2024, Retos, 56, 301-311

Exercise training is effective for arterial stiffness and blood pressure rehabilitation in hypertensive adults
Ejercicio Físico es efectivo para la rehabilitación de la presión y rigidez arterial en adultos con hipertensión

*Cristian Álvarez, *Luis Peñailillo, *Paulina Ibacache-Saavedra, *Marcelo Tuesta, *, **Daniel Jerez-Mayorga,
***Jarosław Domaradzki, ****David C. Andrade, *****Omar Andrade-Mayorga, ******Johnattan Cano-Montoya,
*****Pedro Delgado-Floody
*Universidad Andres Bello (Chile), **Universidad de Granada (España), ***Wroclaw University of Health and Sport Sciences (Polonia), ****Universidad de Antofagasta (España), *****Universidad de La Frontera (Chile), ******Universidad San Sebastian (Chile)

Abstract. There is limited information regarding the arterial stiffness decrease in subjects with hypertension and risk factors to vascular-metabolic (i.e., of blood vessels and metabolism) where the exercise induces a therapeutic and preventive role. This study aimed 1) to test the effects of 6 weeks of concurrent exercise, including high-intensity interval plus resistance training ($CT_{HIIT+RT}$), on the arterial stiffness condition of individuals with different blood pressure controls, and 2) to compare the magnitude of exercise adaptations among different blood pressures and vascular characteristics. An experimental clinical randomized study was conducted in six categories (three controls and three experimental groups) of adults who were divided into six groups: control hypertensive (CG-HTN, *n*=10), control elevated blood pressure (CG-ELE, *n*=10), control normotensive (CG-NT, *n*=10), experimental hypertensive (ExG-HTN, *n*=10), elevated blood pressure (ExG-ELE, *n*=10), or normotensive (ExG-NT, *n*=10). The participants underwent 6 weeks of concurrent training with 5 min of high-intensity interval plus 5 min of resistance training ($CT_{HIIT+RT}$), where pulse wave velocity of the brachial artery (PWV_{ba}) (primary outcome) and additional secondary blood pressure, body composition, and vascular outcomes were measured before and after 6 weeks of intervention. After 6 weeks of $CT_{HIIT+RT}$, significant reductions in ΔPWV_{ba} were reported in ExG-HTN vs. ExG-NT (*diff.* 0.86 m/s^{-1}) and between ExG-ELE and ExG-NT (*diff.* 0.76 m/s^{-1}). In conclusion, 6 weeks of $CT_{HIIT+RT}$ reduced arterial stiffness in adults with different blood pressure controls but with a superior magnitude in HTN patients. Additional benefits include remission of high blood pressure in patients with hypertension.
Keywords: Arterial hypertension; Endothelial dysfunction; Pulse wave velocity; Augmentation index; Ankle brachial index

Resumen. Existe limitada información respecto a la reducción de la rigidez arterial entre sujetos con hipertensión y factores de riesgo para enfermedades vascular-metabólicas (i.e., de los vasos sanguíneos), donde el ejercicio induce un rol fisioterapéutico y preventivo. El objetivo del estudio fue 1) testear los efectos de 6 semanas de ejercicio concurrente de tipo alta intensidad interválico y de fuerza ($CT_{HIIT+RT}$) en la rigidez arterial de sujetos con diferente control de presión arterial y 2) comparar la magnitud de estas adaptaciones al ejercicio en diferentes variables secundarias de presión arterial y vasculares. Estudio clínico experimental aleatorizado desarrollado en seis categorías (3 controles y 3 experimentales) de adultos; controles hipertensos (CG-HTN, *n*=10), control presión elevada (CG-ELE, *n*=10), controles normotensos (CG-NT, *n*=10), o experimental hipertensos (ExG-HTN, *n*=10), presión elevada (ExG-ELE, *n*=10), o normotensos (ExG-NT, *n*=10). Los sujetos desarrollaron 6 semanas de $CT_{HIIT+RT}$, donde la velocidad de onda de pulso de la arteria braquial (PWV_{ba}) (resultado primario) y variables de presión arterial, composición corporal y vasculares (resultados secundarios), fueron medidas antes y después de 6 semanas de intervención. Posterior a 6 semanas de $CT_{HIIT+RT}$ se observaron diferencias significativas en la magnitud de reducción de ΔPWV_{ba} en el grupo ExG-HTN versus grupo ExG-NT (*diff.* 0.86 m/s^{-1}) y entre el grupo ExG-ELE vs. ExG-NT (*diff.* 0.76 m/s^{-1}). En conclusión, 6 semanas de $CT_{HIIT+RT}$ reducen la rigidez arterial en adultos con diferente control de presión arterial, con una magnitud superior en pacientes hipertensos. Beneficios adicionales se encontraron en cese de la presión arterial elevada en los pacientes hipertensos.
Palabras claves: Hipertensión arterial; Disfunción endotelial; Velocidad de onda de pulso; Índice de aumentación; índice tobillo-braquial

---

Fecha recepción: 18-02-24. Fecha de aceptación: 28-03-24
Cristian Alvarez
cristian.alvarez@unab.cl

Introduction

Endothelial dysfunction (EDys) is an inflammatory state of the endothelial cells in the arteries (i.e., into blood vessels) characterized by micro- and macro-vascular damage in vessels and their progression to platelet accumulation or atherosclerosis (Lobato et al., 2012). Hypertension (HTN) is a common risk factor associated with EDys and is highly associated with the future development of cardiovascular disease (Whelton et al., 2018). HTN is usually the result of a combination of lifestyle behaviors, including “physical inactivity” (i.e., not adhering to international physical activity guidelines of adhering to 150 to 300 minutes/week of moderate physical activity, or 75 to 150 minutes/week of vigorous physical activity) (Bowden Davies et al., 2021), poor diet, tobacco habits, and alcohol consumption (Alvarez et al., 2023). Although the HTN prevalence in United States is around 45.6% (Chen & Chauhan, 2019), in South American countries such as Chile the current prevalence of HTN in adults is of 26.9% following the last National Health Survey 2026-2017 (Petermann et al., 2017). On the other hand, EDys decreases arterial vasodilation, which can be measured by flow-mediated dilation and pulse wave velocity of the brachial artery (PWV_{ba}), which is a marker of arterial stiffness (Heiss et al., 2022; Thijssen et al., 2019). PWV_{ba} is a well-reported outcome that detects both “functional” and “structural” changes in the vascular wall (Kim et al., 2022; Yan et al., 2022). Interestingly, while traditional brachial blood pressure electronic devices that measures systolic (SBP) and diastolic (DBP) blood pressure could only detect normal, or high blood pressure (i.e., elevated, or hypertensive state), nowadays other technologies could report PWV_{ba} which indicates the degree of the arterial stiffness that could predict early a future hypertensive condition while this population is asymptomatic under traditional blood pressure cuffs (Ring et al., 2014).

Exercise training is prescribed as a therapy for patients with EDys and HTN because it reduces SBP and DBP and improves several other vascular parameters (Oviedo et al., 2015; Pescatello et al., 2019; Román et al., 2019). Exercise training can also decrease the augmentation index (i.e., brachial [Aix_{ba}] or aortic [Aix_{ao}]), where higher values usually denote greater load to the left ventricle (Munir et al., 2008), which is potentially proposed as dose-dependent by intensity (Forde et al., 2020; Ramírez-Vélez et al., 2020; Ramírez-Vélez et al., 2019) and inversely correlated with higher levels of skeletal muscle mass (Lee et al., 2021). Additionally, exercise training has also been related to other vascular improvements, including ankle brachial index (ABI) of 0.9 to 1.4 points as a normality range, where low ABI rates suggest more risk of peripheral artery disease or atherosclerosis development (Farahati et al., 2020). In this sense, the American College of Sports Medicine (ACSM) (Garber et al., 2011) and the American Diabetes Association (ADA) recommend exercise in populations with cardiovascular or vascular and metabolic risk factors (ADA, 2023; Colberg et al., 2016; Kanaley et al., 2001). One of the main exercise training modalities frequently suggested to subjects with poor cardiometabolic control is resistance training (RT), which increases skeletal muscle mass, improves glucose control, and facilitates skeletal muscle recovery by the increase of muscle strength together favoring a more oxidative than glycolytic metabolic control. On the other hand, the American Diabetes Association has recently promoted in the 2023 guidelines for diabetes control the recommendation to prescribe high-intensity interval training (HIIT) (Potosí-Moya et al., 2024), as a time-efficient exercise modality for improving glucose levels in populations with diabetes (ADA, 2023).

The combination of both HIIT and RT is known as concurrent training ($CT_{HIIT+RT}$) (Gómez-Rossel & Merellano-Navarro, 2024), proposed as a method for inducing both physiological benefits of HIIT and RT in cardiometabolic subjects and those with HTN or diabetes. However, there is a scarcity of $CT_{HIIT+RT}$ studies applied, including time-efficient protocols (i.e., exercise sessions ≤30 min per session) that can be more suitable for future exercise applications in clinical contexts. Thus, this study aimed to test the effects of 6 weeks of concurrent exercise including high-intensity interval plus resistance training ($CT_{HIIT+RT}$) on the arterial stiffness condition of individuals with different blood pressure control, and 2) to compare the magnitude of exercise adaptations among different blood pressure and vascular characteristics. We hypothesized that 6 weeks of $CT_{HIIT+RT}$ could decrease arterial stiffness by PWV_{ba} with greater magnitude in hypertensive than in normotensive blood pressure control adults.

Material and methods

This experimental randomized controlled clinical study was conducted as part of the VASCU-HEALTH (*i.e.*, from vascular and health terms) clinical trial in which hypertensive patients and normotensive adults are evaluated and monitored by exercise training by professionals of rehabilitation (Alvarez et al., 2023). In the first stage of the study, adult men and women participated in an initial evaluation of their cardiometabolic, vascular health and physical condition, but in the present study (second part of the clinical trial), they had the possibility of an invitation to participate to an exercise training intervention of 6 weeks in the Exercise and Rehabilitation Sciences Institute of the Universidad Andres Bello (ICER-UNAB), where vascular outcomes were monitored by the present study.

Participants

The present study was a randomized controlled experimental clinical trial developed in participants of different health conditions. Participants were adult members of the Universidad Andres Bello community (i.e., faculties, students, or professionals/technicians employees), and adult residents of neighborhoods around the university that were all invited by different media (e-mail and whattup) by social leaders to participate of the study. The study involved adults (≥18 years) with different blood pressure levels as normotensive, elevated BP, or hypertensive subjects not diagnosed or diagnosed under pharmacological treatment. The sample size was intentionally distributed immediately after blood pressure categorization into one of three blood pressure groups (normotensive, elevated blood pressure, or HTN condition) based on the American Heart Association blood pressure categorization (Whelton et al., 2018). The study was registered on the Clinical Trials.gov by the code NCT05710653.

The eligibility criteria were as follows: a) hypertension, elevated blood pressure (treated with updated pharmacotherapy) or normotensive blood pressure condition, b) normal, overweight, or obese condition determined by body mass index [BMI <40 kg/m^2]), c) normoglycemic, hyperglycemic, or type 2 diabetes mellitus condition (treated with updated pharmacotherapy), d) physically inactive (last 3 months no exercise regularly), and e) address located in the local city of the study. Exclusion criteria were a) history of abnormal ECG (i.e., the question: Have you ever had an ECG that was considered altered by a physician?), or other cardiovascular abnormalities diagnosed by a physician; b) HTN stage 3 (systolic blood pressure [SBP] ≥169 mmHg or

DBP >95 mmHg); c) type 1 diabetes mellitus; f) varicose ulcers, nephropathies, or muscle-skeletal disorders such as osteoarthritis); and g) the use of pharmacological treatment influencing body composition or weight loss, such as caffeine products or others. Participants provided a written consent to the study, and the project was conducted by the Declaration of Helsinki and was approved by the Ethics Committee of Universidad Andres Bello, Chile (Approval N° 026/2022).

The sample size was calculated using G*Power 3.1.9.7 sample size software. A minimum of ten subjects (n=10) per group were determined to have a statistical power of ≥80% with a 95% confidence interval and an alpha error of 5%. Firstly, eighty-five (n=85) participants were enrolled, including hypertensive, elevated blood pressure and normotensive adults and twenty-five (n=25) were excluded for different reasons in this stage (n=13) do not adhere to the inclusion criteria; (n=3) were under weight loss pharmacological treatment; (n=2) had address in rural areas; (n=4) report osteo-arthritis disease; and (n=3) report heart disease). Thus, from the (n=60) subjects; (n=20) with HTN; (n=20) in elevated blood pressure; and (n=20) normotensive), these were allocated 1:6 according to their blood pressure classification, and by following six groups: control hypertensive (CG-HTN, n=10), control elevated blood pressure (CG-ELE, n=10), control normotensive (CG-NT, n=10), or experimental hypertension (ExG-HTN, n=10), elevated blood pressure (ExG-ELE, n=10), or normotensive (ExG-NT, n=10), and all values of SBP and DBP in mmHg).

Experimental procedures

Blood pressure categorization (Main outcomes)

The systolic blood pressure (SBP) and diastolic blood pressure (DBP) of participants were classified according to American Heart Association guidelines (Whelton et al., 2018). Normal blood pressure was defined as SBP/DBP less than 120/80 mmHg, elevated blood pressure (Ele) as SBP/DBP between 120-129/80 mmHg, stage 1 hypertension as SBP/DBP between 130-139/80-89 mmHg, and stage 2 hypertension as SBP/DBP ≥140/90 mmHg (Whelton et al., 2018). Additionally, pulse pressure (PP) and mean arterial pressure (MAP) were calculated. Readings were taken twice in the left arm using an automatic monitor (OMRON^{TM}, model HEM 7114, United States) with a pneumatic cuff positioned for at least 10 min prior to the seated position. To compare the magnitude of the pre- and post-intervention effects, each outcome was shown in delta (Δ) changes as follows: ΔSBP, ΔDBP, ΔPP, and ΔMAP.

Arterial stiffness (Main outcomes)

For the PWV_{ba} measurement, each subject was positioned on a stretcher in the supine position during 20 min of resting, where electronic equipment with a pneumatic cuff in the left arm was inflated x 2 times for 5 min (Arteriograph, TENSIOMED^{TM}, Hungary). The equipment was programmed automatically to inflate/deflate the cuff and show an electrocardiography figure. The systolic blood pressure of the ankle was inserted before the equipment, as well as the weight, height, date of birth, and arm circumference of the subject. This information was processed using the Arteriograph^{TM} Software (v.1.9.9.2; TensioMed, Budapest, Hungary) on a desktop computer, and immediately by the software, a PDF sheet document was developed and stored. The Arteriograph^{TM} equipment has been validated against gold-standard equipment (Ring et al., 2014). A cutoff point of >10 (m/s^{-1}) is considered a high cardiovascular risk in adults. To compare the magnitude of the pre-post intervention effects, PWV_{ba} is shown as delta changes as follows: ΔPWV_{ba}.

Anthropometric and body composition (Secondary outcomes)

Weight (kg), waist circumference (WC, cm), body fat (in % and kg), and skeletal muscle mass (SMM, in %) were measured using digital bio-impedance equipment (OMRON^{TM} model HBF-514C, United States). Height (m) was measured using a stadiometer (SECA model 214, United States). For this procedure, the subjects of each group arrived at the lab in the afternoon and used light clothing without shoes and any other metal accessories. Fat-free mass (FFM) was calculated. The basal metabolic rate (BMR, kcal/kg/min) was used from the same equipment. BMI was calculated by weight and height data, and the adiposity was categorized based on the 'underweight, 'normal weight, 'overweight' or 'obesity' condition by international categorization (WHO, 2000). To compare the magnitude of the pre- and post-intervention effects, each anthropometric/body composition outcome was shown in delta changes as follows: Δweight, ΔWC, ΔBody Fat, ΔSMM, ΔFFM, and ΔBMR. (**Table 1)** shows the baseline characteristics of the participants.

Table 1.
Baseline characteristics of subjects.

Outcomes	CG-HTN	CG-ELE	CG-NT	ExG-HTN	ExG-ELE	ExG-NT
(n =)	10	10	10	10	8	10
Age (y)	44.8±12.8	34.2±11.2	37.5±11.6	44.5±9.9	50.3±14.8	42.5±15.5
Anthropometric/Body composition						
Weight (kg)	77.9±14.3	83.4±12.9	67.77.4	86.9±16.5	76.5±16.0	66.3±10.1
Height (m)	166±0.10	1.64±0.10	1.61±0.06	1.71±0.11	1.63±0.07	1.59±0.06
BMI ($kg\cdot m^2$)	28.4±4.9	31.2±4.2	26.0±2.2	30.3±4.0	28.5±4.2	26.2±2.7
Body fat (kg)	26.8±12.1	32.4±10.8	24.4±6.7	31.6±7.2	29.7±9.6	26.3±6.3
Skeletal muscle mass (%)	32.0±6.5	28.4±7.7	29.8±7.7	28.2±3.7	26.1±3.0	25.2±3.7
Fat free mass (kg)	51.0±9.3	50.9±12.2	43.2±7.9	55.3±13.2	46.7±10.3	39.9±6.6
Waist circumference (cm)	96.1±5.8	102.0±11.6	90.9±8.4	104.0±9.4	98.3±10.9	90.1±11.2

Basal metabolic rate (Kcal/min/kg)	1595±222	1635±227	1430±180	1713±305	1510±235	1364±171
Blood pressure						
Systolic BP (mmHg)	145±7	125±3	109±7	142±12	123±2	111±8
Diastolic BP (mmHg)	87±10	84±8	74±9	89±12	82±10	75±5
PP (mmHg)	58±6	42±8	36±9	53±9	42±8	36±9
Mean arterial pressure (mmHg)	106±8	97±5	86±7	106±11	95±7	87±5
Heart rate						
Heart rate rest (beast/min)	74±8	72±7	74±10	75±7	78±13	79±12
Vascular						
SBP$_{ank}$	161±12	137±9	127±11	156±23	129±18	122±13
DBP$_{ank}$	86±9	80±4	75±8	89±15	91±24	73±8
SBP$_{ao}$	131±17	113±14	104±11	130±19	121±8	108±8
PP$_{ao}$	55±11	46±7	42±6	52±15	47±8	45±10
Ejection duration (ms)	298±12.1	317±21.9	303±33.0	305±12.8	316±11.6	320±13.4
AIx$_{ao}$ (%)	30.6±14.8	24.9±12.1	24.8±10.9	27.7±12.9	35.5±10.5	29.2±10.1
AIx$_{ba}$ (%)	−9.5±25.9	−24.0±22.4	−27.2±21.8	−19.6±25.5	−4.21±20.7	−10.8±24.0
PWV$_{ba}$ (m/s^{-1})	8.46±1.19	7.70±1.41	7.54±1.75	9.63±1.56	9.29±1.31	7.76±1.33
Ankle brachial index	1.18±0.09	1.22±0.10	1.15±0.07	1.18±0.09	1.15±0.06	1.11±0.12
Pharmacotherapy						
ACE inhibitors (*n* = / total)						
Beta blocker (*n* = / total)	1/10			1/10		
Metformin (*n* = / total)		1/10				

Data are shown as mean and SD to continuous outcomes. Groups are described as; (CG-HTN) Hypertension control, (ExG-HTN) Hypertension experimental, (CG-ELE) Elevated blood pressure control, (ExG-ELE) Elevated blood pressure experimental and (CG-NT) Normotensive control (ExG-NT) Normotensive experimental exercise group. (#) Denotes that heart rate peak was measured previously by a volitional progressive cycling test. (SBP$_{ank}$) Systolic BP of the left ankle. (DBP$_{ank}$) Diastolic BP of the left ankle. (SBP$_{ank}$) Systolic BP aortic. (PP$_{ao}$) Pulse pressure aortic. (AIx$_{ao}$) Augmentation index aortic. (AIx$_{ba}$) Augmentation index of the brachial artery. (PWV$_{ba}$) Pulse wave velocity of the brachial artery. (ACE) Angiotensin-converting enzyme inhibitors.

Additional (Vascular Outcomes)

Systolic BP (SBP$_{ank}$, in mmHg) and diastolic BP (DBP$_{ank}$, in mmHg) of the left ankle were determined in the left leg (OMRON™, model HEM 7114, United States). Systolic aortic BP (SBP$_{ao}$, in mmHg), aortic pulse pressure (PP$_{ao}$, in mmHg), ejection duration (ED, in seconds), ankle-brachial index (ABI), augmentation indices of the brachial artery (AIx$_{ba}$, in %), and aortic augmentation index (AIx$_{ao,}$ in %), all vascular parameters were measured by the electronic digital equipment (Arteriograph, TENSIOMED™, Hungary) (Ring et al., 2014). The equipment is connected by bluetooth technology to a laptop, which a software store and develop a PDF inform (Arteriograph Software v.1.9.9.2; TENSIOMED, Budapest, Hungry). To compare the magnitude of the pre-post intervention effects, each vascular outcome is shown in delta changes as follows: ΔSBP$_{ank}$, ΔSBP$_{ao}$, ΔDBP$_{ank}$, ΔPP$_{ao}$, ΔAIx$_{ba}$, and ΔAIx$_{ao}$.

Progressive volitional cycling test

Before and after the intervention, a volitional cardiorespiratory cycling test was performed to determine HR$_{peak}$ data by the Astrand cycling test. This test is a progressive and volitional cardiorespiratory test developed until subject exhaustion or interrupted by standardized criteria such as a) show revolutions per minute (rpm) of cadence <60 rpm, b) does not increase heart rate between stages, c) voluntarily to stop the test (Åstrand, 2003). The test progression increased the load step by step for men (50 watts) and women (25 watts). To the test, an electromagnetic cycle ergometer (model Ergoselect 200, ERGOLINE™, Lindenstrasse, Germany) was used. The heart rate was continuously monitored using a telemetric heart rate sensor (Model A370, Polar™, Finland), where we registered the maximum heart rate of each Astrand test stage.

HR$_{peak}$ was used in the session-by-session program, the new threshold for both 80-100 HR$_{peak}$ (intervals of work) and the exercise intensity for recovery time (≤70% HR$_{peak}$). Heart rate at rest (HRR) was measured using a watch cardiometer (A370; Polar™, Finland). Using a volitional progressive cycling Astrand test with an electromagnetic cycle ergometer (Ergoselect 200, ERGOLINE™, Germany), we determined the heart rate peak (HR$_{peak}$). To compare the magnitude of the pre-post intervention effects, each heart rate outcome is shown as delta changes as follows: ΔHRR and ΔHR$_{peak}$.

Rehabilitation exercise training program

The rehabilitation program was applied by using two exercise modalities such as high-intensity interval (HIIT) during five minutes using bikes (Impulse™, Model PS 300, SPARTA, Chile) plus resistance training (RT) during five minutes, modality of exercise frequently named as concurrent training (CT$_{HIIT+RT}$). Thus, the program was of ten minutes of exercise plus around 20 minutes of recovery periods between each exercise interval, including around 30 minutes per session of time investment for participants. Firstly, for 5 minutes of HIIT, participants were 60 s cycling (x 5 times) at vigorous intensity (80 to 100% heart rate peak (HR$_{peak}$), previously tested by the Astrand test), interspersed by 120 seconds or less resting time to reach target heart rate recovery. We established previously that the parameter of ≤70% of HR$_{peak}$ was assumed as an individual in a recovery state and ready to start another exercise interval). To the next five minutes of RT, the subjects developed 3 strength exercises; biceps curl (2 sets), shoulder press (2 times), and back exercise (1 time) during 60 seconds at moderate intensity (~20 to 50% of 1RM) following the American College of Sports Medicine recommendations (Thompson et al., 2021). A resting period of 60 seconds was used to get a recovery state (previously stated by the rated of perceived exertion of 1-3 subjective (1-10) modified Borg scale to start the next RT exercise interval. Thus, the total exercise time per session was 30 min (i.e., only 10 min of pure exercise), and more short-term duration (i.e., 6 weeks). The program was of 6 weeks.

Statistical analysis

All data are shown in tables and figures as the mean ±SD. Normality and homoscedasticity assumptions were checked using the Shapiro-Wilk test and Levene's test (F), respectively. The Wilcoxon test was used for non-parametric data. One-way ANOVA was applied to test differences between the control (CG-HTN, CG-ELE, and CG-NT) and experimental exercise (ExG-HTN, ExG-ELE, and ExG-NT) groups. When the F value was significant, Tukey's *post-hoc* test was used to determine differences, particularly (HTN control vs. HTN experimental, ELE control vs. ELE experimental, and NT control vs. NT experimental exercise groups). Statistical analyses were performed using Graph Pad Prism 8.0 software (Graph Pad Software, San Diego, CA, United States). The alpha level was fixed at ($p \leq 0.05$) for all statistical significance.

Results

Baseline characteristics

(Table 1) Describe baseline characteristics of the sample at the level of anthropometric, body composition, blood pressure, heart rate and secondary vascular parameters (Table 1).

Training—induced changes in anthropometric/body composition

In Δweight, ExG-HTN was significantly different vs. CG-HTN (−0.46 vs. −0.43 kg), and ExG-NT vs. CG-NT (−0.77 vs.) (Fig. 1, panel A). In Δbody Fat, ExG-HTN was significantly different vs. CG-HTN (−1.5 vs. +0.6 kg), ExG-ELE vs. CG-ELE (−1.0 vs. +0.5 kg), and ExG-NT vs. CG-NT (−1.3 vs. +0.1 kg), all $p<0.05$ (Fig. 1, panel B). No significant differences were observed in ΔBody Fat among the exercise groups (Fig. 1, panel B). In ΔSMM, there were significant differences between ExG-HTN vs. CG-HTN (+1.2 vs. −0.02 kg), ExG-ELE vs. CG-ELE (+0.6 vs. −0.01 kg), both $p<0.05$ (Fig. 1, panel C). No significant differences were observed in ΔSMM among the exercise groups (Fig. 1, panel C). In ΔFFM, ExG-HTN was significantly different vs. CG-HTN (+1.13 vs. −0.25 kg), and ExG-ELE vs. CG-ELE (+0.78 vs. −0.59 kg), both $p<0.05$ (Fig. 1, panel D). No significant differences were observed in ΔFFM among the exercise groups (Fig. 1, panel C). In ΔWC, Ex-HTN was significantly different vs. CG-HTN (−4.3 vs. +0.7 cm), ExG-ELE vs. CG-ELE (−2.0 vs. +0.3 cm), and ExG-NT vs. CG-NT group (−2.3 vs. −0.7 cm), all $p<0.05$ (Fig. 1, panel E). No significant differences were observed in ΔWC between the exercise groups (Fig. 1, panel E). In ΔBMR, ExG-HTN was different vs CG-HTN (+218.7 vs. −15.5 kcal/kg/min), ExG-ELE vs. CG-ELE (+93.0 vs. −24.4 kcal·kg·min), and ExG-NT vs. CG-NT group (+49.8 vs. −20.4 kcal/kg/min), all $p<0.05$ (Fig. 1, panel F). Significant differences were observed in the ΔBMR between ExG-HTN and ExG-ELE (*diff.* 125.7 kcal/kg/min, $p<0.05$) and between ExG-HTN and ExG-NT (*diff.* 168.9 kcal/kg/min, $p<0.0001$) (Fig. 1, panel F).

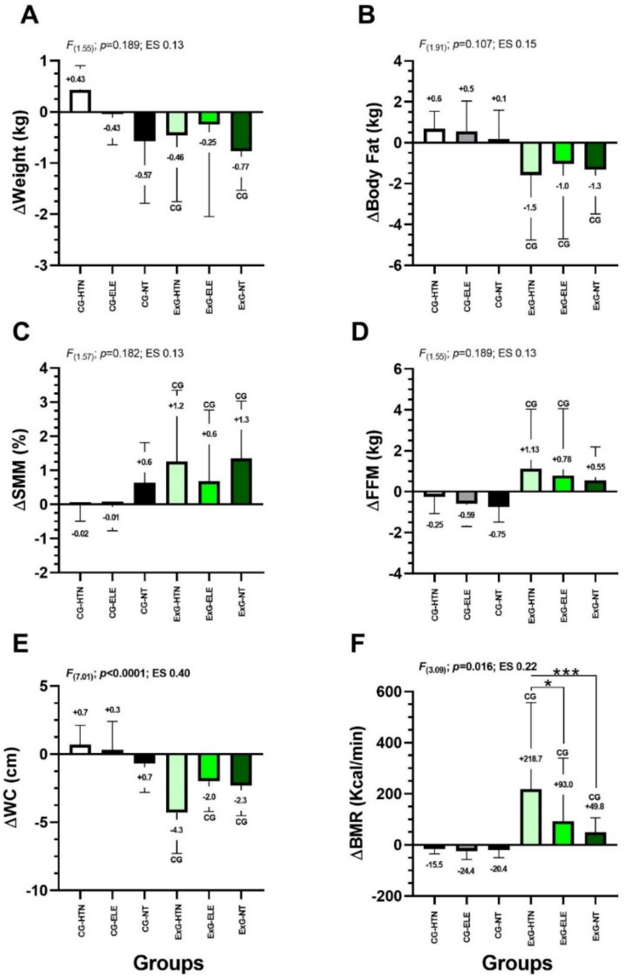

Figure 1. Anthropometric and body composition delta changes (Δ) after six weeks of $CT_{HIIT+RT}$ intervention. The groups are described as control hypertensive (CG-HTN), control elevated blood pressure (CG-ELE), control normotensive (CG-NT), experimental hypertensive (ExG-HTN), experimental elevated blood pressure (ExG-ELE), and experimental normotensive (ExG-NT). The outcomes are described as (ΔSMM) Delta Skeletal muscle mass. (ΔFFM) Delta fat-free mass. (ΔWC) Delta Waist circumference. (ΔBMR) Delta Basal metabolic rate. (Bold values) Denote significant group interactions by One-way ANOVA. (CG) Denotes significant differences vs. similar HTN, ELE, or NT categories in the control group by Tukey's post hoc test at $p<0.05$. (*) Denotes Significant difference at $p<0.05$. (***) Significant differences at $p<0.0001$.

Blood pressure and heart rate at rest and during exercise (secondary outcomes)

In ΔSBP, ExG-HTN was different vs. CG-HTN (−13.5 vs. +0.01 mmHg), ExG-ELE vs. CG-ELE (−6.7 vs. +0.4 mmHg), and ExG-NT vs. CG-NT group (−5.4 vs. +0.7 mmHg), all $p<0.05$ (Fig. 2, panel A). Significant differences were observed in ΔSBP between the ExG-HTN and ExG-ELE groups (*diff.* 6.8 mmHg, $p<0.05$), and between ExG-HTN and ExG-NT (*diff.* 8.1 mmHg, $p<0.05$) (Fig. 2, panel A). In ΔDBP, ExG-HTN vs. CG-HTN group (−5.2 vs. −0.1 mmHg), and ExG-NT vs. CG-NT (−3.2 vs. −1.0 mmHg), both $p<0.05$ (Fig. 1, panel B). No significant differences were observed in ΔDBP between the exercise groups (Fig. 2, panel B). In ΔPP, ExG-HTN was different vs CG-HTN (−8.3 vs. +0.1 mmHg), and ExG-ELE vs. CG-ELE (−5.1 vs. +0.5 mmHg), both $p<0.05$ (Fig. 2, panel C). In ΔPP, there were significant differences between ExG-HTN vs. ExG-NT (*diff* 6.1 mmHg, $p<0.05$) (Fig. 2, panel C). In ΔMAP, ExG-HTN was different vs. CG-HTN (−7.9 vs. −0.07 mmHg), ExG-ELE vs. CG-ELE (−3.3 vs. +0.07 mmHg), and ExG-NT vs. CG-NT group (−3.9 vs. −0.04 mmHg), all $p<0.05$ (Fig. 2, panel D). Significant differences were observed in ΔMAP between ExG-ELE and ExG-ELE (*diff*. 4.6 mmHg, $p<0.05$) (Fig. 2, panel D). In ΔHRR, ExG-HTN was different vs. CG-HTN (−3.1 vs. +0.4 beats/min) $p<0.05$ (Fig. 2, panel E). No significant differences were detected in ΔHRR among the exercise groups (Fig. 2, panel E). In ΔHR_{peak}, there were significant differences between ExG-HTN vs. CG-HTN (+7.4 vs. −2.9 beats/min) (Fig. 2, panel F). In ΔHR_{peak}, ExG-HTN was different vs. CG-HTN (+7.4 vs. −2.9 beats/min), ExG-ELE vs. CG-ELE (+4.3 vs. −0.3 beats/min), ExG-ELE vs. CG-ELE (+9.5 vs. −1.6), all $p<0.05$ (Fig. 2, panel F). No significant differences were detected in HR_{peak} among the exercise groups (Fig. 2, panel F).

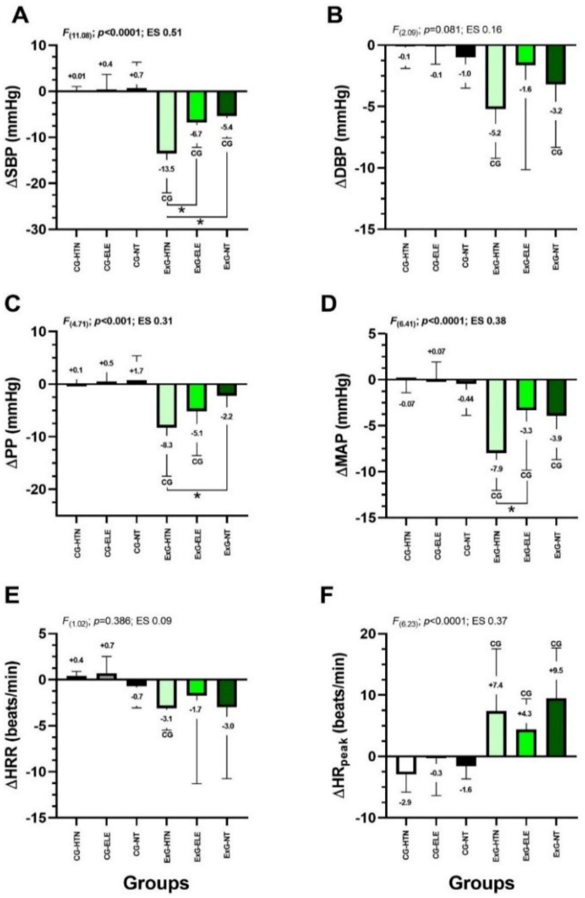

Figure 2. Blood pressure and heart rate outcomes changed after 6 weeks of $CT_{HIIT+RT}$ intervention. The groups are described as control hypertensive (CG-HTN), control elevated blood pressure (CG-ELE), control normotensive (CG-NT), experimental hypertensive (ExG-HTN), experimental elevated blood pressure (ExG-ELE), and experimental normotensive (ExG-NT). Outcomes were described as; (SBP) systolic blood pressure. (DBP) diastolic blood pressure. (PP) Pulse pressure. (MAP) mean arterial pressure. (HRR) Heart rate at rest. (HR_{peak}) Heart rate peak obtained from a cycling exercise test. (Bold values) Denote significant group interactions by One-way ANOVA. (CG) Denotes significant differences vs. similar HTN, ELE, or NT categories in the control group by Tukey's post hoc test at $p<0.05$. (*) Denotes Significant difference at $p<0.05$.

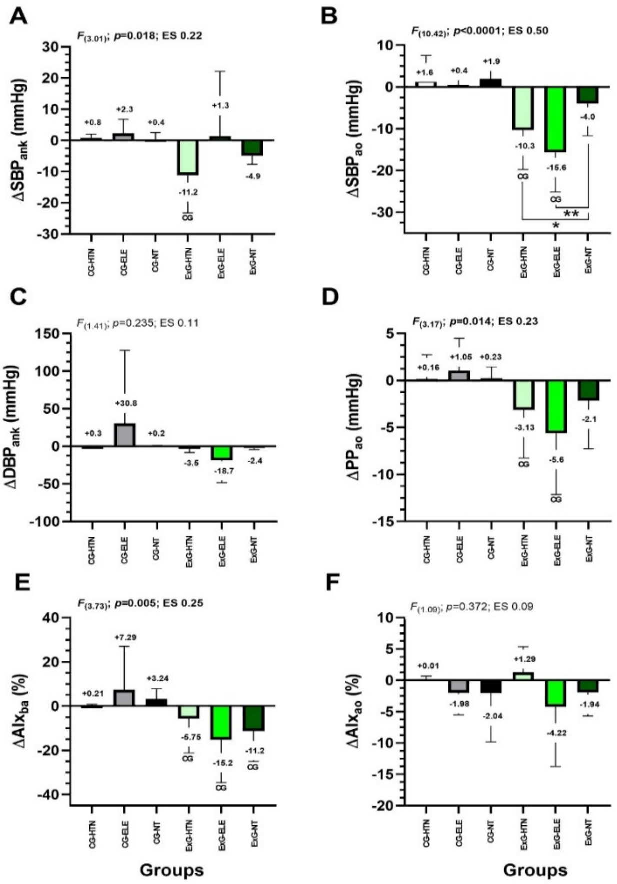

Figure 3. Blood pressure and secondary vascular outcomes changed after 6 weeks of $CT_{HIIT+RT}$ intervention. The groups are described as control hypertensive (CG-HTN), control elevated blood pressure (CG-ELE), control normotensive (CG-NT), experimental hypertensive (ExG-HTN), experimental elevated blood pressure (ExG-ELE), and experimental normotensive (ExG-NT). Outcomes were described as follows: (SBP_{ank}) ankle systolic blood pressure. (DBP_{ank}) Ankle diastolic blood pressure. (PP_{ao}) Aortic pulse pressure. (SBP_{ao}) aortic systolic blood pressure. (ΔAIx_{ba}) Augmentation index of the brachial artery. (ΔAIx_{ao}) Aortic augmentation index. (Bold values) Denote significant group interactions by One-way ANOVA. (CG) Denotes significant differences vs. similar HTN, ELE, or NT categories in the control group by Tukey's post hoc test at $p<0.05$. (*) Denotes Significant difference at $p<0.05$. (**) Significant difference at $P<0.01$.

Secondary blood pressure and vascular parameters (Secondary outcomes)

In ΔSBP_{ank}, there were significant differences between ExG-HTN vs. CG-HTN (−11.2 vs. +0.8 mmHg) (Fig. 3, panel A). No significant differences were detected in ΔSBP_{ank} among the exercise groups (Fig. 3, panel A). In ΔSBP_{ao}, there were significant differences between ExG-HTN vs. CG-HTN (−10.3 vs. +1.6 mmHg), and between ExG-ELE vs. CG-ELE (−15.6 vs. +0.4 mmHg) both $p<0.05$ (Fig. 3, panel B). Significant differences were detected in ΔSBP_{ao} between the ExG-HTN and ExG-NT groups (*diff*. 6.3 mmHg, $p<0.05$) and between ExG-ELE and ExG-NT (*diff*. 11.6 mmHg, $p<0.01$) (Fig. 3, panel B). ΔDBP_{ank} did not differ among the groups (Fig. 3, panel C). In ΔPP_{ao}, there were significant differences between ExG-HTN vs. CG-HTN (−3.13 vs. +0.16 mmHg), and ExG-ELE vs. CG-ELE (−5.6 vs. +1.05 mmHg), both $p<0.05$ (Fig. 3, panel D). No significant differences were detected in ΔPP_{ao} among the exercise groups (Fig. 3, panel D). In ΔAIx_{ba}, there were significant differences between ExG-HTN vs. CG-HTN (−5.75 vs. +0.21 %), ExG-ELE vs. CG-ELE (−15.2 vs. +7.29 %), and between ExG-NT vs. CG-NT (−11.2 vs. +3.24 %) (Fig. 3, panel E). No significant differences were detected in ΔAIx_{ba} among the exercise groups (Fig. 3, panel E). No significant interactions were detected in ΔAIx_{ao} among any of the groups (Fig. 3, panel F).

Arterial stiffness and secondary vascular parameters

In ΔPWV_{ba}, there were significant differences between ExG-HTN vs. CG-HTN (−1.22 vs. +0.15 m/s^{-1}), ExG-ELE vs. CG-ELE (−1.12 vs. +0.14 m/s^{-1}), both $p<0.05$ (Fig. 4, panel A). No significant differences were detected in ΔPWV_{ba} among control groups (Fig. 3, panel D). Significant differences were detected in ΔPWV_{ba} between the ExG-HTN and ExG-NT groups (*diff.* 0.86 m/s^{-1}, $p<0.0001$) and between ExG-ELE and ExG-NT (*diff.* 0.76 m/s^{-1}, $p<0.05$) (Fig. 4, panel A). Finally, no significant interactions were observed in ΔABI and ΔED among all groups (Fig. 4, panels B-C).

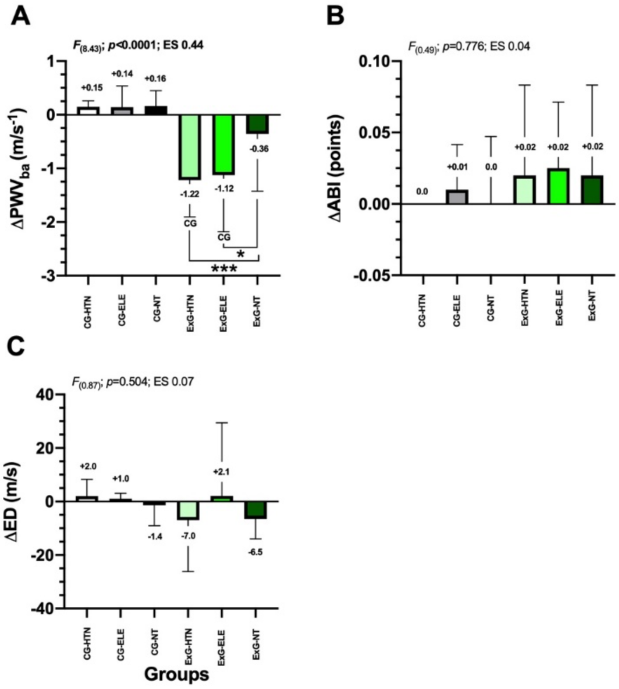

Figure 4. Arterial stiffness was measured by pulse wave velocity of the brachial artery (PWV_{ba}), and secondary vascular outcomes, ankle brachial index (ABI), and ejection duration (ED), all expressed as delta changes after 6 weeks of $CT_{HIIT+RT}$ intervention. The groups are described as control hypertensive (CG-HTN), control elevated blood pressure (CG-ELE), control normotensive (CG-NT), experimental hypertensive (ExG-HTN), experimental elevated blood pressure (ExG-ELE), and experimental normotensive (ExG-NT). The outcomes are described as (ΔPWV_{ba}) delta pulse wave velocity of the brachial artery. (ΔABI) Delta ankle–brachial index. (Δ ED) Delta of ejection duration. (Bold values) Denote significant group interactions by One-way ANOVA. (CG) Denotes significant differences vs. similar HTN, ELE, or NT categories in the control group by Tukey's post hoc test at $p<0.05$. (*) Denotes Significant difference at $p<0.05$. (***) Significant differences at $p<0.0001$.

Discussion

This study aimed 1) to test the effects of 6 weeks of concurrent exercise including high-intensity interval plus resistance training ($CT_{HIIT+RT}$) on the arterial stiffness condition of individuals with different blood pressure controls, and 2) to compare the magnitude of exercise adaptations among different blood pressures and vascular characteristics. The main findings of this study showed that *i*) 6 weeks of $CT_{HIIT+RT}$ significantly reduced ΔPWV_{ba} by a major magnitude in ExG-HTN compared with ExG-NT (*diff.* 0.86 m/s^{-1}), and similarly *ii*) in those with elevated blood pressure ExG-ELE when compared with ExG-NT (*diff.* 0.76 m/s^{-1}). These findings were displayed with additional and known major beneficial adaptations in other blood pressure outcomes (SBP, PP, MAP), in favor of those with higher blood pressure (i.e., HTN and elevated blood pressure experimental groups) than those with normal blood pressure.

(Hasegawa et al., 2018) conducted a study of 8 weeks of MICT in sedentary adults (2 session/week, 45 min at 60-70% VO_{2peak}), and they reported a decrease of body fat from 28.5 to 27.7% (Δ−0.8 %), and increased serum adiponectin from 7.8 to 9.3 ng/mL (Δ+1.5 μg/mL), and the Nobel recently identified adipokines C1q/tumor necrosis factor-related proteins (CTRP3) from 199.3 to 253.7 ng/mL (Δ+54.4 μg/mL), and CTRP5 from 9.2 to 16.8 ng/mL (Δ+7.6 μg/mL).

These results were displayed with blood pressure decreases in SBP (Δ−9 mmHg), DBP (Δ−4 mmHg), HRR (Δ −3 beat/min) and PWV (Δ−0.13 m/s^{-1}) equivalent to a Δ−11.4% of PWV reduction and measured from the carotid to femoral anatomic points. A study of exercise training in HTN patients from (Molmen-Hansen et al., 2012), reported that 12 weeks of HIIT (4×4 min at 85–90% VO_2max, walking/running, 38 min total session) or MICT (60% VO_2max, walking/running, 47 minutes total session) both exercise modalities reduced 24-hour SBP by Δ−12 mmHg (HIIT) and Δ−4.5 mmHg (MICT). Our results in the present study are in accordance with these authors; however, our $CT_{HIIT+RT}$ is applied in a more feasible time-investment clinical context.

The arterial stiffness reduction in patients with HTN is in concordance with the same effects that exercise training promotes in reducing blood pressure in as SBP or DBP more in hypertensive subjects than in normotensive subjects (Pescatello et al., 2015; Pescatello et al., 1999). Interestingly, the training-induced effects on PWV reductions were negatively associated with both CTRP3 and CTPR5 adipokines, linking MICT exercise with increases in adipokines and subsequent reduction of arterial stiffness. In the present study, we decreased PWV Δ−1.22 m/s^{-1} in ExG-HTN, and in ExG-ELE Δ−1.12 m/s^{-1} and body fat decreases (Δ−1.5 kg) in Ex-HTN and (Δ−1.0 kg) in Ex-ELE groups. Our study protocol is interesting for future application in association with more complex plasma and molecular proteins, and above from the clinical perspective.

Conversely, not all research has established a correlation between elevated PWV and higher blood pressure, particularly in terms of SBP and DBP. For instance, Kim et al. (Kim et al., 2007) did not find a relationship between PWV and SBP/DBP; however, they found that pulse pressure significantly predicted arterial stiffness behavior measuring PWV by invasive methods. However, more recent epidemiological studies in (n=1449) Finnish adults (30-45 y), reported that the PWV measured from 2007 to 2011 was directly and independently associated with SBP/DBP measured in 2011, concluding that PWV predicts the progression of blood pressure being a valuable tool for HTN prediction (Koivistoinen et al., 2018). (Ashor et al., 2014) reported that aerobic exercise improved arterial stiffness by reducing PWV, and this effect was enhanced with higher aerobic exercise intensity and in participants with greater arterial stiffness at baseline, being in coherence with the present results.

Other studies have reported that a greater cross-sectional muscle area of the thigh in Male adults is associated with lower PWV_{ba} (Ochi et al., 2010). The effects of exercise training on blood pressure normalization are well known (Cade et al., 1984; Guimaraes et al., 2010; Olea et al., 2017; Pescatello et al., 2015). Some of the mechanisms by how? Exercise reduces blood pressure due to acute transitory mechanisms, including i) reduction in vascular peripheral resistance (Wilkins et al., 2004), ii) increase in nitric oxide (Augeri et al., 2009), iii) decrease in vasoconstrictor factors (Low et al., 2007), iv) increase in shear stress (Birk et al., 2012), v) decrease in sympathetic nervous activity (Halliwill, 2001), and other structural chronic adaptations at the vascular wall (Pedralli et al., 2020). From a molecular perspective, the angiogenesis promoted by exercise in small blood vessels is dependent on several physiological processes, including biochemical (i.e., nitric oxide and vascular endothelial growth factor), cellular mediators (i.e., circulating angiogenic blood cells), and paracrine signaling mechanisms, such as exosomes (i.e., extracellular vesicles that are exported from skeletal muscle to other organs). Angiogenesis is dependent on several physiological processes, including biochemical (i.e., nitric oxide and vascular endothelial growth factor), cellular mediators (i.e., circulating angiogenic blood cells), and paracrine signaling mechanisms such as exosomes (i.e., extracellular vesicles exported from skeletal muscle to other organs) (Ross et al., 2023).

Strengths and limitations

Some strengths were that *i*) we used a simple and validated equipment (Arteriograph^{TM}) for PWV_{ba} measurement using a brachial cuff that could be replicated easily in other clinical contexts without more specific procedures, and *ii*) the $CT_{HIIT+RT}$ exercise therapy was proposed using a time-efficient clinical context which is a time per session of ≤30 min per session. As limitations, we did not include other more robust physical fitness outcomes, such as cardiorespiratory variables, to correlate with vascular outcomes, or did not include other muscle strength variables to test muscle strength after the 6-week intervention.

Conclusion

In conclusion, 6 weeks of $CT_{HIIT+RT}$ reduced arterial stiffness in adults with different blood pressure controls but with superior magnitude in hypertensive patients. Additional benefits include the high blood pressure remission in the mean group of hypertensive patients. Future studies should explore the underlying mechanisms by which $CT_{HIIT+RT}$ promotes these benefits in vascular health.

Acknowledgments

We like to recognize all those participants who accepted to participate in our research at the Universidad Andres Bello, and that additionally participated of all stages of this study.

Statement of ethics

The study was conducted by the Declaration of Helsinki and approved by the Institutional Review Board of the BIOETICAL COMMITTEE OF UNIVERSIDAD ANDRES BELLO (Approval 026/2022 of September 22nd).

Conflicts of interest statement

C.A., L.P., P.I., M.T., D.J-M., J.D., D.C.A., O.A., J.C-M., and P.D.-F declare no conflict of interest.

Funding sources

This research was funded by Dirección General de Investigación, Vicerrectoría de Investigación y Doctorado, Concurso de Ciencias Biomédicas y Clínicas, Universidad Andrés Bello 2022 Código N° DI-01-CBC/22".

Author contributions

C.A. designed the study. C.A. performed the experiments. C.A., L.P., P.I., M.T., D.J.-M., J.D., D.C.A., O.A.-M., J.C.-M., and P.D.-F. analyzed the data. All authors interpreted the data and wrote the manuscript. All authors reviewed, revised, and approved the final manuscript.

Informed consent statement

"Informed consent was obtained from all subjects involved in the study."

Data availability statement

The current study's datasets are available from the corresponding author on reasonable request.

References

ADA. (2023). 5. Facilitating Positive Health Behaviors and Well-being to Improve Health Outcomes: Standards of Care in Diabetes—2024. *Diabetes Care*, *47*(Supplement_1), S77-S110. https://doi.org/10.2337/dc24-S005

Alvarez, C., Campos-Jara, C., Ciolac, E. G., Guimaraes, G. V., Andrade-Mayorga, O., Cano-Montoya, J., Andrade, D. C., Delgado-Floody, P., Alonso-Martínez, A., & Izquierdo, M. (2023). Hypertensive patients show higher heart rate response during incremental exercise and elevated arterial age estimation than normotensive adult peers: VASCU-HEALTH PROJECT Pacientes hipertensos muestran una mayor respuesta de la frecuencia cardíaca durante el ejercicio progresivo en relación con pares adultos normotensos: PROYECTO VASCU-HEALTH. *Retos-Nuevas Tendencias En Educacion Fisica Deporte Y Recreacion*, *50*, 25-32. https://doi.org/10.47197/retos.v50.99716

Ashor, A. W., Lara, J., Siervo, M., Celis-Morales, C., & Mathers, J. C. (2014). Effects of Exercise Modalities on Arterial Stiffness and Wave Reflection: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *PloS one*, *9*(10), e110034. https://doi.org/10.1371/journal.pone.0110034

Åstrand, P.-O. (2003). *Textbook of work physiology: physiological bases of exercise*. Human kinetics.

Augeri, A. L., Tsongalis, G. J., Van Heest, J. L., Maresh, C. M., Thompson, P. D., & Pescatello, L. S. (2009). The endothelial nitric oxide synthase− 786 T> C polymorphism and the exercise-induced blood pressure and nitric oxide responses among men with elevated blood pressure. *Atherosclerosis*, *204*(2), e28-e34. https://doi.org/10.1016/j.atherosclerosis.2008.12.015

Birk, G. K., Dawson, E. A., Atkinson, C., Haynes, A., Cable, N. T., Thijssen, D. H., & Green, D. J. (2012). Brachial artery adaptation to lower limb exercise training: role of shear stress. *Journal of Applied Physiology*, *112*(10), 1653-1658. https://doi.org/10.1152/japplphysiol.01489.2011

Bowden Davies, K. A., Norman, J. A., Thompson, A., Mitchell, K. L., Harrold, J. A., Halford, J. C., Wilding, J. P., Kemp, G. J., Cuthbertson, D. J., & Sprung, V. S. (2021). Short-term physical inactivity induces endothelial dysfunction. *Front Physiol*, *12*, 659834. https://doi.org/10.3389/fphys.2021.659834

Cade, R., Mars, D., Wagemaker, H., Zauner, C., Packer, D., Privette, M., Cade, M., Peterson, J., & Hood-Lewis, D. (1984). Effect of aerobic exercise training on patients with systemic arterial hypertension. *The American journal of medicine*, *77*(5), 785-790. https://doi.org/10.1016/0002-9343(84)90513-8

Chen, H.-Y., & Chauhan, S. P. (2019). Hypertension among women of reproductive age: Impact of 2017 American College of Cardiology/American Heart Association high blood pressure guideline. *International Journal of Cardiology Hypertension*, *1*, 100007. https://doi.org/10.1016/j.ijchy.2019.100007

Colberg, S. R., Sigal, R. J., Yardley, J. E., Riddell, M. C., Dunstan, D. W., Dempsey, P. C., Horton, E. S., Castorino, K., & Tate, D. F. (2016). Physical Activity/Exercise and Diabetes: A Position Statement of the American Diabetes Association. *Diabetes Care*, *39*(11), 2065-2079. https://doi.org/10.2337/dc16-1728

Farahati, S., Hosseini, S. R. A., Moazzami, M., Daloee, M. H., & Daloee, S. H. (2020). The Impact of High-Intensity Interval Training Versus Moderate-Intensity Continuous Training on Carotid Intima-Media Thickness and Ankle-Brachial Index in Middle-Aged Women. *Int J Prev Med*, *11*, 62. https://doi.org/10.4103/ijpvm.IJPVM_524_18

Forde, C., Johnston, M., Haberlin, C., Breen, P., Greenan, S., Gissane, C., Comyns, T., Maher, V., & Gormley, J. (2020). Low Dose Resistance Exercise: A Pilot Study Examining Effects on Blood Pressure and Augmentation Index Between Intensities. *High Blood Pressure & Cardiovascular Prevention*, *27*(1), 83-91. https://doi.org/10.1007/s40292-020-00362-5

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., Nieman, D. C., Swain, D. P., & American College of Sports, M. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc*, *43*(7), 1334-1359. https://doi.org/10.1249/MSS.0b013e318213fefb

Gómez-Rossel, O., & Merellano-Navarro, E. (2024). Efectos del entrenamiento concurrente en indicadores de condición física y calidad de vida de adultos sanos (Effects of concurrent training on indicators of physical condition and quality of life of healthy adults). *Retos-Nuevas Tendencias En Educacion Fisica Deporte Y Recreacion*, *54*, 24-35.

Guimaraes, G. V., Ciolac, E. G., Carvalho, V. O., D'Avila, V. M., Bortolotto, L. A., & Bocchi, E. A. (2010). Effects of continuous vs. interval exercise training on blood pressure and arterial stiffness in treated hypertension. *Hypertens Res*, *33*(6), 627-632. http://dx.doi.org/10.1038/hr.2010.42

Halliwill, J. R. (2001). Mechanisms and clinical implications of post-exercise hypotension in humans. *Exerc Sport Sci Rev*, *29*(2), 65-70. https://doi.org/10.1097/00003677-200104000-00005

Hasegawa, N., Fujie, S., Horii, N., Uchida, M., Kurihara, T., Sanada, K., Hamaoka, T., & Iemitsu, M. (2018). Aerobic exercise training-induced changes in serum C1q/TNF-related protein levels are associated with reduced arterial stiffness in middle-aged and older adults. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *314*(1), R94-R101. https://doi.org/10.1152/ajpregu.00212.2017

Heiss, C., Rodriguez-Mateos, A., Bapir, M., Skene, S. S., Sies, H., & Kelm, M. (2022). Flow-mediated dilation reference values for evaluation of endothelial function and cardiovascular health. *Cardiovascular Research*. https://doi.org/10.1093/cvr/cvac095

Kanaley, J. A., Fenicchia, L. M., Miller, C. S., Ploutz-Synder, L. L., Weinstock, R. S., Carhart, R., & Azevedo, J. L., Jr. (2001). Resting leptin responses to acute and chronic resistance training in type 2 diabetic men and women. *Int J Obes Relat Metab Disord*, *25*(10), 1474-1480. https://doi.org/10.1038/sj.ijo.0801797

Kim, E. J., Park, C. G., Park, J. S., Suh, S. Y., Choi, C. U., Kim, J. W., Kim, S. H., Lim, H. E., Rha, S. W., Seo, H. S., & Oh, D. J. (2007). Relationship between blood pressure parameters and pulse wave velocity in normotensive and hypertensive subjects: invasive study. *Journal of Human Hypertension*, *21*(2), 141-148. https://doi.org/10.1038/sj.jhh.1002120

Kim, H. M., Rhee, T.-M., & Kim, H.-L. (2022). Integrated approach of brachial-ankle pulse wave velocity and cardiovascular risk scores for predicting the risk of cardiovascular events. *PloS one*, *17*(4), e0267614.

Koivistoinen, T., Lyytikäinen, L.-P., Aatola, H., Luukkaala, T., Juonala, M., Viikari, J., Lehtimäki, T., Raitakari, O. T., Kähönen, M., & Hutri-Kähönen, N. (2018). Pulse Wave Velocity Predicts the Progression of Blood Pressure and

Development of Hypertension in Young Adults. *Hypertension*, *71*(3), 451-456. https://doi.org/doi:10.1161/HYPERTENSIONAHA.117.10368

Lee, D., Byun, K., Hwang, M.-H., & Lee, S. (2021). Augmentation index is inversely associated with skeletal muscle mass, muscle strength, and anaerobic power in young male adults: a preliminary study. *Applied Sciences*, *11*(7), 3146.

Lobato, N. S., Filgueira, F. P., Akamine, E. H., Tostes, R. C., Carvalho, M. H., & Fortes, Z. B. (2012). Mechanisms of endothelial dysfunction in obesity-associated hypertension. *Braz J Med Biol Res*, *45*(5), 392-400. https://doi.org/10.1590/s0100-879x2012007500058

Low, D. A., Shibasaki, M., Davis, S. L., Keller, D. M., & Crandall, C. G. (2007). Does local heating-induced nitric oxide production attenuate vasoconstrictor responsiveness to lower body negative pressure in human skin? *Journal of Applied Physiology*, *102*(5), 1839-1843. https://doi.org/10.1152/japplphysiol.01181.2006

Molmen-Hansen, H. E., Stolen, T., Tjonna, A. E., Aamot, I. L., Ekeberg, I. S., Tyldum, G. A., Wisloff, U., Ingul, C. B., & Stoylen, A. (2012). Aerobic interval training reduces blood pressure and improves myocardial function in hypertensive patients. *European Journal of Preventive Cardiology*, *19*(2), 151-160. https://doi.org/10.1177/1741826711400512

Munir, S., Jiang, B., Guilcher, A., Brett, S., Redwood, S., Marber, M., & Chowienczyk, P. (2008). Exercise reduces arterial pressure augmentation through vasodilation of muscular arteries in humans. *American Journal of Physiology-Heart and Circulatory Physiology*, *294*(4), H1645-H1650. https://doi.org/10.1152/ajpheart.01171.2007

Ochi, M., Kohara, K., Tabara, Y., Kido, T., Uetani, E., Ochi, N., Igase, M., & Miki, T. (2010). Arterial stiffness is associated with low thigh muscle mass in middle-aged to elderly men. *Atherosclerosis*, *212*(1), 327-332. https://doi.org/10.1016/j.atherosclerosis.2010.05.026

Olea, M. A., Mancilla, R., Martínez, S., & Díaz, E. (2017). Entrenamiento interválico de alta intensidad contribuye a la normalización de la hipertensión arterial. *Rev Med Chil*, *145*(9), 1154-1159. http://dx.doi.org/10.4067/s0034-98872017000901154

Oviedo, G., Niño, O., Bellomío, C., González, R., & Guerra, M. (2015). Entrenamiento, presión arterial y lípidos en adultos con prehipertensión. *Retos: nuevas tendencias en educación física, deporte y recreación*(27), 67-72. https://doi.org/10.47197/retos.v0i27.34350

Pedralli, M. L., Marschner, R. A., Kollet, D. P., Neto, S. G., Eibel, B., Tanaka, H., & Lehnen, A. M. (2020). Different exercise training modalities produce similar endothelial function improvements in individuals with prehypertension or hypertension: a randomized clinical trial Exercise, endothelium and blood pressure. *Scientific reports*, *10*(1), 1-9. https://doi.org/10.1038/s41598-020-64365-x

Pescatello, L. S., Buchner, D. M., Jakicic, J. M., Powell, K. E., Kraus, W. E., Bloodgood, B., Campbell, W. W., Dietz, S., Dipietro, L., George, S. M., Macko, R. F., Mctiernan, A., Pate, R. R., Piercy, K. L., & committee*, F. t. p. a. g. a. (2019). Physical Activity to Prevent and Treat Hypertension: A Systematic Review. *Medicine & Science in Sports & Exercise*, *51*(6), 1314-1323. https://doi.org/10.1249/mss.0000000000001943

Pescatello, L. S., MacDonald, H. V., Lamberti, L., & Johnson, B. T. (2015). Exercise for hypertension: a prescription update integrating existing recommendations with emerging research. *Current hypertension reports*, *17*(11), 1-10.

Pescatello, L. S., Miller, B., Danias, P. G., Werner, M., Hess, M., Baker, C., & Jane De Souza, M. (1999). Dynamic exercise normalizes resting blood pressure in mildly hypertensive premenopausal women. *Am Heart J*, *138*(5 Pt 1), 916-921. https://doi.org/S000287039900321X [pii]

Petermann, F., Durán, E., Labraña, A. M., Martínez, M. A., Leiva, A. M., Garrido-Méndez, A., Poblete-Valderrama, F., Díaz-Martínez, X., Salas, C., & Celis-Morales, C. (2017). Factores de riesgo asociados al desarrollo de hipertensión arterial en Chile. *Rev Med Chil*, *145*(8), 996-1004. http://dx.doi.org/10.4067/s0034-98872017000800996

Potosí-Moya, V., Paredes-Gómez, R., & Durango-Sánchez, X. (2024). HIIT y su influencia sobre el VO2max en estudiantes de fisioterapia (HIIT and its influence on VO2max in physiotherapy students). *Retos-Nuevas Tendencias En Educacion Fisica Deporte Y Recreacion*, *54*, 616-624.

Ramírez-Vélez, R., Castro-Astudillo, K., Correa-Bautista, J. E., González-Ruíz, K., Izquierdo, M., García-Hermoso, A., Álvarez, C., Ramírez-Campillo, R., & Correa-Rodríguez, M. (2020). 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. *The Journal of Strength & Conditioning Research*, *34*(8), 2178-2188.

Ramírez-Vélez, R., Hernández-Quiñones, P. A., Tordecilla-Sanders, A., Álvarez, C., Ramírez-Campillo, R., Izquierdo, M., Correa-Bautista, J. E., Garcia-Hermoso, A., & Garcia, R. G. (2019). Effectiveness of HIIT compared to moderate continuous training in improving vascular parameters in inactive adults. *Lipids in health and disease*, *18*(1), 42. http://dx.doi.org/10.1519/JSC.0000000000003533

Ring, M., Eriksson, M. J., Zierath, J. R., & Caidahl, K. (2014). Arterial stiffness estimation in healthy subjects: a validation of oscillometric (Arteriograph) and tonometric (SphygmoCor) techniques. *Hypertension Research*, *37*(11), 999-1007. https://doi.org/10.1038/hr.2014.115

Román, C., Fernández, M., Acevedo, M., Alarcón, G., Araya, M. V., Barquín, I., Barrenechea, J., Díaz, H., Lama, D., Lanas, F., López, R., Oliveros, M. J., Prat, H., Rouliez, K., Santibáñez, C., Serón, P., Troncoso, E., & Varleta, P. (2019). Ejercicio: una herramienta clave en la prevención cardiovascular. Consenso de la Sociedad Chilena de Cardiología y Cirugía Cardiovascular y de la Sociedad Chilena de Kinesiología en Cardiología y Cirugía Cardiovascular. *Revista chilena de cardiología*, *38*, 149-157. http://www.scielo.cl/scielo.php?script=sci_arttext&pid=S0718-85602019000200149&nrm=iso

Ross, M., Kargl, C. K., Ferguson, R., Gavin, T. P., & Hellsten, Y. (2023). Exercise-induced skeletal muscle angiogenesis: impact of age, sex, angiocrines and cellular mediators. *Eur J Appl Physiol*, *123*(7), 1415-1432. https://doi.org/10.1007/s00421-022-05128-6

Thijssen, D. H., Bruno, R. M., van Mil, A. C., Holder, S. M., Faita, F., Greyling, A., Zock, P. L., Taddei, S., Deanfield, J. E., & Luscher, T. (2019). Expert consensus and evidence-based recommendations for the assessment of flow-mediated dilation in humans. *European Heart Journal*, *40*(30), 2534-2547. http://dx.doi.org/10.1093/eurheartj/ehz350

Thompson, W., Gordon, N., & Pescatello, L. (2021). *Manual*

ACSM para la valoración y prescripción del ejercicio (3ª edición ed.).

Whelton, P. K., Carey, R. M., Aronow, W. S., Casey, D. E., Collins, K. J., Himmelfarb, C. D., DePalma, S. M., Gidding, S., Jamerson, K. A., Jones, D. W., MacLaughlin, E. J., Muntner, P., Ovbiagele, B., Smith, S. C., Spencer, C. C., Stafford, R. S., Taler, S. J., Thomas, R. J., Williams, K. A., . . . Wright, J. T. (2018). 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. *Hypertension*, *71*(6), 1269-1324. https://doi.org/doi:10.1161/HYP.0000000000000066

WHO. (2000). Obesity: preventing and managing the global epidemic. 894:i–xii, 891–253.

Wilkins, B. W., Minson, C. T., & Halliwill, J. R. (2004). Regional hemodynamics during postexercise hypotension. II. Cutaneous circulation. *Journal of Applied Physiology*, *97*(6), 2071-2076.

Yan, J., Cai, X., Zhu, G., Guo, R., Yan, H., & Wang, Y. (2022). A non-invasive blood pressure prediction method based on pulse wave feature fusion. *Biomedical Signal Processing and Control*, *74*, 103523. https://doi.org/https://doi.org/10.1016/j.bspc.2022.103523

Datos de los autores:

Cristian Alvarez	cristian.alvarez@unab.cl	Autor/a
Luis Peñailillo	luis.penailillo@unab.cl	Autor/a
Paulina Ibacahe-Saavedra	paulina.ibacahe@unab.cl	Autor/a
Marcelo Tuesta	marcelo.tuesta@unab.cl	Autor/a
Daniel Jerez-Mayorga	djerezmayorga@ugr.es	Autor/a
Jarosław Domaradski	jaroslaw.domaradzki@awf.wroc.pl	Autor/a
David C. Andrade	david.andrade@uantof.cl	Autor/a
Omar Andrade-Mayorga	omar.andrade@ufrontera.cl	Autor/a
Johnattan Cano-Montoya	johnattan.cano@uss.cl	Autor/a
Pedro Delgado-Floody	pedro.delgado@ufrontera.cl	Autor/a