Mini-Review/Systematic Review

Exercise intensity and modality are modulators of arterial stiffness in aging: a systematic review

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Abstract - Aim: As individuals age, mechanisms regulating endothelial function can deteriorate, leading to increased arterial stiffness, a key factor associated with cardiovascular events. **Methods:** This systematic review examines the impact of various types and intensities of physical exercise programs on arterial stiffness in older adults (≥ 60 years), based on findings from experimental studies conducted between 2010 and 2024. We searched for studies in both Portuguese and English using Scopus (Elsevier), Google Scholar, and Medline (PubMed) with MeSH terms, including "aerobic training", "resistance training", "arterial stiffness", "pulse wave velocity", "exercise benefits", and "aging". **Results:** Out of 35 studies identified, 16 met the inclusion criteria and were categorized as aerobic training (9 studies), resistance training (3 studies), or combined aerobic + resistance training (4 studies). **Conclusion:** Aerobic exercise (regardless of intensity), resistance exercise (low to moderate intensity), and combined training programs (any intensity) have significant effects on reducing arterial stiffness in adults aged 60 years and older. Nonetheless, further research is needed to clarify these effects in aging populations.

Keywords: older, aerobic exercise, resistance exercise, combined exercise, pulse wave velocity, arterial stiffness.

Introduction

The global population is undergoing significant aging, with projections estimating that by 2030, individuals aged 60 and older will represent over 25% of the global population[1]. As the population ages, the prevalence of chronic diseases, including cardiovascular diseases, increases, strongly influenced by lifestyle factors[2]. In addition, the global prevalence of insufficient physical activity has increased during the last decades from 23.4% in 2000 to 31.3% in 2022[3]. The population aged 60 years and older is the most affected, especially in the Latin America and Caribbean region, which may compromise the 2030 target of the World Health Organization (WHO) Global Action Plan for Physical Activity[1,3].

With advancing age, arterial stiffness increases, and this increase is a major risk marker for cardiovascular diseases[4]. Endothelial dysfunction, characterized by a loss of vascular tone regulation and an increase in inflammatory responses, is one of the underlying processes that contribute to cardiovascular events[5-7]. In this context, physical exercise programs have been considered essential in the nonpharmacological management of cardiovascular diseases, providing benefits such as improved insulin resistance, lipid profile, blood pressure, neurocognitive function, and functional capacity, which contribute to healthier and more active aging[8,9].

Regular physical exercise increases blood flow and shear stress on arterial walls, thereby improving vascular homeostasis through greater nitric oxide availability and oxygen supply to the endothelium[10]. Evidence demonstrates the benefits of aerobic, resistance, and combined (aerobic + resistance) training programs on cardiovascular function, particularly in reducing arterial stiffness[11,12]. Thus, the objective of this systematic review was to investigate the effects of different modalities and intensities of physical exercise programs on arterial stiffness in older adults, based on experimental studies conducted between 2010 and 2024.

Methods

Research strategy and study selection

This systematic review was conducted in six distinct stages: 1) defining the research question; 2) selecting databases (along with establishing inclusion and exclusion criteria); 3) identifying priority data for analysis; 4) conducting a refined evaluation of the selected studies; 5) analyzing the results; and 6) synthesizing the findings of the review[13].

To guide the development of this review, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[14] were used, and to better delineate the research question, the Population, Interest, and Context (PICo) strategy was applied[14]. Accordingly, the following strategy was developed for the research question: P - aging; I - aerobic and/or resistance exercise interventions and/or combined exercises; Co - changes in arterial stiffness. This review aimed to examine whether physical exercise (acute or chronic aerobic, resistance, or combined, regardless of its intensity) is effective in modifying cardiovascular mechanisms related to arterial stiffness in the aging process.

The literature search was conducted between April and October 2024 by two independent authors (VTA and BF). The following electronic databases were consulted: Scopus (Elsevier), Google Scholar, Medical Literature Analysis and Retrieval System Online (MEDLINE, accessed via the PubMed portal), and scientific articles published from January 2010 to October 2024 were considered for screening. Keywords in Portuguese and English were selected based on Medical Subject Headings (MeSH) descriptors, and the Boolean search syntax used was: aerobic exercise (exercício aeróbio) "OR" resistance exercise (exercício resistido) "AND" arterial stiffness (rigidez arterial) "OR" pulse wave velocity (PWV/VOP) "OR" benefits of exercise (benefícios do exercício) "AND" aging (envelhecimento). The sequence for study selection was as follows: 1) search by keywords and selection based on title relevance; 2) abstract review; 3) full-text review; and 4) final selection of studies for review.

Inclusion and exclusion criteria

For selection, experimental studies were required to achieve a score of ≥ 6 points on the Physiotherapy Evidence Database (PEDro) scale[15] (see Table 1).

The following inclusion criteria were applied: 1) Population: older adults (aged 60 years and older) with or without comorbidities; 2) Intervention: aerobic, resistance, and combined (aerobic + resistance) exercise; 3) Outcome: measurement of arterial stiffness before and after exercise interventions or comparison between groups; 4) Study Design: randomized controlled trials and cohort (longitudinal) studies.

The studies were reviewed and approved by two independent evaluators (VTA and BF). In cases of disagreement, a third evaluator (EGC) was consulted to reach a consensus. Studies were excluded if they were research projects, review articles (including systematic reviews and meta-analyses), experimental studies involving animals, studies involving participants younger than 60 years, or studies lacking arterial stiffness assessment.

Data analysis

The results of this systematic review are presented descriptively and qualitatively (for example, means and standard deviations). The summaries of the data are presented as tables and figures to facilitate comparison and interpretation.

Results

Electronic searches identified 17,533 articles. After screening by title and abstract, 56 articles were selected, of which 20 duplicates were removed. The full-text screening identified 56 articles, of which 19 were excluded because they were book chapters, systematic reviews, meta-analyses, or other types of study (thesis, dissertation or research project). Ultimately, a total of 16 articles were included in this review (Figure 1), with 9 presenting interventions involving aerobic exercise, 3 involving resistance exercise, and 4 involving combined exercise (aerobic + resistance), as summarized in Table 2.

Aerobic exercise

Nine studies using aerobic exercise/training protocols are detailed in Table 2. These studies involved a total sample of 452 individuals, primarily comprising older adults (n = 442, aged 58 ± 2 to 74 ± 5 years), including 185 men and 267 women. Notably, 8 of the selected studies exclusively focused on older women with hypertension (n = 100).

Among the participants, 407 were previously sedentary, while 45[16,17] were physically active, serving only as comparison parameters. Six studies assessed populations with chronic diseases, one study included obese individuals[18], and two studies involved participants with associated cardiovascular diseases[19,20]. Most studies evaluated the chronic effects of exercise, except for one[17], which assessed acute effects. All nine studies measuring aerobic exercise also evaluated arterial stiffness (central and/or peripheral) before and after interventions (pre and post), either in isolation[19] or alongside other associated variables[16-18,20-24].

Table 1 - Methodological validity scale (PEDro).

Author/Year	Eligibility	Random allocation	Allocation secrecy	Similar groups	Blinding subjects	Blinding therapist	Blinding evaluators	Main result in at least 85% of subjects	Treatment intention	Statistical comparison between groups	Point measure	PEDro score
Kawasaki et al. 2011	●	●	●	●	○	○	●	●	●	●	●	8/10
Madden et al. 2013	●	●	●	●	○	○	●	●	○	●	●	7/10
Vogel et al. 2013	●	●	○	●	○	●	●	●	●	●	●	8/10
Williams et al. 2013	●	●	○	●	○	●	●	●	●	●	●	8/10
Fujie et al. 2014	●	○	○	●	○	○	●	●	●	●	●	6/10
Fujie et al. 2015	●	●	○	●	○	●	●	●	●	●	●	9/10
Jablonski et al. 2015	●	●	●	○	●	●	●	●	●	●	●	9/10
Thiebaud et al. 2016	●	●	○	○	○	●	●	●	●	●	●	7/10
Fujie et al. 2017	●	○	○	●	○	○	●	●	●	●	●	6/10
Jefferson et al. 2016	●	●	○	●	○	●	●	●	●	●	●	8/10
Son et al. 2016	●	●	○	●	○	●	●	●	●	●	●	9/10
Perissou et al. 2016	●	●	○	○	○	●	●	●	●	●	●	7/10
Shiotsu et al. 2018	●	●	●	●	○	●	●	○	●	●	●	8/10
Wong et al. 2019	●	●	●	●	○	●	●	●	●	●	●	9/10
Bouaziz et al. 2019	●	●	●	●	○	●	●	●	●	●	●	9/10
Teixeira do Amaral et al. 2024	●	●	○	●	○	○	●	●	○	●	●	7/10

PEDro scale for methodological validity of the studies selected for this review. ●: Yes. ○: No.

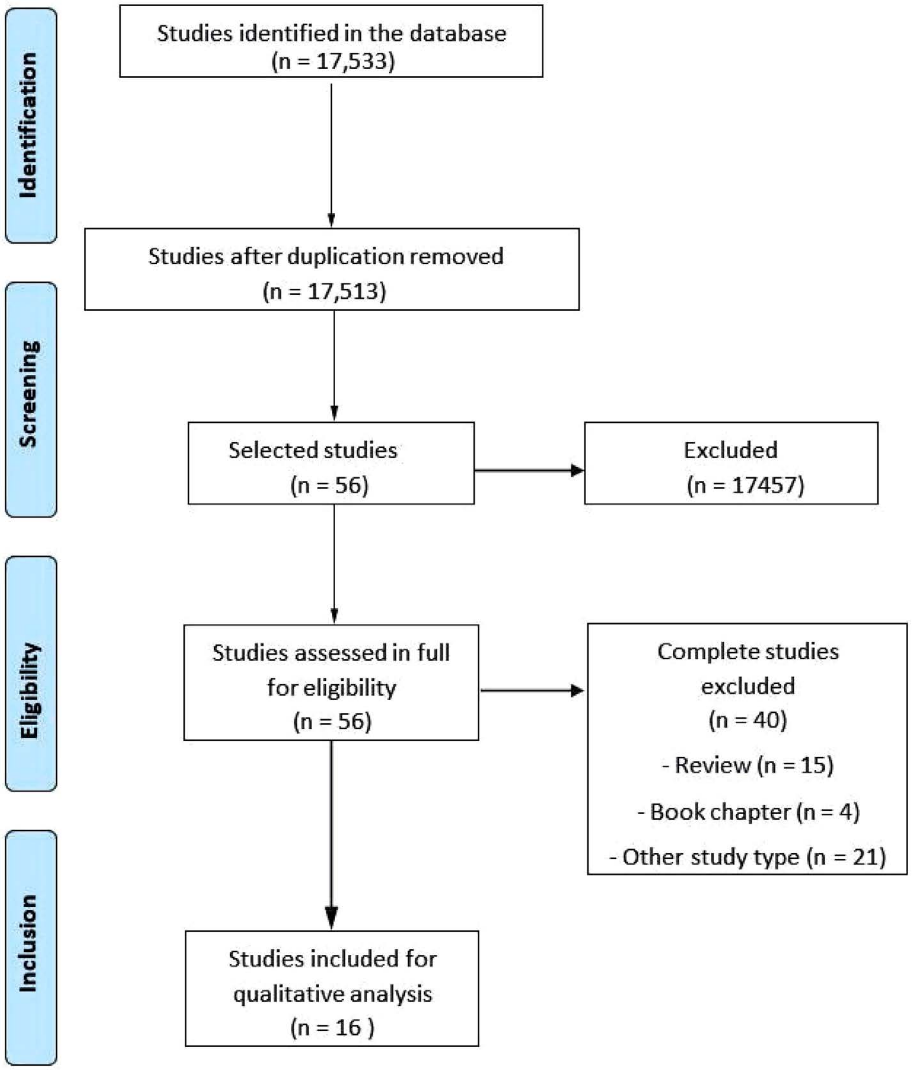

Figure 1 - Flowchart of study.

Among the nine studies, five reported improvements in arterial stiffness following the exercise protocols[17,19-21,24], while four indicated improvements attributed to changes in correlated cardiovascular variables, such as increased plasma levels of apelin and NOx[23] and decreased NF-kB signaling[16], as shown in Table 2.

Resistance exercise

Three studies focused on resistance exercise/training protocols[25-27], resulting in a general sample of 117 previously sedentary individuals[25,27] and physically active individuals[26].

The sample included 73 men and 44 women, predominantly older adults (n = 91, aged 60 years or older, from 66.7 ± 4.3 to 68 ± 3 years). Younger and middle-aged adults (n = 26) were included solely for comparative analysis[26]. Two studies included apparently healthy populations[26,27], while one study included obese individuals without restrictions on participation in exercise protocols[25]. Two studies evaluated the chronic effects of physical exercise[25,27], while one assessed acute effects[26].

All three studies assessed arterial stiffness (central and/or peripheral) before and after the interventions, regardless of the assessment methods or other measured variables[25-27]. Although two studies did not show significant changes in arterial stiffness across the entire sample[26,27], one study reported a minimal reduction in arterial stiffness specifically in women[27].

The study by Jefferson et al.[25]did not show direct differences in arterial stiffness but indicated that physical exercise led to reductions in body weight, consequently improving arterial elasticity.

Combined exercise (aerobic + resistance)

Four studies focused on combined exercise/training protocols (aerobic + resistance)[28-31], resulting in a total

Table 2 - Studies assessing the effects of aerobic, resistance, and combined exercise on arterial stiffness.

Author(s)/ year/design	Sample	Sex (M/F)	Group	Variables	Type	Time	Exercise protocol	Results/outcomes
Madden et al. 2013/ RCT/ (Canada)	52 older sedentary individuals, with diabetes, hypertension and hypercholesterolemia	30m/ 22f	Aerobic n = 25, 68 ± 1 Control n = 27,70 ± 1	- PWV carotid-radial - PWV carotid-femoral	Aerobic	6 months	Vigorous aerobic exercise: 3 times/week, 60 min: 10 min warm-up + 40 min aerobic training (60-75% HRreserve) + 10 min stretching - All participants performed 3 assessments: pre, after 3 and 6 months of training.	↓ PWV in 3 months of aerobic but 6 months were not efficient to maintain ↓ PWV. ↑ of VO_2max
Vogel et al. 2013/ RCT/ (France)	71 older community-dwelling individuals	36m/ 35f	Aerobic n = 36, 67 ± 7	- PWV carotid-radial - PWV carotid-femoral - SBP and DBP	Aerobic	9 weeks	Cycle ergometer: Twice-weekly, 30 min. Each session involved 6 sessions to 5 min of AE, 4 min at the first ventilatory threshold alternating to cycle of 1 min at 90% of the maximum tolerated power.	↓ SBP, DBP and PWV carotid-femoral. Aerobic not reduce carotid-radial
Fujie et al. 2014/ RCT/ (Japan)	34 healthy middle-aged and older individuals	14m/ 20f	Aerobic n = 16, 66 ± 2 Control n = 16, 68 ± 1	-Plasma concentrations of apelin and nitrite / nitrate (NOx) - VO_2peak - Arterial stiffness index (carotid)	Aerobic	8 weeks	Cycle ergometer: 3 times/week, 55 min each session: 5 min warm-up + AE at 60-70% peak oxygen consumption VO_2peak) + 5 min cool-down	↑ Plasma levels of apelin and NOx. ↓ PWV Plasma level of apelin was negatively correlated with β-carotid stiffness and was also positively correlated with NOx level in plasma
Fujie et al. 2015/ RCT/ (Japan)	40 healthy older and middle-aged individuals	14m/ 26f	Aerobic n = 28, 67 ± 1 Control n = 12, 68 ± 2	- VO_2Peak - β-carotid stiffness index - Plasma NOx concentrations -Serum adropine - Levels of cholesterol and triglycerides	Aerobic	8 weeks	Cycle ergometer: 3 times/week, 55 min. 5-min warm-up + peak of 40% VO_2 each session, reduced by 45 min of cycling to a resistance that caused 60-70% VO_2peak, and ended with a period of 5 min at 40% VO_2peak	↑ Level of serum adropine. The adropine level, altered by exercise, contributes to reduced arterial stiffness via increased NOx bioavailability
Jablonski et al. 2015/ RCT/ (USA)	31 sedentary individuals	22m/ 9f	Young sedentary: n = 10, 23 ± 1 Middle age and sedentary older: n = 9, 61 ± 2 Middle age and trained older: n = 12, 58 ± 2	- Body mass index - SBP and DBP -Total plasma, cholesterol, LDL and HDL, triglycerides - VO_2max (spirometry) - PWV carotid-femoral	Aerobic	3 days	All received placebo and salsalate (inhibitor of NFkB signaling) -The middle age and trained older group performed Aerobic exercise at least 4 times/week at high intensity for at least 2 years. -The sedentary youth group and the middle age and sedentary older group have not undergone	↑ PWV with age, but was 20% lower in individuals trained than sedentary - Inhibition of NFkB signaling can reduce arterial stiffness in middle-aged and older adults who regularly exercise. - Suppression of NFkB signaling in trained people may reduce the risk of cardiovascular events

(*continued*)

Table 2 - continued

Author(s)/ year/design	Sample	Sex (M/F)	Group	Variables	Type	Time	Exercise protocol	Results/outcomes
							physical training for at least 2 years.	
Fujie et al. 2017/ (cross-sectional)/ (Japan)	13 obese older individuals	4m/ 9f	Aerobic: n = 13, 65 ± 2	- VO_2peak - β-carotid stiffness - Body fat (%) - SBP, DBP and HR - Plasma NOx and adropine -Total cholesterol, HDL, triglycerides and fasting blood glucose	Aerobic	8 weeks	Cycle ergometer: 3 times/week, 55 min. 5 min warm-up + 40% VO_2peak, followed by 45 min of cycling to cause 60-70% VO_2peak + 5 min 40% VO_2peak	↑ Serum levels of adropine Increase of serum levels of adropine in obese adults were correlated with changes induced by training in carotid β-stiffness, plasma NOx level and abdominal visceral fat
Perissiou et al. 2018/ RCT / (Australia)	51 older individuals	42m/ 9f	VO_2peak (mL.kg^{-1}. min^{-1}) Low: 22.3 ± 3.1 n = 17, 74 ± 5 Medium: 27.5 ± 2.4 n = 17, 69 ± 4 High: 36.3 ± 6.5 n = 17, 70 ± 6	- PWV - Magnification index (AIx) - Magnitude of reflection (MR)	Aerobic	Acute	Acute exercise: 1 control session, 1 continuous AE session at moderate intensity (40% of VO_2peak) and high intensity interval AE session (70% of VO_2peak) - All variables were measured at rest and during 90 min after each protocol	PWV ↑ at rest and ↓ after an interval of greater exercise intensity, regardless of the level of physical fitness
Wong et al. 2019/ RCT / (Korea)	110 hypertensive older females sedentary in the post menopause	110f	Aerobic n = 52, 74 ± 4 Control n = 48, 73 ± 4	- SBP and DBP - PWV carotid-brachial - AIx- Body fat (%)- Handgrip strength - VO_2max	Aerobic	20 weeks	Swimming: 3-4 times/week (5 weeks: 25 to 30 min at 60% of HR_{MAX}, after 5 weeks, it evolved to 40-45 min at 70-75% of HR_{MAX}). The intensity was controlled by a frequency-meter	↓ PWV, wave reflex, SBP and DBP ↑ Isometric muscle strength and cardiorespiratory capacity
Bouaziz et al. 2019/RCT/ (France)	60 sedentary older	16m/ 44f	Aerobic n = 30, 73 ± 2 Control n = 30, 74 ± 3	- Endothelial Function - PWV carotid-radial - PWV femoral carotid - SBP, DBP and HR - Anthropometric	Aerobic	9.5 weeks	Cycle ergometer: Twice-weekly, 30 min (6 × 4 min on the first ventilatory threshold) + 1 min at 40% of the first ventilatory threshold on	↓ SBP, DBP and Endothelial Function
Williams et al. 2013/ RCT/ (Australia)	49 sedentary older	23m/ 26f	Resistance n = 25, 67 ± 4 Flexibility n = 24, 66 ± 4	- Brachial PWV- Central BP	Resistance	16 weeks resistance x 4 weeks (resting) x 16 weeks flexibility exercise	Resistance: Twice weekly, 2-3 sets of 4 exercises (8-12 reps); prog.: 3 sets of 5 functional bodyweight exercises after 5 weeks. Flexibility: Twice weekly, static stretching (≥2 exercises per muscle group); prog.: 12 full-body stretching exercises after 5 weeks.	↓ PWV only in female

(*continued*)

Table 2 - continued

Author(s)/ year/design	Sample	Sex (M/F)	Group	Variables	Type	Time	Exercise protocol	Results/outcomes
Thiebaud et al. 2016/ RCT/ (USA)	36 active males	36m	Young: n = 12, 26 ± 3 Adults: n = 14, 49 ± 6 Older: n = 10, 67 ± 6	- Brachial PWV - Central BP - Central and peripheral PWV	Resistance	Acute exercise/ 3 days inter-intervention	Acute exercise: Leg press, bench press, knee flexion, pull down and knee extension at ~ 65% of 1RM for 3 sets of 10 repetitions - All participants performed to control and exercise conditions	A single session of resistance exercise of moderate intensity does not affect brachial and central BP, as well as PWV regardless of age
Jefferson et al. 2016/ RCT/ (USA)	32 older obese and sedentary	14m/ 18f	Resistance n = 16, 68 ± 3 Resistance + caloric restriction: n = 16, 69 ± 3	- Brachial-ankle PWV -Higher arterial elasticity and lower arterial elasticity- Waist circumference	Resistance	5 months	Resistance: 3x/week, 5 min warm-up + 70% 1RM for main muscles; others until 2×10 reps with load. Resistance + calorie restriction: Same training with a 600 kcal/day deficit.	Resistance + caloric restriction led to a modest weight ↓ and tended ↑ the elasticity of the larger artery compared to the Resistance alone. Reductions in waist circumference and BP can promote improvements in the elasticity of arteries.
Kawasaki et al. 2011/ RCT/ (Japan)	57 sedentary and clinically healthy older individuals	22m/ 35f	Aerobic + Resistance n = 35, 61 ± 1 Control n = 22, 63 ± 1	-Anthropometric- Body fat (%)- SBP and DBP- PWV carotid-femoral- PWV brachial-ankle- Plasma glucose, HbA1c, serum lipid profile, electrolytes and body sway	Aerobic + Resistance	6 months	Twice-weekly, 2 hours (5-10 min stretching + 20 min exercise bike + 10 min resistance on the ground + 40 min walk in the heated pool against a source of water flow (0.9m / s) + 20 minutes of swimming in still water (50% of $HR_{RESERVE}$)	↓ PWV brachial-ankle↓ SBP and DBP ↓ Body sway
Son et al. 2016/RCT/ (Korea)	20 postmenopausal females with stage I hypertension and sedentary	20f	Aerobic + Resistance n = 10, 75 ± 2 Control n = 10, 76 ± 5	- PWV brachial-ankle - SBP and DBP - Nitrite/nitrate - Endothelin-1 -Physical fitness (sit and stand, push-up, sit and reach, agility test and 6 min walk test) -Body composition -Cardiovascular capacity	Aerobic + Resistance	12 weeks	3 times/week, 60 min. (10 min. warm-up, 20 min of resistance and 30 min. of aerobic). The intensity was gradually increased from 40% to 70% of $HR_{RESERVE}$ every 4 weeks	↓ BP ↓PWV ↓Endothelin-1 ↑ Nitrite/nitrate levels ↑ Strength and functional capacity Improved cardiovascular health and muscular strength
Shiotsu et al. 2018/ RCT/ (Japan)	45 older community dwelling without uncontrolled and sedentary pathologies	45m	Aerobic before Resistance: n = 16, 70 ± 4 Resistance before aerobic: n = 16, 69 ± 5 Control n = 13, 71 ± 4	- PWV carotid-femoral - Endothelial Function - SBP and DBP - Physical fitness (handgrip, walking speed of 10 m, TUG, balance test, functional reach test and sit and reach) – Anthropometric - Muscle strength (1 RM)	Aerobic + Resistance	10 weeks	Aerobic before Resistance *versus* Resistance before Aerobic: Twice-weekly, 3 sets of 8 to 12 repetitions for 5 different exercises and 70 to 80% of a 1RM + bicycle at 60% of $HR_{RESERVE}$	Aerobic before Resistance ↓PWV ↓Endothelial Function Both: ↓ Waist circumference ↑ Strength ↑ Ability to walk Combining aerobic exercise with high-intensity resistance training in the same session may positively affect arterial stiffness

(*continued*)

Table 2 - continued

Author(s)/ year/design	Sample	Sex (M/ F)	Group	Variables	Type	Time	Exercise protocol	Results/outcomes
Teixeira do Amaral et al. 2024/ RCT / (Brazil)	92 low-income older females	92f	HIIT+RT, n = 34, 75 + 6 MICT+RT, n = 38, 74 + 6	-PWV carotid-femoral-SBP, DBP, HR, - Functional capacities (handgrip strength, flexibility, TUG, sit-and-reach test, 6MWT)	Aerobic + Resistance	9 months	9 months of HIIT+RT or MICT+RT, twice-weekly. HIIT: 7 sets of 1 to 2 min of 15-17 RPE MICT: 30 minutes of walking in 11-13 RPE RT: 3 sets of 15 repetitions	HIIT+RT: ↓ PWV ↓ SBP HIIT +RT and MICT+RT: ↓ Waist circumference ↑ Functional capacity

MWT: 6-minutes walking test. AIx: Magnification index. BP: blood pressure. DBP: diastolic blood pressure. HbA1c: glycated hemoglobin. HDL: high-density lipoprotein. HR: heart rate. HIIT + RT: high-intensity interval training combined with resistance training. LDL: low-density lipoprotein. M/F: male/female. MICT + RT: moderate intensity continuous training combined with resistance training. 1RM: 1-repetition maximum. NF-kB: factor nuclear kappa B. NOx: Nitric oxide. PWV: pulse wave velocity. RCT: randomized clinical trials. SBP: systolic blood pressure. TUG: timed up and go. VO_{2max}: maximum volume oxygen.

sample of 194 previously sedentary individuals, including 67 men and 127 women aged 60 years or older (from 61.5 ± 0.8 to 75.3 ± 1.2 years).

Two studies involved clinically healthy participants[28,31], while two studies included stage one hypertensive patients with associated and controlled pathologies; there were no restrictions or limitations on participation in the exercise protocols[29,30].

All four studies assessed the chronic effects of physical exercise and evaluated arterial stiffness (central and/ or peripheral) before and after the interventions, regardless of measurement methods or other variables assessed[28-31]. These studies consistently reported reductions in arterial stiffness following combined exercise interventions, despite differences in exercise intensity. The main findings of this review can be observed in Figure 2.

Discussion

The findings of the current review highlight the significant impact of various forms of exercise on arterial stiffness, particularly in older adults. The study by Madden et al.[19] demonstrated a reduction in arterial stiffness after three months of high-intensity training in sedentary older individuals with cardiovascular diseases. However, this effect was not maintained after 6 months, despite improvements in VO_{2MAX}[19].

This suggests that while exercise can confer short-term benefits, the underlying pathophysiological changes associated with aging and cardiovascular risk may limit the long-term efficacy of such interventions. The progressive and often irreversible stiffening of arteries in high cardiometabolic risk populations is influenced by factors such as increased collagen concentration, non-enzymatic glycation, and hypertrophy of vascular smooth muscle[32,33]. In this context, long-term exercise interventions are of paramount importance to a better understanding of its benefits on arterial stiffness and underlying pathophysiological mechanisms, as well as for reducing the risk of all-cause mortality and the burden of non-communicable diseases[1].

Aerobic exercise appears to offer better outcomes for glycation, facilitating the breakdown of collagen cross-links and enhancing the production of NOx, which promotes vasodilation[32]. This could explain the initial reduction in arterial stiffness, although it may not be sustainable long-term.

In another relevant study involving postmenopausal hypertensive women, Wong et al.[20] found that aerobic training in a heated pool over 20 weeks led to reductions in brachial arterial stiffness and improvements in muscle strength and VO_{2MAX}[20]. The unique environment of pool-based exercise, which offers greater resistance for the upper limbs, may enhance local endothelial function[34],

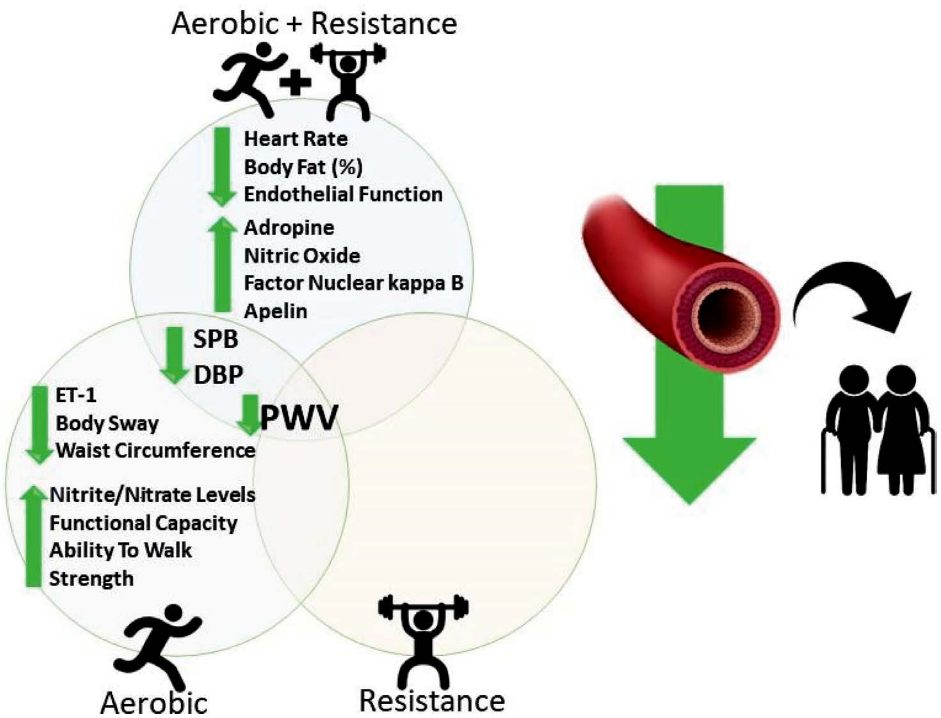

Figure 2 - Benefits of aerobic, resistance and combined exercise on arterial stiffness in older people. DBP: diastolic blood pressure. ET-1: edothelin-1. PWV: pulse wave velocity. SBP: systolic blood pressure.

providing additional insights into the mechanisms by which exercise affects arterial health.

Fujie's studies[18,22,23] further elucidate the complex relationship between exercise and vascular function. Their findings suggest that continuous moderate-intensity training can positively affect plasma levels of apelin and NOx, which play crucial roles in promoting vasodilation and reducing arterial stiffness. Specifically, increased bioavailability of NOx may counteract the decline in endothelial function associated with aging, even when apelin levels decrease[35]. This emphasizes the importance of maintaining endothelial health through regular exercise.

Moreover, the work by Jablonski et al.[16] indicates that aerobic exercise can inhibit NF-kB signaling, which is linked to inflammation and arterial stiffness. By inducing an anti-inflammatory response, regular exercise may reduce the risk of cardiovascular events, further supporting the recommendation for aerobic training as a primary intervention for improving vascular health.

Resistance exercise

Resistance exercise has shown promise in enhancing muscle strength and addressing risk factors for cardiovascular and metabolic diseases across all age groups[2]. This type of training is effective for increasing muscle mass and strength, even when initiated later in life[36], and it also aids in maintaining bone mineral density, which declines with age[37]. Furthermore, resistance training has been linked to improved insulin sensitivity and increased daily energy expenditure[38,39].

However, the relationship between resistance exercise and arterial stiffness remains unclear. Some studies reported no significant effects on arterial stiffness with low- to moderate-intensity resistance training[40,41], while others suggested that high-intensity resistance training may temporarily elevate arterial stiffness[41]. This discrepancy may be attributable to differences in training protocols and population characteristics.

In the present review, it was noted that 60% of the studies examining one-repetition maximum (1 RM) in young, active, and older individuals found no significant changes in arterial stiffness[26]. Factors such as autonomic nervous system imbalances during and post-exercise, which can elevate arterial stiffness[42], and changes in endothelial function due to increased levels of endothelin-1 (ET-1) also warrant consideration[43].

Despite some evidence suggesting no changes in arterial compliance with progressive resistance training[44], the present review identified improvements in arterial stiffness in sedentary older women[27]. This finding reinforces the necessity for more nuanced studies to clarify the effects of resistance exercise on arterial stiffness, particularly in older adults with comorbidities.

Combined exercise (aerobic + resistance)

The integration of aerobic and resistance training is posited to offer synergistic benefits for arterial health. Studies indicate that moderate-intensity combined training for 12 weeks can lead to significant improvements in arterial stiffness and overall hemodynamic profiles in populations such as postmenopausal women[45]. The findings from the present review support this, with evidence that aerobic and resistance exercise together reduced arterial stiffness, mean arterial pressure, and enhanced endothelial function in older adults[30].

Interestingly, some studies have reported that performing aerobic exercise after resistance training may mitigate arterial stiffness typically induced by the latter[46]. This may be particularly beneficial for older adults who are more susceptible to the adverse effects of resistance exercise alone.

As highlighted in the literature, factors such as age, hypertension, diabetes, and renal impairment significantly impact PWV[47,48]. The effects of gender on arterial stiffness also present a complex picture, with varying findings regarding the rate of increase in stiffness across sexes[47,49].

The studies discussed here underscore the importance of tailoring exercise regimens that consider individual health profiles, particularly in older populations who face various cardiovascular risks.

Study limitations

This systematic review encountered limitations due to the heterogeneity of the exercise interventions, participant characteristics, and assessment methodologies for arterial stiffness. Variations in aerobic, resistance, and combined exercise protocols, along with the demographic diversity of participants (age, gender, health status), hindered the ability to conduct a meta-analysis. Future intervention studies should strive to standardize these variables to facilitate more robust comparisons and conclusions regarding the effects of exercise on arterial stiffness.

Conclusion

In summary, despite some non-significant findings, this review suggests that long-term aerobic exercise (both interval and continuous; high and moderate intensity), low to moderate intensity resistance exercise, and primarily combined exercise can improve or maintain arterial stiffness values in individuals aged 60 years and older, regardless of health status. These findings support the promotion of diverse exercise programs for the prevention and management of cardiovascular and metabolic diseases, ultimately aiming to reduce mortality rates associated with these conditions. However, further studies are warranted to better elucidate the intricate relationships between exercise modalities and arterial health during the aging process.

Contribution to the field statement

Arterial stiffness, a critical indicator of vascular health, typically worsens with aging, exacerbated by factors such as hypertension, diabetes, dyslipidemia, and obesity. This study presents key assessments for measuring arterial stiffness and elucidates its significance in cardiovascular and metabolic disease risk. Our findings indicate that physical exercise, regardless of modality or intensity, can enhance arterial health in older adults. The implications of these results highlight the necessity for implementing structured exercise interventions aimed at improving cardiovascular health and mitigating the risks associated with aging and chronic disease.

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