



## Effects of resistance exercises on hemodynamic responses: a systematic review with meta-analysis

### Efeitos dos exercícios resistidos nas respostas hemodinâmicas: uma revisão sistemática de revisões com meta-análise

Ramon Martins Barbosa<sup>1,2</sup> , Alan Carlos Nery dos Santos<sup>2</sup> , Marvyn de Santana do Sacramento<sup>1,3,4</sup> , Tailma Costa de Jesus<sup>5</sup> , Jefferson Petto<sup>1,3</sup> 

1. Escola Bahiana de Medicina e Saúde Humana – EBMS, Salvador, BA, Brazil

2. Faculdade da Região Sisaleira – FARESI, Conceição do Coité, BA, Brazil

3. Actus Cordios Reabilitação Cardiovascular, Salvador, BA, Brazil

4. Faculdade Adventista da Bahia, Capoeiruçu, BA, Brazil

5. Centro Universitário Social da Bahia, Salvador, BA, Brazil

#### ABSTRACT

**Objectives:** To analyze the effects of Resistance Exercise (RE) on hemodynamic responses related to blood pressure. **Methods:** Systematic review, Prospero CRD42023422584, carried out on the following databases: PubMed/Medline, PEDro, Cochrane and VHL Regional Portal, between June and December 2023. Descriptors: “Resistance Training”, “Blood Pressure” and, “Systematic Reviews. Included: Systematic reviews, composed of randomized clinical trials and/or controlled intervention studies, which tested static or dynamic resistance exercise interventions, in adult individuals, for outcomes associated with hemodynamic responses such as: blood pressure, heart rate and  $VO_{2max}$ . There were no restrictions on the time of publication of the studies. The risk of bias was assessed using the AMSTAR-2 scale. **Results:** 174 articles were identified, but after analysis 7 were included. These were published between 2005 and 2020, totaling a sample of 7,818 individuals of both sexes. The main results indicate that RE promotes a statistically significant and clinically relevant improvement in systolic blood pressure (SBP), diastolic blood pressure (DBP) and mean arterial pressure (MAP). There were improvements in  $VO_{2max}$  and  $VO_{2peak}$ . **Conclusion:** We concluded that RE was statistically significant and clinically relevant for reducing SBP, DBP and MAP. An improvement in  $VO_{2max}$  and  $VO_{2peak}$  was also observed. Furthermore, Isometric Resistance Exercise promoted a greater blood pressure reduction when compared to Aerobic Resistance Exercise and Dynamic Resistance Exercise. These results are supported by the high/moderate methodological quality of the included reviews.

**Keywords:** resistance training; blood pressure; hypertension

#### RESUMO

**Objetivos:** Analisar os efeitos do Exercício Resistido (ER) nas respostas hemodinâmicas relacionadas a pressão arterial. **Métodos:** Revisão sistemática, Prospero CRD42023422584, realizada nas bases de dados: PubMed/Medline, PEDro, Cochrane e Portal Regional da BVS, entre junho e dezembro de 2023. Descritores: “Resistance Training”, “Blood Pressure” e, “Systematic Reviews. Incluídos: Revisões sistemáticas, composta por ensaios clínicos randomizados e/ou estudos de intervenção controlados, que testaram intervenções de exercício resistido estático ou dinâmico, em indivíduos adultos, para desfechos associados as respostas hemodinâmicas como: pressão arterial, frequência cardíaca e  $VO_{2max}$ . Não foram realizadas restrições quanto ao tempo de publicação dos estudos. O risco de viés foi avaliado pela escala AMSTAR-2. **Resultados:** Identificamos 174 artigos, contudo, após análise, 7 foram incluídos. Esses foram publicados entre 2005 e 2020, totalizando amostra de 7.818 indivíduos de ambos os sexos. Os principais resultados indicam que o ER promove uma melhora estatisticamente significativa e clinicamente relevante na pressão arterial sistólica (PAS), pressão arterial diastólica (PAD) e Pressão arterial média (PAM). Houve melhoras do  $VO_{2max}$  e no  $VO_2$  de Pico. **Conclusão:** Nós concluímos que o ER foi estatisticamente significativo e clinicamente relevante para redução da PAS, PAD e PAM. Também foi observada uma melhora no  $VO_{2max}$  e o  $VO_2$  de Pico. Além disso, o Exercício Resistido Isométrico promoveu uma redução pressórica maior quando comparado ao Exercício de Resistência Aeróbica e o Exercício Resistido Dinâmico. Esses resultados são apoiados pela alta/moderada qualidade metodológica das revisões incluídas.

**Palavras-chave:** treinamento resistido; pressão arterial; hipertensão

## Introduction

Cardiovascular diseases are a global public health problem. They directly or indirectly resulted in high costs for health agencies, and it is worth mentioning their negative impacts on morbidity and mortality, functional and biopsychosocial aspects of the population affected by such a clinical condition [1]. Annually, around 17 million people die from cardiovascular diseases, with Arterial Hypertension (AH) being responsible for 9.4 million deaths and a disease burden of 7% [2]. Added to this, AH is responsible for 49% of deaths from heart disease and 51% from stroke, however these data may be underestimated, since the prevalence of AH is higher in middle and low-income countries, and the number of unpublished and untreated patients is large, which may reflect deficiencies in health services and, making AH an important global health condition [3,4].

Interestingly, a population study suggested that the prevalence of AH has almost doubled in the last three decades. Thus, in the 1980s, around 600 million individuals over the age of 25 had high blood pressure and, by mid-2008, this number had already grown to around 1 billion people [5]. Another point is that physical inactivity, overweight and obesity, smoking, excess salt in the diet and alcohol consumption have been described as risk factors that, once modified, can alter blood pressure [6]. Furthermore, although a large part of the population uses antihypertensive medications, which are effective and most of the time have minimal side effects, the costs end up being high and they may not be the best strategy for blood pressure control, since around 50% of patients do not benefit from such a medication strategy [7].

With this in mind, the main national and international recommendations suggest that evidence-based non-pharmacological lifestyle strategies are first-line therapies for attenuating BP. Therefore, weekly moderate physical activity levels close to 150 minutes, weight reduction and smoking are effective strategies that express a statistically significant and clinically relevant reduction in BP [8]. Furthermore, studies suggest that aerobic exercise is the most prescribed modality for BP control, however its adherence is reduced, mainly due to the time spent and the considerable energy expenditure to obtain such gains [9,10].

Added to this, although previously associated with exaggerated hypertensive responses, recent studies suggest that resistance exercise (RE) is a safe and effective intervention to promote BP reduction, being more expressed in studies involving isometric resistance exercise. In this way, it can be configured as a potential strategy, once properly prescribed, it can result in lower individual costs, as well as to health bodies, and perhaps shorter execution time [11-13]. Thus, the present study aims to analyze the effects of resistance exercise on hemodynamic responses related to blood pressure.

## Methods

### *Study type*

This is a systematic review composed of systematic reviews with meta-analysis, structured based on the criteria established by the “Preferred Reporting Items for Systematic Reviews and Meta-Analyses” (PRISMA) guideline [14], and the methodological guide proposed by Smith *et al.* [15], to answer the following clinical question: What are the chronic effects of static and dynamic resistance exercise on hemodynamic responses associated with blood pressure? The study was prospectively registered in Prospero under the protocol number: CRD42023422584.

### *Eligibility criteria*

The study included: 1) Systematic reviews; 2) composed of randomized clinical trials and/or controlled intervention studies; 3) that tested static or dynamic resistance exercise interventions; 4) in adult individuals; 5) for outcomes associated with hemodynamic responses such as blood pressure, heart rate, and maximum oxygen uptake ( $VO_{2max}$ ). 6) Such studies should be available in full. There were no restrictions regarding language or publication time of the studies. On the other hand, the following were excluded: 8) systematic reviews about RE that conducted mixed protocols with other training modalities (aerobic training and breathing exercises, and training with blood flow restriction), 9) systematic reviews about RE that did not describe the comparison groups of the included studies; 10) systematic reviews that aimed to analyze only the principles related to the prescription of RE; and 11) systematic reviews that analyzed only pre-hypertensive and hypertensive individuals, or those with other associated comorbidities.

### *Outcome of interest*

For the study, “*Hemodynamic Responses*” are related to the movements and forces involved in the displacement of blood through the cardiovascular system. “*Blood Pressure*” is related to the pressure exerted by blood on the walls of the arteries during ventricular systole, defined based on the “*Medical Subject Headings*”.

### *Search strategy*

Searches were conducted in the databases: PubMed/Medline, PEDro, COCHRANE, and Regional Portal of BVS, by two independent authors [R.M.B and A.C.N.S], between June and December 2023. The descriptors were selected using the “*Medical Subject Headings*” - (MESH) and “*Descritores em Ciências da Saúde*” (DeCS), selecting the following descriptors: “*Resistance Training*”, “*Blood Pressure*”, and “*Systematic Reviews*”, using the boolean operators [AND], [OR], and [NOT] for the respective intersections, as described in chart I.

Chart I - Search strategies for databases	
PubMed / MEDLINE	("Resistance Training"[Title/Abstract] AND "Blood Pressure"[Title/Abstract]) AND (meta-analysis[Filter] OR systematicreview[Filter])
	((("Resistance Training"[Title/Abstract] AND "Strength Training"[Title/Abstract] AND "Weight-Lifting Strengthening Program"[Title/Abstract] AND "Strengthening Programs, Weight-Lifting"[Title/Abstract] AND "Weight-Lifting Strengthening Programs"[Title/Abstract] AND "Exercise Programs, Weight-Lifting"[Title/Abstract] AND "Strengthening Program, Weight-Bearing"[Title/Abstract] AND "Strengthening Programs, Weight-Bearing"[Title/Abstract] AND "Weight-Bearing Strengthening Programs"[Title/Abstract] AND "Weight-Bearing Exercise Program"[Title/Abstract] AND "Exercise Program, Weight-Bearing"[Title/Abstract]) AND ("Pressure, Blood"[Title/Abstract] AND "Diastolic Pressure"[Title/Abstract] AND "Pressure, Diastolic"[Title/Abstract] AND "Pulse Pressure"[Title/Abstract] AND "Pressure, Pulse"[Title/Abstract] AND "Systolic Pressure"[Title/Abstract] AND "Pressure, Systolic"[Title/Abstract] AND "Pressures, Systolic"[Title/Abstract])) AND (meta-analysis[Filter] OR systematicreview[Filter]))
	("Breathing Exercises"[Title/Abstract] AND "Blood Pressure"[Title/Abstract]) AND (meta-analysis[Filter] OR systematicreview[Filter])
	("Breathing Exercises"[Title/Abstract] AND "exercise breathing"[Title/Abstract] AND "Respiratory Muscle Training"[Title/Abstract] AND "muscle training respiratory"[Title/Abstract] AND "training respiratory muscle"[Title/Abstract] AND ("pressure blood"[Title/Abstract] AND "Diastolic Pressure"[Title/Abstract] AND "pressure diastolic"[Title/Abstract] AND "Pulse Pressure"[Title/Abstract] AND "pressure pulse"[Title/Abstract] AND "Systolic Pressure"[Title/Abstract] AND "pressure systolic"[Title/Abstract] AND "pressures systolic"[Title/Abstract])) AND (meta-analysis[Filter] OR systematicreview[Filter]))
	((("Resistance Training"[Title/Abstract]) AND ("Breathing Exercises"[Title/Abstract])) AND ("Blood Pressure"[Title/Abstract]))
Portal Regional da BVS / LILACS	(strength training OR weight training OR bodybuilding OR weightlifting strengthening program OR weightlifting strengthening program OR weightlifting strengthening program OR weightlifting strengthening program) AND (hemodynamics OR hemodynamic phenomena OR hemodynamic processes) AND (type_of_study:(("systematic_reviews")))
	(Strength Training OR Weight Training OR Bodybuilding OR Weightlifting Strengthening Program OR Weightlifting Strengthening Program OR Weightlifting Strengthening Program OR Weightlifting Strengthening Program) AND (Breathing Exercise OR Exercises for the Respiratory Muscles AND Hemodynamics OR Hemodynamic Phenomena OR Hemodynamic Processes) AND (Hemodynamics OR Hemodynamic Phenomena OR Hemodynamic Processes)
SciELO	"Resistance Training" AND "Blood Pressure"
EBSCOhost / SPORTDiscus	"Resistance Training" AND "Blood Pressure"
PEDro	Resistance Training* Blood Pressure* Systematic Reviews*
Cochrane Library	"Resistance Training" in Title Abstract Keyword AND "Pressure, Blood" in Title Abstract Keyword - (Variations of the word have been searched)

### *Searching other resources*

Additionally, with the aim of identifying other published, unpublished, or ongoing studies, we consulted the PROSPERO prospective register of systematic reviews and grey literature using Google Scholar. We conducted direct citation tracking of all included studies (and other relevant studies) using Google Scholar ([scholar.google.co.uk/](https://scholar.google.co.uk/)) for additional references to relevant studies.

### *Study selection and data extraction*

Study selection was conducted by two independent authors [R.M.B] and [A.C.N.S], and in case of any disagreements, a third reviewer was consulted [J.P]. Thus, a thorough review of titles and abstracts was conducted, with final selection based on the aforementioned eligibility criteria. As shown in Tables 1 and 2, eligible studies were selected for full-text reading, further evaluation against the selection criteria, and data extraction regarding: 1) Author and year of study publication; 2) Objective of the systematic review; 3) Type of systematic review/number of studies included in the review; 4) Population (population characteristics); 5) Intervention protocol (type of resistance exercise, weekly frequency, intensity, and duration); 6) Control (control form); 7) Methods (outcome measurements); 8) Outcomes (blood pressure); and 9) Main results obtained by the studies.

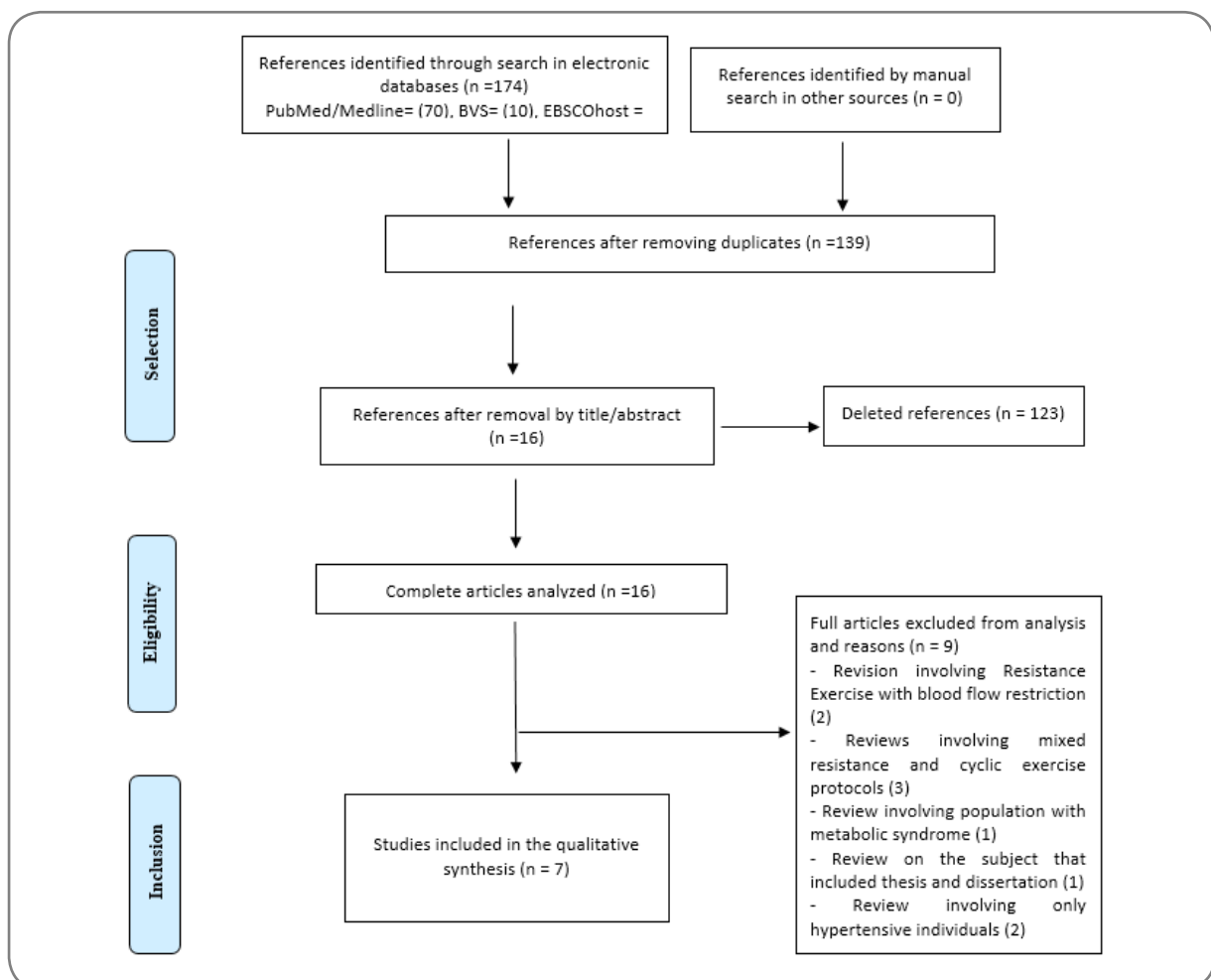
The references reviewed and included in this review were analyzed by the second reviewer [A.C.N.S], aiming to identify potential studies not identified in the searches of electronic databases. Figure 1 summarizes the study selection strategies that compose the scope of this systematic review.

### *Risk of bias*

The quality of each review was assessed by two independent authors [R.M.B and A.C.N.S], using the methodological evaluation criteria proposed by the AMSTAR-2 scale. It consists of a checklist composed of 16 items, which can be answered with “Yes”, “Partial Yes”, or “No”, with the aim not to generate a final score. It classifies the review as “High Quality” = Zero or one non-critical weakness: The systematic review provides a precise and comprehensive summary of the results. “Moderate Quality” = More than one non-critical weakness \*: The systematic review has more than one weakness, but no critical flaws. “Low Quality” = One critical flaw with or without non-critical weaknesses: The review has one critical flaw and may not provide a precise and comprehensive summary of the available studies, and “Critically Low Quality” = More than one critical flaw with or without non-critical weaknesses: The review has more than one critical flaw and should not be considered to provide a precise and comprehensive summary of the available studies. This is the validated and frequently used AMSTAR scale revision.

## Results

The search strategies and references analyzed through manual search returned a total of 174 articles. However, after review by the reviewers [R.M.B and A.C.N.S], 35 were eliminated due to duplication, leaving 139 studies. After removal based on title and abstract, 16 studies remained. In another stage, after screening based on eligibility criteria, another 9 studies were excluded. The main reasons for exclusion were: systematic reviews involving resistance exercise with blood flow restriction, reviews on resistance exercise in metabolic syndrome, reviews containing mixed protocols of resistance exercise with cyclic exercise, reviews involving theses and dissertations of master's and doctoral degrees, and reviews involving only hypertensive individuals and/or those with underlying pathologies. Finally, 7 studies [11,16-21] met the established selection criteria, as summarized in Figure 1.



**Figure 1** - Flowchart of selection of studies that make up the review  
Source: Prepared by the authors

According to the data presented in Table I, we can observe that the included studies were published between 2005 and 2020, and 100% of the studies were systematic reviews with meta-analyses. Additionally, the number of articles included in each review varied between 6 and 93 randomized clinical trials and controlled inter-

vention studies, with over 60% of the groups involved in the clinical trials being normotensive individuals. Regarding the characteristics of the population, the sample size ranged from 139 to 5,223 individuals, totaling 7,818 individuals of both sexes, with reported ages ranging from 19 to 84 years. Furthermore, the included studies aimed to analyze the effects of resistance exercise on blood pressure responses in normotensive, pre-hypertensive, and hypertensive individuals, based on our outcomes of interest: systolic blood pressure, diastolic blood pressure, mean arterial pressure, heart rate, and  $VO_{2max}$ .

**Table I** - Characteristics of studies and population

Author/year	Purpose of the study	Studies included	Population characteristics
Cornelissen <i>et al.</i> , 2005 [16]	Evaluate the effects of RE on resting BP in sedentary adult individuals	Review with meta-analysis/ 9 RCT/ 12 GP of normotensive and hypertensive studies.	341 individuals of both sexes, with a dropout rate of 15%, leaving 290 individuals (200 normotensive). Age: 20 -72 years (median 69).
Cornelissen <i>et al.</i> , 2011 [17]	Assess the impacts of RE on BP and cardiovascular risk factors	Review with meta-analysis/ 28 RCTs/ 13 groups involved normotensive individuals	1,124 individuals of both sexes, with a dropout rate of 3.3%, leaving 1,012 individuals. Age 19-84 (median 53.6). Baseline mean resting BP ranged from 103.2 to 154.1 mm Hg (mean 126.0) for SBP and from 59.3 to 95.1 mm Hg (mean 74.5) for DBP.
Cornelissen <i>et al.</i> , 2013 [18]	Quantify and compare BP changes for each training modality (ARE, DRE, IRE) and identify patient subgroups exhibiting the greatest BP changes	Review with meta-analysis/ 93 RCTs/ 47 groups involving normotensives, 14 from ER	5,223 individuals, 3,401 from the intervention group.
Carlson <i>et al.</i> , 2014 [19]	Effects of IRE on SBP, DBP and MAP in subclinical populations and, examine whether the magnitude of change in SBP	Review with meta-analysis/ 9 RCTs/ 6 involving normotensive patients	223 participants, 127 from the intervention group
Inder <i>et al.</i> , 2015 [11]	Analyze the effects of IRE on resting BP in adults	Review with meta-analysis / 11 RCTs involving normotensive and hypertensive patients	302 individuals of both sexes, ages ranging from 16 to 80 years
Valenciano <i>et al.</i> , 2019 [20]	Effects of IRE on BP in adult subjects	Review with meta-analysis / 9 RCTs involving normotensive patients	492 participants, 266 IG and 226 CG, mean age 40.4±5.2 years, 60% men
Betancur <i>et al.</i> , 2020 [21]	Effect of IRE on BP in normotensive adult participants	Review with meta-analysis, 6 RCTs	139 individuals, 81 GI and 58 CG

RE = Resistance Exercise; BP = Blood Pressure; RCT = Randomized clinical trial; ARE = Aerobic resistance Exercise; DRE = Dynamic Resistance Exercise; IRE = Isometric Resistance Exercise; SBP = Systolic Blood Pressure; DBP = Diastolic Blood Pressure; MAP = Mean arterial Pressure; IG = Intervention Group; CG = Control Group

In Table II, we can observe that in 100% of the studies, participants in the intervention group were subjected to RE for lower limbs, upper limbs, and trunk, being prescribed in static and/or dynamic modalities. The intervention protocol for Dynamic Resistance Exercise (DRE) ranged from 1 to 14 exercises, 1 to 4 sets of 6 to 36 repetitions, with intensities from 30% to 100% of 1RM, while for Isometric Resistance Exercise (IRE), most protocols used 4 sets of 2 to 3 minutes of manual grip or leg exercises, with intensities from 10% to 40% of maximal voluntary contraction. Training frequency ranged from 1 to 7 times per week, with durations from 3 to 52 weeks. Furthermore, when examining the comparison methods, the most used were control group without any intervention and recommendations to follow a normal lifestyle, maintaining physical activity levels, stretching sessions three times a week, in addition to continued education sessions and dialogue calls on physical exercise. Outcomes such as: Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), Mean Arterial Pressure (MAP), Maximum Oxygen Volume ( $VO_{2max}$ ), and heart rate were evaluated by methods such as: automated BP measurements, auscultation, brachial oscillometry, and ambulatory blood pressure monitoring (ABPM).

The main results observed in the studies included in this review indicate that resistance exercise promotes a statistically significant and clinically relevant improvement in SBP, DBP, and MAP. Additionally, improvements in  $VO_{2max}$  and Peak  $VO_2$  were observed. Resistance exercise was statistically significant but not clinically relevant for improving resting heart rate (RHR).

Regarding methodological quality, as shown in Table III, we can see that one of the studies has high methodological quality [21], while the other six studies have moderate methodological quality [11,16-20]. The most critical point was regarding the funding source of the included studies, where none of the studies declared the related information.



**Table II** - Summary of the evaluation process, intervention, outcomes and main results of the studies reviewed

Author / year	Intervention protocols		Methods	Main outcomes	Results
	Exercise group	Control group			
Cornelissen <i>et al.</i> , 2005 [16]	Isotonic and isometric RE for arms, trunk and legs. Protocol: 1-14 exercises, 1-4 sets, 1-25 rep, 30 – 90% of 1MR, 3-4x week, 6-26 weeks.	CGWI and, normal lifestyle, and physical activity routines, receiving calls for lifestyle consultations and BP measurements	BP measurement method not declared.	SBP, DBP, HR, VO <sub>2max</sub>	<ul style="list-style-type: none"> <li>- Exercise groups showed mean net changes in SBP of +2 to -16.8 mmHg and of +1.4 to -16.5 mmHg for DBP.</li> <li>- The overall combined effect of training on SBP and DBP was 3.2 mmHg (P ¼ 0.10) and 3.5 mmHg (P &lt; 0.01).</li> <li>- VO<sub>2max</sub> significantly increased by 10.5% [95% CI (CL) 1.2–19.4%] after training.</li> <li>- There was no significant change in HR.</li> </ul>
Cornelissen <i>et al.</i> , 2011 [17]	Isotonic and isometric RE with weight machines and elastic bands for upper and lower limbs. Protocol: 6 – 30 repetitions, 1-14 exercises performed, 1-6 exercise sessions for each muscle group, 2 – 3 sessions per week, from 6 to 52 weeks, from 30%-100% 1RM or, 30%-40 % of MVC. The ERI 4x2 minutes, bilateral or unilateral, 3 minutes of rest and 1 minute between contractions.	CGWI or, stretching 3x a week, normal lifestyle, and physical activity routines, participated in continuing education sessions on exercise and BP	BP measurements in supine and sitting positions, with manual and semi-automatic sphygmomanometer	BP, VO <sub>2Peak</sub>	<ul style="list-style-type: none"> <li>- RE induced a significant decrease in BP (P 0.01), with a mean reduction of 3.9 in SBP (95% CL, 6.2; 1.5) and 3.6 in DBP (95% CL, 5.0; 2.1) mmHg.</li> <li>- IRE resulted in a greater reduction in BP [-13.5 (-16.5; -10.5) SBP/-6.1(-8.3; -3.9) DBP mm Hg], when compared to DRE.</li> <li>- VO<sub>2Peak</sub> increased by 10.6% after DRE (P = 0.01).</li> </ul>
Cornelissen <i>et al.</i> , 2013 [18]	Isotonic and isometric RE Protocol: 4-52 weeks, 1-7 times a week, 30%-70% of 1RM, 30%-40% for TRI	CGWI e, Normal Lifestyle, and Physical Activity Routines, Taking Lifestyle Consultation Calls, and Participating in Continuing Education Sessions on Exercise and BP	BP measurements in supine and sitting positions, with manual and semi-automatic sphygmomanometers and ABPM	BP	<ul style="list-style-type: none"> <li>- Statistically significant reductions were found for SBP after ARE (3.5 mm Hg [4.6 to 2.3], DRE (1.8 mm Hg [3.7 to 0.011], P = 0.049) and IRE (10.9 mm Hg [14.5 to 7.4], P &lt; 0.0001), but not after EC (1.4 mm Hg [4.2 to +1.5], P = 0.34).</li> <li>- DBP was significantly reduced after ARE (2.5 mm Hg [3.2 to 1.7], P &lt; 0.0001), TRD (3.2 mm Hg [4.5 to 2.0], P &lt; 0.0001), IRE (6.2 mm Hg [10.3 to 2.0], P = 0.003) and EC (2.2 mm Hg [3.9 to 0.48], P = 0.012). there were no significant differences between the effects of ARE, IRE and EC on SBP and DBP (P &gt; 0.05 for all).</li> <li>- There was no significant difference between ARE, DRE, IRE and CE in SBP and DBP.</li> </ul>

Table II - Continuation

Author / year	Intervention protocols		Methods	Main outcomes	Results
	Exercise group	Control group			
Carlson <i>et al.</i> , 2014 [19]	IRE with handgrip and leg exercises.  Protocols over 4 weeks with 4x2 minutes of 30-50% of MVC and 1 to 3 minutes of rest.	Control group with guidelines	Automated BP, Doppler and Auscultation measurements	SBP, DBP, MAP, CRF	- The IRE had a mean SBP difference (MD), 6.77 mm Hg (95% CI, 7.93 to 5.62 mm Hg; $P < 0.001$ ); and DBP, 3.96 mm Hg (95% CI, 4.80 to 3.12 mm Hg; $P < 0.001$ ); and MAP, 3.94 mm Hg (95% CI, 4.73 to 3.16 mm Hg; $P < 0.001$ ). A slight reduction in CRF was also observed (MD, 0.79 beats/min; 95% CI, 1.23 to 0.36 beats/min; $P = 0.003$ )
Inder <i>et al.</i> , 2015 [11]	IRE with handgrip and leg exercises.  Protocol: 3-5 days a week, 3-10 weeks	CG without intervention	Automated BP, doppler and auscultation measurements	SBP, DBP, MAP	- (MD) SBP - 5.20 mm Hg (95% CI) - 6.08 to - 4.33, $P < 0.00001$ ; DBP: MD - 3.91 mm Hg (95% CI - 5.68 to - 2.14, $P < 0.00001$ ); MAP: MD - 3.33 mm Hg (95% CI - 4.01 to - 2.66, $P < 0.00001$ ).  - Subjects who performed $\geq 8$ weeks of IRE demonstrated a greater reduction in SBP: MD - 7.26 mm Hg (95% CI - 8.47 to - 6.04) and MAP: MD - 4.22 mm Hg (95% CI - 5.08 to - 3.37) than those who performed 8 weeks.
Valenciano <i>et al.</i> , 2019 [20]	IRE MMSS and MMII 3-12 weeks, 3-5 days, intensity 5 -35% 1MR	CG Not specified	Brachial oscillometry, Automated BP measurements, Doppler and Auscultation	SBP, DBP and MAP	- IRE showed statistically significant ( $P < 0.05$ ) and clinically relevant ( $>2$ mmHg) positive effects on SBP (5.23 mmHg) and MAP (2.9 mmHg). The IRE showed a statistically significant but not clinically relevant reduction in DBP (1.64 mmHg).
Betancur <i>et al.</i> , 2020 [21]	IRE for upper limbs and lower limbs  4 x 2 - 3 minutes, 10% - 34% of MVC	CG Not specified	Oscilometria braquial, Medições automatizadas de PA, Doppler e Ausculta	SBP, DBP, MAP	- Clinically relevant and statistically significant reductions in SBP (-2.83 mm Hg; $P < 0.00001$ ), DBP (-2.73 mm Hg; $P = 0.0003$ ), and MAP (-3.07 mm Hg; $P = 0.005$ ) in normotensive adult participants. However, substantial heterogeneity has been reported for MAP

RE = Resistance Exercise; 1MR = 1 Maximum repetition; CGWI = Control Group without Intervention; BP = Blood Pressure; SBP = Systolic Blood Pressure; DBP = Diastolic Blood Pressure; MAP = Mean Arterial Pressure; HR = Heart Rate;  $VO_{2max}$  = Maximum Oxygen Volume ; MVC = Maximum Voluntary Contraction; IRE = Isometric Resistance Exercise; CRF = Cardiovascular Risk Factors; ABPM = Ambulatory Blood Pressure Monitoring; ARE = Aerobic Resistance Exercise; DRE = Dynamic Resistance Exercise; CE = Combined Exercise; RHR = Resting Heart Rate

**Table III** - Methodological quality - AMSTAR 2

Article	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Final Quality
Cornelissen <i>et al.</i> , 2005 [16]	X		X	X	X	X		X	X		X	X	X	X	X	X	MODERATE
Cornelissen <i>et al.</i> , 2011 [17]	X		X	X	X	X	X	X	X		X	X	X	X		X	MODERATE
Cornelissen <i>et al.</i> , 2013 [18]	X	/	X	X	X	X	X		X		X	X	X	X	X		MODERATE
Carlson <i>et al.</i> , 2014 [19]	X		X	/	X	X		X	X		X	X	X		X	X	MODERATE
Valenciano <i>et al.</i> , 2019 [20]	X	/	X	/	X	X	X		X		X	/	X	X	X	X	MODERATE
Inder <i>et al.</i> , 2015 [11]	X	/	X	/	X	X	X	X	X		X	X	X		X	X	MODERATE
Betancur <i>et al.</i> , 2020 [21]	X	/	X	X	X	X	X	X	X		X	X	X	X	X	X	HIGH

X= Yes; / = Partial Yes.

1. The research questions and inclusion criteria for the review included the components of PICO; 2. The review report contained an explicit statement that the review methods were established before the review was conducted and the report justified any significant deviations from the protocol; 3. Review authors explained their selection of study designs for inclusion in the review; 4. Review authors used a comprehensive literature search strategy; 5. The review authors carried out the study selection in duplicate; 6. Review authors performed data extraction in duplicate; 7. The review authors provided a list of excluded studies and justified the exclusions; 8. The review authors described the included studies in adequate detail; 9. The review authors used a satisfactory technique to assess the risk of bias (RoB) in individual studies that were included in the review; 10. Review authors reported the funding sources for the studies included in the review; 11. If a meta-analysis was performed, the review authors used appropriate methods for statistical combination of results; 12. If a meta-analysis was performed, the review authors assessed the potential impact of RoB in individual studies on the results of the meta-analysis or other evidence synthesis; 13. Review authors took RoB into consideration in individual studies when interpreting/discussing review results; 14. The review authors provided a satisfactory explanation for, and discussion of, any observed heterogeneity in the review results; 15. If they performed a quantitative synthesis, the review authors performed an adequate investigation of publication bias (minor study bias) and discussed its likely impact on the review results; 16. Review authors have reported any potential sources of conflict of interest, including any funding they received to conduct the review

## Discussion

In response to the objectives of this systematic review, we identified that resistance exercise was statistically significant and clinically relevant for reducing SBP, DBP, and MAP. Additionally, an improvement in  $VO_{2max}$  and  $VO_{2peak}$  was observed. Moreover, IRE promoted greater blood pressure reductions compared to Aerobic Resistance Exercise (ARE) and DRE. These results are supported by the high/moderate methodological quality of the included reviews.

Regarding the reduction of SBP and DBP, the included studies suggest a statistically significant and clinically relevant reduction [11,16-21]. In fact, evidence suggests that a clinically relevant reduction is around 2 mmHg for SBP and 3 mmHg for DBP [22]. Additionally, this data is crucial, as studies suggest that a decrease at this level may reduce the risk of coronary artery disease by 5%, stroke by 8%, and all-cause

mortality by 4% [23].

Furthermore, the studies suggest some physiological mechanisms that may justify the reduction in blood pressure after resistance exercise. Thus, research has indicated that resistance exercise can increase the release of nitric oxide metabolites and vasodilatory substances, which may result in a reduction in peripheral vascular resistance and consequently cardiac output [11,16,19]. Indeed, IRE can promote an acute stimulus to the metaboreflex aiming to re-establish muscle blood flow, which may result in lower tissue oxidative stress, improved vascular endothelial function, and baroreflex sensitivity as well as long-term autonomic balance, associated with increased parasympathetic activation [11,19,24-26].

Moreover, when other related variables were evaluated, there was a reduction in  $VO_{2max}$  and  $VO_{2peak}$  [16,17]. Thus, resistance exercise can promote improvements in cardiorespiratory conditioning. In fact, a recent review suggests that much of this improvement is due to the release and action of myokines [27]. They induce local changes in muscle regulating muscle development/function, as they can potentiate metabolic pathways and attenuate inflammatory responses, which would increase maximum oxygen consumption by muscle tissue [27,28]. Another point is that a significant portion of the prescribed exercises were bi-articular, thus involving various muscle groups, a fact that may have potentiated metabolic demand and consequently increased  $VO_{2max}$  and  $VO_{2peak}$ . Thus, the amount of muscle mass used during exercise seems to be one of the determinants for the increment of the aerobic component during resistance exercise. Improvement in this valence has been associated with physical fitness improvement, which is commonly associated with reduced cardiovascular event deaths and increased longevity [29].

Another interesting finding is that IRE promoted greater blood pressure reductions compared to ARE and DRE [18]. Thus, studies suggest that IRE is capable of promoting sustained arterial occlusion during training, resulting in a rebound effect, capable of inducing arterial vasodilation, related to the release of substances by the vascular endothelium, improving peripheral vascular resistance [30]. In addition, the literature has been pointing to an IRE protocol, composed of 4 sets of 2-3 minutes, with 3 minutes of interval between repetitions, with intensity of 10-40% of MVC, being able to promote such systemic effects [17-21].

In addition to the aspects discussed above, the findings have some limitations that need to be discussed. First, most of the included reviews did not report an average of the blood pressure levels of the studies included in the reviews, which limits the analysis of the findings. Secondly, there was great heterogeneity related to intervention protocols, which limits data extrapolation, as well as the definition of a minimally effective protocol, especially related to DRE. Another point is regarding the outcome measurement methods, which varied between studies, thus limiting comparison of measurement methods. Finally, the evidence quality of most studies included in the reviews was moderate, which indicates that the true effect is close to that estimated, but there is a possibility of being substantially different. However,

these limitations do not invalidate the presented data, as they are consistent with others presented in the literature.

## Conclusion

We conclude that resistance exercise was statistically significant and clinically relevant for reducing SBP, DBP, and MAP. Additionally, an improvement in  $VO_{2max}$  and  $VO_{2peak}$  was observed. Moreover, IRE promotes greater blood pressure reduction compared to ARE and DRE. These results are supported by the high/moderate methodological quality of the included reviews.

### Conflicts of interest

The authors declare that they have no conflict of interest.

### Financing source

The authors did not receive any direct or indirect funding for their research.

### Authors' contribution

**Conception and design of the research:** Barbosa RM, Santos ACN; **Data acquisition:** Barbosa RM, Santos ACN; **Data analysis and interpretation:** all authors; **Manuscript writing:** all authors; **Critical review of the manuscript for important intellectual content:** Petto J, Santos ACN.

## References

1. Roth GA, Mensah GA, Johnson CO, Addolorato G, Ammirati E, Baddour LM, *et al.* GBD-NHLBI-JACC Global Burden of Cardiovascular Diseases Writing Group. Global Burden of Cardiovascular Diseases and Risk Factors, 1990-2019: Update from the GBD 2019 Study. *J Am Coll Cardiol.* 2020 Dec 22;76(25):2982-3021. doi: 10.1016/j.jacc.2020.11.010
2. World Health Organization. Global Status Report on Noncommunicable Diseases 2014. Geneva, Switzerland: World Health Organization; 2014.
3. Mills KT, Stefanescu A, He J. The global epidemiology of hypertension. *Nat Rev Nephrol.* 2020 Apr;16(4):223-37. doi: 10.1038/s41581-019-0244-2
4. Sarki AM, Nduka CU, Stranges S, Kandala NB, Uthman OA. Prevalence of hypertension in low- and middle-income countries: a systematic review and meta-analysis. *Medicine (Baltimore).* 2015 Dec;94(50):e1959. doi: 10.1097/MD.0000000000001959
5. World Health Organization. A Global brief on hypertension: silent killer, global public health crisis. Geneva, Switzerland: World Health Organization; 2013.
6. Ng R, Sutradhar R, Yao Z, Wodchis WP, Rosella LC. Smoking, drinking, diet and physical activity-modifiable lifestyle risk factors and their associations with age to first chronic disease. *Int J Epidemiol.* 2020 Feb 1;49(1):113-30. doi: 10.1093/ije/dyz078
7. Hajjar I, Kotchen TA. Trends in prevalence, awareness, treatment, and control of hypertension in the United States, 1988-2000. *JAMA.* 2003 Jul 9;290(2):199-206. doi: 10.1001/jama.290.2.199
8. Warburton DE, Nicol CW, Bredin SS. Health benefits of physical activity: the evidence. *CMAJ.* 2006 Mar 14;174(6):801-9. doi: 10.1503/cmaj.051351
9. Kelley GA, Kelley KA, Tran ZV. Aerobic exercise and resting blood pressure: a meta-analytic review of randomized, controlled trials. *Prev Cardiol.* 2001 Spring;4(2):73-80. doi: 10.1111/j.1520-037x.2001.00529.x
10. Igarashi Y, Akazawa N, Maeda S. Regular aerobic exercise and blood pressure in East Asians: A meta-analysis of randomized controlled trials. *Clin Exp Hypertens.* 2018;40(4):378-89. doi: 10.1080/10641963.2017.1384483
11. Inder JD, Carlson DJ, Dieberg G, McFarlane JR, Hess NC, Smart NA. Isometric exercise training for blood pressure management: a systematic review and meta-analysis to optimize benefit. *Hypertens Res.* 2016 Feb;39(2):88-94. doi: 10.1038/hr.2015.111
12. Baffour-Awuah B, Pearson MJ, Dieberg G, Smart NA. Isometric resistance training to manage hypertension:

- systematic review and meta-analysis. *Curr Hypertens Rep.* 2023 Apr;25(4):35-49. doi: 10.1007/s11906-023-01232-w
13. Smart NA, Way D, Carlson D, Millar P, McGowan C, Swaine I, Baross A, Howden R, Ritti-Dias R, Wiles J, Cornelissen V, Gordon B, Taylor R, Bleile B. Effects of isometric resistance training on resting blood pressure: individual participant data meta-analysis. *J Hypertens.* 2019 Oct;37(10):1927-38. doi: 10.1097/HJH.0000000000002105
14. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 2009;6(7):e1000097. doi:10.1371/journal.pmed.1000097
15. Smith V, Devane D, Begley CM, Clarke M. Methodology in conducting a systematic review of systematic reviews of healthcare interventions. *BMC Med Res Methodol.* 2011;11(1):1-6. doi:10.1186/1471-2288-11-15
16. Cornelissen VA, Fagard RH. Effect of resistance training on resting blood pressure: a meta-analysis of randomized controlled trials. *J Hypertens.* 2005 Feb;23(2):251-9. doi: 10.1097/00004872-200502000-00003
17. Cornelissen VA, Fagard RH, Coeckelberghs E, Vanhees L. Impact of resistance training on blood pressure and other cardiovascular risk factors: a meta-analysis of randomized, controlled trials. *Hypertension.* 2011 Nov;58(5):950-8. doi: 10.1161/HYPERTENSIONAHA.111.177071
18. Cornelissen VA, Smart NA. Exercise training for blood pressure: a systematic review and meta-analysis. *J Am Heart Assoc.* 2013 Feb 1;2(1):e004473. doi: 10.1161/JAHA.112.004473
19. Carlson DJ, Dieberg G, Hess NC, Millar PJ, Smart NA. Isometric exercise training for blood pressure management: a systematic review and meta-analysis. *Mayo Clin Proc.* 2014 Mar;89(3):327-34. doi: 10.1016/j.mayocp.2013.10.030
20. López-Valenciano A, Ruiz-Pérez I, Ayala F, Sánchez-Meca J, Vera-García FJ. Updated systematic review and meta-analysis on the role of isometric resistance training for resting blood pressure management in adults. *J Hypertens.* 2019 Jul;37(7):1320-1333. doi: 10.1097/HJH.0000000000002022
21. Loaiza-Betancur AF, Pérez Bedoya E, Montoya Dávila J, Chulvi-Medrano I. Effect of isometric resistance training on blood pressure values in a group of normotensive participants: a systematic review and meta-analysis. *Sports Health.* 2020 May/Jun;12(3):256-262. doi: 10.1177/1941738120908070
22. Whelton PK, Carey RM, Aronow WS, Casey DE Jr, Collins KJ, Dennison Himmelfarb C *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. *Hypertension.* 2018 Jun;71(6):1269-324. Erratum in: *Hypertension.* 2018 Jun;71(6):e136-e139. Erratum in: *Hypertension.* 2018 Sep;72(3):e33. doi: 10.1161/HYP.0000000000000066
23. Tian D, Meng J. Exercise for prevention and relief of cardiovascular disease: prognoses, mechanisms, and approaches. *Oxid Med Cell Longev.* 2019 Apr 9;2019:3756750. doi: 10.1155/2019/3756750
24. Green DJ, Maiorana A, O'Driscoll G, Taylor R. Effect of exercise training on endothelium-derived nitric oxide function in humans. *J Physiol.* 2004;15;561(Pt 1):1-25. doi: 10.1113/jphysiol.2004.068197
25. Lawrence MM, Cooley ID, Huet YM, Arthur ST, Howden R. Factors influencing isometric exercise training-induced reductions in resting blood pressure. *Scand J Med Sci Sports.* 2015 Apr;25(2):131-42. doi: 10.1111/sms.12225
26. Taylor AC, McCartney N, Kamath MV, Wiley RL. Isometric training lowers resting blood pressure and modulates autonomic control. *Med Sci Sports Exerc.* 2003;35(2):251-6. doi: 10.1249/01.MSS.0000048725.15026.B5
27. Smart TFF, Doleman B, Hatt J, Paul M, Toft S, Lund JN, Phillips BE. The role of resistance exercise training for improving cardiorespiratory fitness in healthy older adults: a systematic review and meta-analysis. *Age Ageing.* 2022 Jun 1;51(6):afac143. doi: 10.1093/ageing/afac143
28. Gonzalez-Gil AM, Elizondo-Montemayor L. The Role of exercise in the interplay between myokines, hepatokines, osteokines, adipokines, and modulation of inflammation for energy substrate redistribution and fat mass loss: a review. *Nutrients.* 2020 Jun 26;12(6):1899. doi: 10.3390/nu12061899
29. Kokkinos P, Faselis C, Samuel IBH, Pittaras A, Doumas M, Murphy R, Heimall MS, Sui X, Zhang J, Myers J. Cardiorespiratory fitness and mortality risk across the spectra of age, race, and sex. *J Am Coll Cardiol.* 2022 Aug 9;80(6):598-609. doi: 10.1016/j.jacc.2022.05.031
30. Badrov MB, Bartol CL, DiBartolomeo MA, Millar PJ, McNevin NH, McGowan CL. Effects of isometric handgrip training dose on resting blood pressure and resistance vessel endothelial function in normotensive women. *Eur J Appl Physiol.* 2013;113(8):2091-100. doi: 10.1007/s00421-013-2644-5

