponding EG1 value at the $p < 0.05$ level.
[c] Significantly different from corresponding EG2 value at the $p < 0.05$ level.
[d] Significantly different from corresponding EG3 value at the $p < 0.05$ level.

5. Conclusion

The results of the present study indicate that the implementation of a strength training program, based on an individual assessment of the load-velocity relationship, combined with MICT in the same session, 2 days per week for 12 weeks, produces significant improvements in blood and metabolic biomarkers, body composition, and physical condition, in adults with hypertension, with these adaptations being superior to those produced by MICT and strength training combined with HIIT, which also show improvements, but to a lesser extent.

CRediT authorship contribution statement

Isabel López-Ruiz: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Fernando Lozano Ruiz-Poveda:** Writing – review & editing, Funding acquisition. **María Dolores Masía:** Writing – review & editing, Visualization, Conceptualization. **Juan Ramón Heredia-Elvar:** Writing – review & editing, Visualization. **Noelia González-Gálvez:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Funding

This research was supported by a grant Research Support Plans from the Universidad Católica de Murcia (Spain), named: "Hyper Exercise Proyect: Effect of four physical exercise programs on cardiovascular, hormonal and metabolic adaptations, body composition and physical condition in adults with hypertension." (code: PMAFI-01/24)

This research was supported by a grant from Sahajanand Medical Technologies (SMT).

Acknowledgments

The authors would like to thank the indispensable collaboration of Centro Oxígeno Sport & Wellness.

References

[1] M. Vaduganathan, G.A. Mensah, J.V. Turco, V. Fuster, G.A. Roth, The global burden of cardiovascular diseases and risk: a compass for future health, J. Am. Coll. Cardiol. 80 (25) (2022) 2361–2371.
[2] G.A. Mensah, V. Fuster, C.J.L. Murray, G.A. Roth, Global burden of cardiovascular diseases and risks, 1990-2022, J. Am. Coll. Cardiol. 82 (25) (2023) 2350–2473.
[3] G. Mancia, R. Kreutz, M. Brunström, M. Burnier, G. Grassi, A. Januszewicz, et al., 2023 ESH guidelines for the management of arterial hypertension the task force for the management of arterial hypertension of the European society of hypertension: endorsed by the international society of hypertension (ISH) and the European renal association (ERA), J. Hypertens. 41 (12) (2023) 1874–2071.
[4] B.K. Pedersen, B. Saltin, Exercise as medicine - evidence for prescribing exercise as therapy in 26 different chronic diseases, Scand. J. Med. Sci. Sports 25 (Suppl 3) (2015) 1–72.
[5] H. Momma, R. Kawakami, T. Honda, S.S. Sawada, Muscle-strengthening activities are associated with lower risk and mortality in major non-communicable diseases: a systematic review and meta-analysis of cohort studies, Br. J. Sports Med. 56 (13) (2022) 755–763.
[6] A. Pelliccia, S. Sharma, S. Gati, M. Bäck, M. Börjesson, S. Caselli, et al., 2020 ESC Guidelines on sports cardiology and exercise in patients with cardiovascular disease: the Task Force on sports cardiology and exercise in patients with cardiovascular disease of the European Society of Cardiology (ESC), Eur. Heart J. 42 (1) (2020) 17–96.
[7] F.J. Charchar, P.R. Prestes, C. Mills, S.M. Ching, D. Neupane, F.Z. Marques, et al., Lifestyle management of hypertension: international society of hypertension position paper endorsed by the world hypertension league and European society of hypertension, J. Hypertens. 42 (1) (2024) 23–49.
[8] P.K. Whelton, R.M. Carey, W.S. Aronow, D.E. Casey Jr., K.J. Collins, C. Dennison Himmelfarb, et al., 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: executive summary: a report of the American college of cardiology/American heart association task force on clinical practice guidelines, Circulation 138 (17) (2018) e426–e483.
[9] H. Hanssen, H. Boardman, A. Deiseroth, T. Moholdt, M. Simonenko, N. Kränkel, et al., Personalized exercise prescription in the prevention and treatment of arterial hypertension: a consensus document from the European association of preventive cardiology (EAPC) and the ESC council on hypertension, Eur. J. Prev. Cardiol. 29 (1) (2021) 205–215.
[10] L.A. Kaminsky, C.J. Lavie, K. Flint, R. Arena, S. Bond, Working toward optimal exercise prescription: strength training should not Be overlooked, J Cardiopulm Rehabil Prev 42 (2) (2022). E32-e3.
[11] S. Masroor, P. Bhati, S. Verma, M. Khan, M.E. Hussain, Heart rate variability following combined aerobic and resistance training in sedentary hypertensive women: a randomised control trial, Indian Heart J. 70 (3) (2018) S28–s35. Suppl 3.
[12] L.G. Lima, J.T.M. Bonardi, G.O. Campos, R.F. Bertani, L.M.L. Scher, J.C. Moriguti, et al., Combined aerobic and resistance training: are there additional benefits for older hypertensive adults? Clinics 72 (6) (2017) 363–369.
[13] G.V. Guimaraes, L.G. de Barros Cruz, M.M. Fernandes-Silva, E.L. Dorea, E. A. Bocchi, Heated water-based exercise training reduces 24-hour ambulatory blood pressure levels in resistant hypertensive patients: a randomized controlled trial (HEx trial), Int. J. Cardiol. 172 (2) (2014) 434–441.
[14] E.S. Dos Santos, R.Y. Asano, I.G. Filho, N.L. Lopes, P. Panelli, C. Nascimento Dda, et al., Acute and chronic cardiovascular response to 16 weeks of combined eccentric or traditional resistance and aerobic training in elderly hypertensive women: a randomized controlled trial, J. Strength Condit Res. 28 (11) (2014) 3073–3084.
[15] V.M. Schneider, L.B. Domingues, D. Umpierre, H. Tanaka, R. Ferrari, Exercise characteristics and blood pressure reduction after combined aerobic and resistance training: a systematic review with meta-analysis and meta-regression, J. Hypertens. 41 (7) (2023) 1068–1076.
[16] I. López-Ruiz, F. Lozano, M.D. Masia, N. González-Gálvez, Multicomponent training and optimal dosing strategies for adults with hypertension: a systematic review and meta-analysis of randomized controlled trials, Sports 11 (6) (2023).
[17] H. Albalawi, E. Coulter, N. Ghouri, L. Paul, The effectiveness of structured exercise in the south Asian population with type 2 diabetes: a systematic review, Physician Sportsmed. 45 (4) (2017) 408–417.
[18] K.L. Way, R.N. Sultana, A. Sabag, M.K. Baker, N.A. Johnson, The effect of high Intensity interval training versus moderate intensity continuous training on arterial stiffness and 24h blood pressure responses: a systematic review and meta-analysis, J. Sci. Med. Sport 22 (4) (2019) 385–391.
[19] L. Li, X. Liu, F. Shen, N. Xu, Y. Li, K. Xu, et al., Effects of high-intensity interval training versus moderate-intensity continuous training on blood pressure in patients with hypertension: a meta-analysis, Medicine (Baltim.) 101 (50) (2022) e32246.
[20] E.C. Costa, J.L. Hay, D.S. Kehler, K.F. Boreskie, R.C. Arora, D. Umpierre, et al., Effects of high-intensity interval training versus moderate-intensity continuous training on blood pressure in adults with pre- to established hypertension: a systematic review and meta-analysis of randomized trials, Sports Med. 48 (9) (2018) 2127–2142.
[21] J.S. Ramos, L.C. Dalleck, A.E. Tjonna, K.S. Beetham, J.S. Coombes, The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: a systematic review and meta-analysis, Sports Med. 45 (5) (2015) 679–692.
[22] L. Carpes, R. Costa, B. Schaarschmidt, T. Reichert, R. Ferrari, High-intensity interval training reduces blood pressure in older adults: a systematic review and meta-analysis, Exp. Gerontol. 158 (2022) 111657.
[23] C. Alvarez, L. Peñailillo, P. Ibacache-Saavedra, D. Jerez-Mayorga, C. Campos-Jara, D.C. Andrade, et al., Six weeks of a concurrent training therapy improves endothelial function and arterial stiffness in hypertensive adults with minimum non-responders, Hipertens. Riesgo Vasc. (2024).
[24] S.S. Kazemi, A. Heidarianpour, E. Shokri, Effect of resistance training and high-intensity interval training on metabolic parameters and serum level of Sirtuin1 in postmenopausal women with metabolic syndrome: a randomized controlled trial, Lipids Health Dis. 22 (1) (2023) 177.
[25] J.J.G. Badillo, J.R. Serna, Bases de la programación del entrenamiento de fuerza: Inde, 2002.
[26] J.J. González-Badillo, L. Sánchez-Medina, J. Ribas-Serna, D. Rodríguez-Rosell, Toward a new paradigm in resistance training by means of velocity monitoring: a critical and challenging narrative, Sports Med Open 8 (1) (2022) 118.
[27] D. Rodríguez-Rosell, J.M. Yáñez-García, L. Sánchez-Medina, R. Mora-Custodio, J. J. González-Badillo, Relationship between velocity loss and repetitions in reserve in the bench press and back squat exercises, J. Strength Condit Res. 34 (9) (2020) 2537–2547.
[28] J.J. González-Badillo, L. Sánchez-Medina, Movement velocity as a measure of loading intensity in resistance training, Int. J. Sports Med. 31 (5) (2010) 347–352.
[29] L. Sánchez-Medina, J.J. González-Badillo, Velocity loss as an indicator of neuromuscular fatigue during resistance training, Med. Sci. Sports Exerc. 43 (9) (2011) 1725–1734.
[30] J.J.G. Badillo, La velocidad de ejecución como referencia para la programación, control y evaluación del entrenamiento de fuerza: Ergotech, 2017.
[31] L. Andreu-Caravaca, D.J. Ramos-Campo, O. Abellán-Aynés, J. Rubio-Arias, Movement velocity as A measure of exercise intensity in persons with multiple sclerosis: a validity study, J. Clin. Med. 9 (8) (2020).
[32] P.J. Marcos-Pardo, J.M. González-Hernández, A. García-Ramos, A. López-Vivancos, P. Jiménez-Reyes, Movement velocity can be used to estimate the relative load during the bench press and leg press exercises in older women, PeerJ 7 (2019) e7533.
[33] D.M. Díez-Fernández, A. Baena-Raya, A. García-Ramos, A. Esteban-Simón, M. A. Rodríguez-Pérez, A.J. Casimiro-Andújar, et al., Estimating the one-repetition maximum on the leg-press exercise in female breast cancer survivors, PeerJ 11 (2023) e16175.
[34] E.C. Schroeder, W.D. Franke, R.L. Sharp, D.C. Lee, Comparative effectiveness of aerobic, resistance, and combined training on cardiovascular disease risk factors: a randomized controlled trial, PLoS One 14 (1) (2019) e0210292.
[35] M. Gorostidi, T. Gijón-Conde, A. De la Sierra, E. Rodilla, E. Rubio, E. Vinyoles, et al., Guía práctica sobre el diagnóstico y tratamiento de la hipertensión arterial en España, 2022. Sociedad Española de Hipertensión-Liga Española para la Lucha contra la Hipertensión Arterial (SEH-LELHA), Hipertens. Riesgo Vasc. 39 (4) (2022) 174–194.
[36] K.J. Stewart, A.C. Bacher, K.L. Turner, J.L. Fleg, P.S. Hees, E.P. Shapiro, et al., Effect of exercise on blood pressure in older persons: a randomized controlled trial, Arch. Intern. Med. 165 (7) (2005) 756–762.
[37] A. Buch, A. Ben-Yehuda, V. Rouach, A.B. Maier, Y. Greenman, E. Izkhakov, et al., Validation of a multi-frequency bioelectrical impedance analysis device for the assessment of body composition in older adults with type 2 diabetes, Nutr. Diabetes 12 (1) (2022) 45.
[38] Y. Lahav, N. Goldstein, Y. Gepner, Comparison of body composition assessment across body mass index categories by two multifrequency bioelectrical impedance analysis devices and dual-energy X-ray absorptiometry in clinical settings, Eur. J. Clin. Nutr. 75 (8) (2021) 1275–1282.
[39] M. Marfell Jones, T. Olds, A. Stewart, L. Carter, Sociedad Internacional para el Avance de la Cineantropometría (ISAK), Manual ISAK, 2006.
[40] ESo Hypertension, Automated devices for clinical use, Dabl Educational Trust, resting cuff sizes 16–24 (2010) 22–32, and 31-45 cm.
[41] G.S. Stergiou, P. Palatini, G. Parati, E. O'Brien, A. Januszewicz, E. Lurbe, et al., 2021 European Society of Hypertension practice guidelines for office and out-of-office blood pressure measurement, J. Hypertens. 39 (7) (2021) 1293–1302.
[42] V. Mathiowetz, N. Kashman, G. Volland, K. Weber, M. Dowe, S. Rogers, Grip and pinch strength: normative data for adults, Arch. Phys. Med. Rehabil. 66 (2) (1985) 69–74.
[43] J.J. González-Badillo, J.M. Yañez-García, R. Mora-Custodio, D. Rodríguez-Rosell, Velocity loss as a variable for monitoring resistance exercise, Int. J. Sports Med. 38 (3) (2017) 217–225.
[44] L. Sánchez-Medina, J.G. Pallarés, C.E. Pérez, R. Morán-Navarro, J.J. González-Badillo, Estimation of relative load from bar velocity in the full back squat exercise, Sports Medicine Int. Open 1 (2) (2017) E80–E88.
[45] R.F. Escamilla, Knee biomechanics of the dynamic squat exercise, Med. Sci. Sports Exerc. 33 (1) (2001) 127–141.
[46] F. Conceição, J. Fernandes, M. Lewis, J.J. Gonzaléz-Badillo, P. Jimenéz-Reyes, Movement velocity as a measure of exercise intensity in three lower limb exercises, J. Sports Sci. 34 (12) (2016) 1099–1106.
[47] D. Rodríguez-Rosell, J.M. Yáñez-García, R. Mora-Custodio, F. Pareja-Blanco, A. G. Ravelo-García, J. Ribas-Serna, et al., Velocity-based resistance training: impact of velocity loss in the set on neuromuscular performance and hormonal response, Appl. Physiol. Nutr. Metabol. 45 (8) (2020) 817–828.

[48] R. Morán-Navarro, A. Martínez-Cava, L. Sánchez-Medina, R. Mora-Rodríguez, J. J. González-Badillo, J.G. Pallarés, Movement velocity as a measure of level of effort during resistance exercise, J. Strength Condit Res. 33 (6) (2019) 1496–1504.
[49] J.R. Gómez-Puerto, M. Edir Da Silva-Grigoletto, B. Hernán Viana-Montaner, D. Vaamonde, J.R. Alvero-Cruz, La importancia de los ajustes de la bicicleta en la prevención de las lesiones en el ciclismo: aplicaciones prácticas, Rev. Andal. Med. Deporte (2008).
[50] P.M. Marqueta, L.F. Bonafonte, J.N. Orellana, D.B. Cuixart, J.C. Nogués, C.C. Soto, et al., Pruebas de esfuerzo en medicina del deporte, Documento de consenso de la Sociedad Española de Medicina del Deporte (SEMED-FEMEDE). Archivos de medicina del deporte: revista de la Federación Española de Medicina del Deporte y de la Confederación Iberoamericana de Medicina del Deporte 33 (1) (2016) 5–83.
[51] B. Ferguson, ACSM's guidelines for exercise testing and prescription 9th, J. Can. Chiropr. Assoc. 58 (2014) 328. © Jcca 2014.; 2014.
[52] T. Yue, Y. Wang, H. Liu, Z. Kong, F. Qi, Effects of high-intensity interval vs. Moderate-intensity continuous training on cardiac rehabilitation in patients with cardiovascular disease: a systematic review and meta-analysis, Front. Cardiovasc. Med. 9 (2022) 845225.
[53] G.G. Cardozo, R.B. Oliveira, P.T. Farinatti, Effects of high intensity interval versus moderate continuous training on markers of ventilatory and cardiac efficiency in coronary heart disease patients, Sci. World J. 2015 (2015) 192479.
[54] D.E. Warburton, D.C. McKenzie, M.J. Haykowsky, A. Taylor, P. Shoemaker, A. P. Ignaszewski, et al., Effectiveness of high-intensity interval training for the rehabilitation of patients with coronary artery disease, Am. J. Cardiol. 95 (9) (2005) 1080–1084.
[55] D. Hansen, A. Abreu, M. Ambrosetti, V. Cornelissen, A. Gevaert, H. Kemps, et al., Exercise intensity assessment and prescription in cardiovascular rehabilitation and beyond: why and how: a position statement from the Secondary Prevention and Rehabilitation Section of the European Association of Preventive Cardiology, European J.Prev. Cardiol. 29 (1) (2021) 230–245.
[56] G. Borg, Borg's Perceived Exertion and Pain Scales, Human kinetics, 1998.
[57] H. Allen, A.R. Coggan, S. McGregor, Training and Racing with a Power Meter, VeloPress, 2019.
[58] W.G. Hopkins, S.W. Marshall, A.M. Batterham, J. Hanin, Progressive statistics for studies in sports medicine and exercise science, Med. Sci. Sports Exerc. 41 (1) (2009) 3–13.
[59] K. Baar, A.R. Wende, T.E. Jones, M. Marison, L.A. Nolte, M. Chen, et al., Adaptations of skeletal muscle to exercise: rapid increase in the transcriptional coactivator PGC-1, FASEB J. 16 (14) (2002) 1879–1886.
[60] K. Node, M. Kitakaze, H. Yoshikawa, H. Kosaka, M. Hori, Reduced plasma concentrations of nitrogen oxide in individuals with essential hypertension, Hypertension 30 (3 Pt 1) (1997) 405–408.
[61] P. Vallance, J. Collier, S. Moncada, Effects of endothelium-derived nitric oxide on peripheral arteriolar tone in man, Lancet 2 (8670) (1989) 997–1000.
[62] A. Gamboa, C. Shibao, A. Diedrich, L. Choi, B. Pohar, J. Jordan, et al., Contribution of endothelial nitric oxide to blood pressure in humans, Hypertension 49 (1) (2007) 170–177.
[63] R.P. Brandes, Endothelial dysfunction and hypertension, Hypertension 64 (5) (2014) 924–928.
[64] E. Schulz, T. Gori, T. Münzel, Oxidative stress and endothelial dysfunction in hypertension, Hypertens. Res. 34 (6) (2011) 665–673.
[65] J. Silva, A.L. Menêses, B.J. Parmenter, R.M. Ritti-Dias, B.Q. Farah, Effects of resistance training on endothelial function: a systematic review and meta-analysis, Atherosclerosis 333 (2021) 91–99.
[66] D. Tian, J. Meng, Exercise for prevention and relief of cardiovascular disease: prognoses, mechanisms, and approaches, Oxid. Med. Cell. Longev. 2019 (2019) 3756750.
[67] F.P. Boeno, T.R. Ramis, S.V. Munhoz, J.B. Farinha, C.E.J. Moritz, R. Leal-Menezes, et al., Effect of aerobic and resistance exercise training on inflammation, endothelial function and ambulatory blood pressure in middle-aged hypertensive patients, J. Hypertens. 38 (12) (2020) 2501–2509.
[68] B.K. Pedersen, M.A. Febbraio, Muscles, exercise and obesity: skeletal muscle as a secretory organ, Nat. Rev. Endocrinol. 8 (8) (2012) 457–465.
[69] X. Tao, Y. Chen, K. Zhen, S. Ren, Y. Lv, L. Yu, Effect of continuous aerobic exercise on endothelial function: a systematic review and meta-analysis of randomized controlled trials, Front. Physiol. 14 (2023) 1043108. Switzerland: Copyright © 2023 Tao, Chen, Zhen, Ren, Lv and Yu.
[70] Q. You, L. Yu, G. Li, H. He, Y. Lv, Effects of different intensities and durations of aerobic exercise on vascular endothelial function in middle-aged and elderly people: a meta-analysis, Front. Physiol. 12 (2021) 803102.
[71] D. Di Raimondo, G. Musiari, G. Miceli, V. Arnao, A. Pinto, Preventive and therapeutic role of muscle contraction against chronic diseases, Curr. Pharm. Des. 22 (30) (2016) 4686–4699.
[72] M.C.K. Severinsen, B.K. Pedersen, Muscle-organ crosstalk: the emerging roles of myokines, Endocr. Rev. 41 (4) (2020) 594–609.
[73] B.K. Pedersen, The anti-inflammatory effect of exercise: its role in diabetes and cardiovascular disease control, Essays Biochem. 42 (2006) 105–117.
[74] M.M. Atakan, Ş.N. Koşar, Y. Güzel, H.T. Tin, X. Yan, The role of exercise, diet, and cytokines in preventing obesity and improving adipose tissue, Nutrients 13 (5) (2021).
[75] M. Khalafi, A. Malandish, S.K. Rosenkranz, A.A. Ravasi, Effect of resistance training with and without caloric restriction on visceral fat: a systemic review and meta-analysis, Obes. Rev. 22 (9) (2021) e13275.
[76] M.A. Wewege, I. Desai, C. Honey, B. Coorie, M.D. Jones, B.K. Clifford, et al., The effect of resistance training in healthy adults on body fat percentage, fat mass and visceral fat: a systematic review and meta-analysis, Sports Med. 52 (2022) 287–300. New Zealand: © 2021. The Author(s), under exclusive licence to Springer Nature Switzerland AG.
[77] S. Carbone, D.L. Kirkman, R.S. Garten, P. Rodriguez-Miguelez, E.G. Artero, D. C. Lee, et al., Muscular strength and cardiovascular disease: an updated state-of-the-art narrative review, J Cardiopulm Rehabil Prev 40 (5) (2020) 302–309.
[78] M. Wewege, R. van den Berg, R.E. Ward, A. Keech, The effects of high-intensity interval training vs. moderate-intensity continuous training on body composition in overweight and obese adults: a systematic review and meta-analysis, Obes. Rev. 18 (6) (2017) 635–646.
[79] S.E. Keating, N.A. Johnson, G.I. Mielke, J.S. Coombes, A systematic review and meta-analysis of interval training versus moderate-intensity continuous training on body adiposity, Obes. Rev. 18 (8) (2017) 943–964.
[80] L.V. Andreato, J.V. Esteves, D.R. Coimbra, A.J.P. Moraes, T. de Carvalho, The influence of high-intensity interval training on anthropometric variables of adults with overweight or obesity: a systematic review and network meta-analysis, Obes. Rev. 20 (1) (2019) 142–155.
[81] B.K. Pedersen, M.A. Febbraio, Muscle as an endocrine organ: focus on muscle-derived interleukin-6, Physiol. Rev. 88 (4) (2008) 1379–1406.
[82] R.M. Enoka, Neural adaptations with chronic physical activity, J. Biomech. 30 (5) (1997) 447–455.
[83] D.G. Sale, Neural adaptation to resistance training, Med. Sci. Sports Exerc. 20 (5 Suppl) (1988) S135–S145.
[84] A. Del Vecchio, A. Casolo, F. Negro, M. Scorcelletti, I. Bazzucchi, R. Enoka, et al., The increase in muscle force after 4 weeks of strength training is mediated by adaptations in motor unit recruitment and rate coding, J. Physiol. 597 (7) (2019) 1873–1887.
[85] F.W. Booth, G.N. Ruegsegger, R.G. Toedebusch, Z. Yan, Endurance exercise and the regulation of skeletal muscle metabolism, Prog Mol Biol Transl Sci 135 (2015) 129–151.
[86] S. Jung, K. Kim, Exercise-induced PGC-1α transcriptional factors in skeletal muscle, Integr. Med.Res. 3 (4) (2014) 155–160.
[87] T. Akimoto, S.C. Pohnert, P. Li, M. Zhang, C. Gumbs, P.B. Rosenberg, et al., Exercise stimulates Pgc-1alpha transcription in skeletal muscle through activation of the p38 MAPK pathway, J. Biol. Chem. 280 (20) (2005) 19587–19593.
[88] J.F. Halling, H. Pilegaard, PGC-1α-mediated regulation of mitochondrial function and physiological implications, Appl. Physiol. Nutr. Metabol. 45 (9) (2020) 927–936.
[89] P.G. Pito, J.R. Cardoso, J. Tufano, D. Guariglia, Effects of concurrent training on 1RM and VO2 in adults: systematic review with meta-analysis, Int. J. Sports Med. 43 (4) (2022) 297–304.
[90] M. Khalafi, M.H. Sakhaei, S.K. Rosenkranz, M.E. Symonds, Impact of concurrent training versus aerobic or resistance training on cardiorespiratory fitness and muscular strength in middle-aged to older adults: a systematic review and meta-analysis, Physiol. Behav. 254 (2022) 113888.
[91] V.G. Coffey, J.A. Hawley, Concurrent exercise training: do opposites distract? J. Physiol. 595 (9) (2017) 2883–2896.
[92] F. Pareja-Blanco, D. Rodríguez-Rosell, L. Sánchez-Medina, J. Sanchis-Moysi, C. Dorado, R. Mora-Custodio, et al., Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations, Scand. J. Med. Sci. Sports 27 (7) (2017) 724–735.