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Review article

Effects of Resistance Training on Arterial Stiffness in Healthy People: A Systematic Review

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Abstract

The influence of aerobic training on cardiovascular disorders has already been demonstrated. However, the effect of resistance training is less well known. Arterial stiffness is an increasingly important measure in cardiovascular health. Therefore, this review attempted to study the results of resistance training-based interventions on arterial stiffness in healthy people, for both acute and chronic interventions. A literature search was conducted for randomized controlled trials on the acute and chronic effects of strength training. Studies published in PubMed and SportDiscus databases between 1999 and April 2019 were analyzed. In chronic strength training effects, the majority of groups showed large (d = -1.49 to -1.20) and moderate (d = -1.07) decreases, and small and trivial changes in arterial stiffness. In acute effects interventions, a very large decrease (d = -3.92) was observed, while large (d = 1.24-1.48) and very large (d = 3.88) increases were also found. A resistance training-based intervention of more than four weeks' duration with a frequency of two days per week seems not to compromise cardiovascular health, due to decreases in arterial stiffness. However, there is a general trend towards both increasing and maintaining arterial stiffness after isolated strength training sessions.

Key words: Resistance training, arterial stiffness, cardiovascular health, chronic effects, acute effects.

Introduction

Arterial stiffness is a significant measure for predicting cardiovascular health (Nitzsche et al., 2016). It increases with age and may have negative consequences for the cardiovascular system because of the risk of developing hypertension, increasing the size of the left ventricle, and developing other heart diseases (Thiebaud et al., 2015). In addition, hypertension has now become the leading cause of cardiovascular disease and mortality, and there is a two-way relationship between hypertension and arterial stiffness (Li et al., 2015).

Arterial stiffness can be quantified by calculating the pulse wave velocity (PWV), obtained from a pulse wave analysis (PWA) (Nitzsche et al., 2016). In fact, arterial stiffness and PWV are directly proportional (i.e. an increase in the latter indicates greater arterial stiffness) (Laurent et al., 2006). There are several ways of measuring PWV: (a) the pulse wave velocity between the carotid and femoral arteries (cfPWV) (Mattace-Raso et al., 2010); (b) the pulse wave velocity between the ankle and the brachial artery (baPWV); or (c) the aortic pulse wave velocity (aPWV). The last two are considered reliable predictors of cardiovascular risk and mortality (Laurent et al., 2006). On the other hand, the augmentation index (AIx) is a measure of central pulse wave analysis that indirectly indicates levels of arterial stiffness. Also, the higher the AIx, the higher the pulse wave velocity and, therefore, the stiffer the arteries (Laurent et al., 2006). Indeed, the higher the PWV or cardio-ankle vascular index (CAVI) value, the greater the arteries' stiffness. It has been shown that an increase of 1m/s in cfPWV increases the risk of cardiovascular mortality by 15% (Vlachopoulos et al., 2010), and an equal increase in baPWV would increase the risk by 13% (Vlachopoulos et al., 2012). More arterial stiffness reference values have also been published (Mattace-Raso et al., 2010).

Physical exercise has been recommended as an ideal non-pharmacological intervention to prevent and treat cardiovascular disorders (Figueiredo et al., 2015). More concretely, resistance training and aerobic training are the two most frequently prescribed types of physical activity. Aerobic training has been shown as a good strategy to improve arterial stiffness (Otsuki et al., 2006; Sugawara et al., 2006; Tanaka et al., 2000). In contrast, less information is available on the consequences of resistance training on the cardiovascular system (Thiebaud et al., 2015). Resistance training is defined as an activity in which voluntary, brief and repeated contractions occur against greater resistance than that usually encountered in daily life (Li et al., 2015). This type of training leads to muscular power and strength improvements through mechanisms such as an increase in the voluntary activation of the trained musculature or changes that occur in the cross-sectional muscle area and fibers (Karavirta et al., 2011). Therefore, from the health point of view, resistance training is postulated as a fundamental factor to consider (Devries and Phillips, 2014).

Resistance training may be an essential element in the control of hypertension and cardiovascular risk, as it produces acute reductions in blood pressure, an effect known as post-exercise hypotension (Figueiredo et al., 2015). However, resistance training may also cause a short-term increase in arterial stiffness (Kingsley et al., 2016). In addition, several studies show a high increase in arterial stiffness in middle-age men undertaking resistance

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training, in terms of chronic effects (Thiebaud et al., 2015).

Although exercise may be helpful in a long term to keep a good arterial health, arteries progressively stiffen in older humans, while the amount of connective tissue and collagen fibers increase. The exercise has an impact on endothelial function and inflammation, all of which positively affect arterial stiffness (Sandri et al., 2016). Overall, recent research in this field shows a wide variety of results, with many discrepancies between them (Nitzsche et al., 2016). A literature analysis is needed to determine the status of the issue and promote future research that allows researchers, trainers, coaches and practitioners to develop better training plans and practices for a population-based approach. Therefore, the aim of this review was to gather evidence, based on RCTs (randomized controlled trials), about the effect of resistance training on arterial stiffness, in both acute and chronic interventions in healthy people.

Methods

Search strategy

A systematic search was conducted for studies investigating the effects of resistance training on arterial stiffness parameters. The searching process was done between February and April 2019. The first and second author performed this process. Papers published between 1999 and April 2019 in PubMed and SportDiscus databases were collected. The search strategy was: ("resistance training" OR "strength training" OR "weight training") AND ("arterial stiffness" OR "arterial elastance" OR "pulse wave velocity" OR "PWV" OR "brachial-ankle pulse wave velocity" OR "baPWV" OR "wave reflection"). The indicators of the PRISMA statement were followed.

The first two authors did data identification, selection and extraction. All data was registered in an Excel file. Also, if any disagreement existed, it was discussed between the researchers. Moreover, the studies' references were reviewed in order to find further studies of potential interest, but all the articles were found with the keywords used from the beginning.

Retrieved articles selection

The information was organized into: (a) studies that used a load based on free weights, resistance machines, elastic bands or combined training (free weights, bodybuilding and/or weight machines); (b) studies performed with the main muscle groups of the upper body train, lower body train, or both (full body); (c) studies with or without blood flow restriction (BFR); (d) eccentric or concentric muscle contraction; (e) low, medium or high intensity; and (f) periodic or continuous loads. With regard to arterial stiffness, this review includes studies of central, peripheral or systemic arterial stiffness. Specifically, measures of central arterial stiffness were: carotid femoral pulse wave velocity (cfPWV); aortic pulse wave velocity (aPWV); and augmentation index (AIx). In terms of peripheral arterial stiffness, pulse wave velocities between ankle and femoral (faPWV) and femoral and tibial arteries (ftPWV) were considered. Finally, heart-ankle vascular index (CAVI) and pulse wave velocity between the ankle and the brachial arteries (baPWV) were the measures of systemic arterial stiffness.

Inclusion criteria

Original RCTs that carried out an intervention based on resistance training were included. They all had a sedentary control group (that did not practice regular physical activity or had a sedentary control phase) or another resistance training group as a control. The included studies either performed single-session interventions (acute effects), or a minimum of four weeks with a frequency of at least two days per week (chronic effects), which is the shortest period necessary for structural and neuronal adaptations (Kraemer and Ratamess, 2004). All subjects who participated in the studies were healthy, normotensive, and had a BMI (body mass index) in the normal range. In addition, they lacked any other pathology or health contraindication that prevented sports practice.

Exclusion criteria

Bibliographic reviews, meta-analyses, letters to the editor, comments or abstracts were excluded, as well as those articles written in any language other than English. Were also excluded studies that: (a) did not perform any intervention (or did not define it in detail); (b) performed other kinds of training in addition to resistance training; (c) did not have a defined control group; (d) did not present data on arterial stiffness before and after the intervention; or (e) had a cross-sectional design.

Quality assessment

The quality of the studies was assessed using the Tool for the Assessment of Study Quality and reporting in Exercise (Testex) (Smart et al., 2015), a specific assessment tool to measure the quality of studies about exercise and training. The studies included in this review had a minimum score of 10 points out of the possible maximum of 15 (Table 1).

Data extraction

The following data were extracted from articles: first author, year of publication, sample size (N), characteristics of the sample (mean, age and gender), resistance training program (intensity, duration, frequency, kind of training and main muscle groups used), arterial stiffness measurements, effects of arterial stiffness training (pre- and post-intervention measures), effect size (Cohen's d) and Testex scale assessment. Information about neither frequency nor duration was shown in the acute-effects studies approach. The magnitude threshold for ES was set at 0–0.2 trivial, > 0.2–0.6 small, > 0.6–1.2 moderate, > 1.2–2 large and > 2 very large (Hopkins et al., 2009). The intensity of training was indicated in two ways: (a) as a percentage of 1 RM (maximum repetition); or (b) as sub-maximal RM tests (e.g. 8 RM or 12 RM). This intensity was categorized as low (<50% 1RM), moderate (50-69% 1RM) or vigorous (>70% 1RM) (Garber et al., 2011). The measurement of arterial stiffness was performed in the supine position and after a period of absolute rest.

Table 1. Studies assessment according to TESTEX.

Items	1	2	3	4	5	6	7	8	9	10	11	12	Total
Chronic effects													
Au et al. (2017)	1	1	1	1	-	2	1	2	1	1	1	1	13
Casey et al. (2007)	1	-	1	1	1	2	1	2	1	-	1	1	12
Cortez-Cooper (2005)	1	-	1	1	-	2	1	2	1	1	1	1	12
Okamoto et al. (2015)	1	1	1	1	1	2	1	2	1	1	1	1	14
Clark et al. (2011)	1	1	1	-	-	1	1	2	1	-	1	1	10
Fahs et al. (2014)	1	1	1	1	-	2	1	2	1	1	1	1	13
Raj et al. (2012)	1	1	1	1	-	1	1	2	1	1	1	1	12
Yasuda et al. (2015)	1	-	1	1	-	1	1	2	1	1	1	1	11
Yasuda et al. (2014)	1	1	1	1	-	2	1	2	1	1	1	1	13
Okamoto et al. (2009a)	1	1	1	1	-	2	1	2	1	1	1	1	13
Acute effects													
Nitzsche et al. (2016)	1	-	1	1	-	2	1	2	1	1	-	1	11
Kingsley et al. (2017)	1	1	1	1	-	3	1	2	1	1	1	1	14
Lefferts et al. (2015)	1	1	1	1	-	1	1	2	1	1	1	1	12
Augustine et al. (2014)	1	1	-	1	-	2	1	2	1	1	1	1	12
Okamoto et al (2014)	1	1	1	1	-	2	1	2	1	1	1	1	13
Yoon et al. (2010)	1	1	1	1	-	2	1	2	1	-	-	1	11

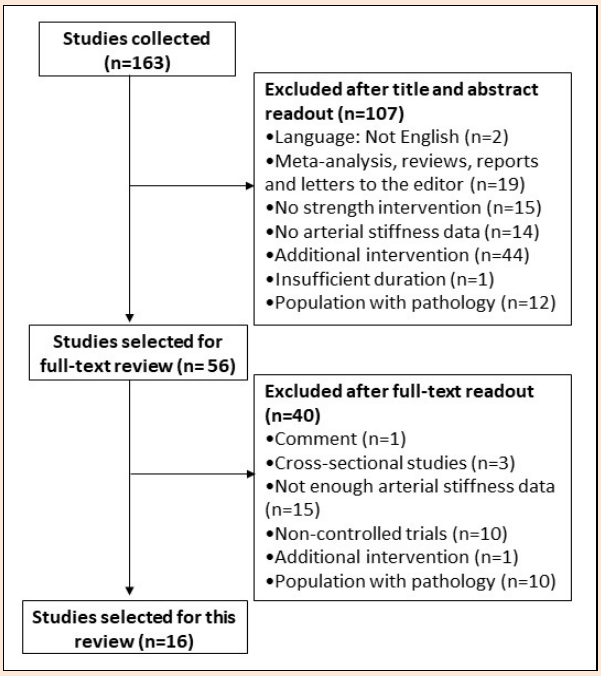

Figure 1. Flow chart of the article selection process.

Results

The literature search provided 163 relevant studies, of which 16 met the inclusion criteria. Figure 1 shows the selection process for the articles and the reasons for their exclusion. Of the selected studies, 10 investigated the chronic effects of resistance training on arterial stiffness, and the remaining six analyzed acute effects.

Table 2 presents the main characteristics of the studies, as well as their quality evaluation and the arterial stiffness results, in terms of chronic and acute effects. With regard to chronic effects and their evaluation in terms of central arterial stiffness, the only measure included was carotid femoral pulse wave velocity (cfPWV) (Au et al., 2017; Casey et al., 2007; Cortez-Cooper et al., 2005). A combined training using full body musculature promoted small changes in arterial stiffness (d = -0.57-0.46) at vigorous intensities (Au et al., 2017; Cortez-Cooper et al., 2005) while a moderate decrease (d= -1.07) was found at low intensities (Au et al., 2017). Nevertheless, a large decrease (d = -1.20) was found in machine-based training at vigorous intensities (Casey et al., 2007).

For peripheral arterial stiffness, both faPWV and ftPWV measurements were taken into consideration. The major changes were found in BFR training situations, using machines for training leg muscles at low intensity (d = -1.49 and 0.71, respectively) (Clark et al., 2011; Fahs et al., 2014) or in trainings without BFR, but at vigorous intensity (d = -0.73) (Clark et al., 2011). Trivial and small changes (d = -0.48-0.22) were found for training the upper or full body, regardless of the intensity, periodization or type of muscle contraction (Clark et al., 2011; Fahs et al., 2014; Okamoto et al., 2015; Raj et al., 2012).

To assess systemic arterial stiffness, CAVI and baPWV measurements were used. Combined training promoted the highest changes (d = 3.05) (Okamoto et al., 2009a) comparing with training with elastic bands (d = -0.40-0.26) (Yasuda et al., 2015) or machines (d = -0.10) (Yasuda et al., 2014), when the exercise involved upper body muscles and was done in a vigorous manner.

With regard to acute effects, all the studies involved measurements of central arterial stiffness (Table 2). The highest increase in arterial stiffness was found with combined training strategies (d = 3.88) (Yoon et al., 2010). The use of free weights for upper body muscle training showed a very large arterial stiffness decrease (d = -3.92) at lower intensities (Okamoto et al., 2014), while the same training exhibited small (d = 0.40) and large increases (d = 1.48) at vigorous intensities (Augustine et al., 2014; Lefferts et al., 2015).

When free weights were used for the full body musculature, the higher the intensity, the lower was the arterial stiffness increase. Small (d = 0.38) and moderate (d = 0.71) increases were found at vigorous intensities (Kingsley et al., 2017; Nitzsche et al., 2016); moderate increases (d = 1.09) at medium intensity, and large increases at low intensity (d = 1.24) (Nitzsche et al., 2016).

The details about days of training, number of exercises, sets, repetitions, intensity and rest intervals were presented in Table 3.

Table 2. Characteristics of the RCTs.

Study	N	Age	Gender	Weeks	Days/ Week	Group (N) Treatment	Arterial Stiffness Outcome	Pre/Post Results	Effect size *(d)*
Au et al. (2017)	46	23 ±2	Male	12	2	G1 (16) CB, FB, LI	cfPWV	6.4±0.7/5.7±0.6 m/s	-1.07
						G2 (16) CB, FB, VI		6.2±0.6/5.8±0.8 m/s	-0.57
						G3 (14) NS		5.9±0.7/6.0±0.7 m/s	0.14
Casey et al. (2007)	42	21.4 ±0.6	Male/ Female	12	3	G1 (24) MA, FB, VI	cfPWV	6.5±0.14/6.3±0.19 m/s	-1.20
						G2 (18) NS		6.9±0.15/7.0±0.16 m/s	0.65
Cortez-Cooper et al. (2005)	33	28.4 ±1.3	Female	11	4	G1 (23) CB, FB, VI	cfPWV	7.91±0.88/8.33±0.96 m/s	0.46
						G2 (10) NS		7.24±0.83/7.80±0.66 m/s	0.75
Okamoto et al. (2015)	18	23 ±1	Male/ Female	16	3	G1 (9) CB, UT, VI, CT	faPWV	8.71±0.31/8.55±0.35 m/s	-0.48
						G2 (9) CB, UT, VI, PT		8.46±0.34/8.49±0.35 m/s	0.09
Clark et al. (2011)	16	24.0 ±1.6	Male/ Female	4	3	G1 (9) MA, LT, LI, BF	faPWV	9.26±0.39/8.73±0.32 m/s	-1.49
						G2 (7) MA, LT, VI		8.19±0.27/7.94±0.40 m/s	-0.73
Fahs et al. (2014)	32	55 ±7	Male/ Female	6	3	G1 (16) MA, LT, LI, BF	ftPWV	8.9±0.8/9.5±0.9 m/s	0.71
						G2 (16) MA, LT, LI		9.0±1.2/9.0±1.1 m/s	0
Raj et al. (2012)	25	68 ±5	Male/ Female	16	2	G1 (13) MA, FB, MI, ET	ftPWV	10.8±3.7/12.1±7.4 m/s	0.22
						G2 (12) MA, FB, VI, CT		14.5±10.3/16.0±10.8 m/s	0.14
Yasuda et al. (2015)	17	70.0 ±5.6	Male/ Female	12	2	G1 (9) EB, UT, BF	CAVI	8.9±1.2/9.2±1.1 m/s	0.26
						G2 (8) EB, UT		8.5±0.7/8.2±0.8 m/s	-0.40
Yasuda et al. (2014)	19	69.4 ±6.5	Male/ Female	12	2	G1 (9) MA, LT, LI	CAVI	9.1±1.4/9.0±0.5 m/s	-0.10
						G2 (10) NS		8.7±0.8/8.5±0.1 m/s	-0.35
Okamoto et al. (2009a)	30	20.1 ±0.4	Male/ Female	10	2	G1 (10) CB, UT, VI	baPWV	11.21±0.40/12.66±0.54 m/s	3.05
						G2 (10) CB, LT, VI		11.55±0.35/11.46±0.37 m/s	-0.25
						G3 (10) NS		no data	-
Nitzsche et al. (2016)	41	23.8 ±2.3	Male/ Female	-	-	G1 (10) FW, FB, LI	cfPWV	5.26±0.48/5.97±0.65 m/s	1.24
						G2 (15) FW, FB, MI		5.45±0.40/5.87±0.37m/s	1.09
						G3 (16) FW, FB, VI		5.30±0.45/5.48±0.50 m/s	0.38
Kingsley et al. (2017)	52	23.0 ±0.5	Male/ Female	-	-	G1 (26) FW, FB, VI	aPWV	5.3±0.7/5.8±0.7 m/s	0.71
						G2 (26) NS		5.4±0.7/5.3±0.6 m/s	-0.15
Lefferts et al. (2015)	40	24 ±4	Male/ Female	-	-	G1 (20) FW, UT, VI	aPWV	5.1±0.5/6.0±0.7 m/s	1.48
						G2 (20) NS		5.1±0.5/5.2±0.5 m/s	0.20
Augustine et al. (2014)	18	24 ±6	Male	-	-	G1 (9) FW, UT, VI	aPWV	5.4±0.5/5.6±0.5 m/s	0.40
						G2 (9) NS		5.6±0.7/5.5±0.6 m/s	-0.16
Okamoto et al. (2014)	20	26 ±5	Male/ Female	-	-	G1 (10) FW, UT, LI	AIx	-5±2/-15±3 %	-3.92
						G2 (10) NS		-4±2/-5±2 %	-0.50
Yoon et al. (2010)	26	20.8 ±2.2	Male	-	-	G1 (13) CB, FB, MI	AIx	-13.4±0.8/-10.3±0.8 %	3.88
						G2 (13) NS		-6.9±7.3/-9.4±6.0 %	-0.37

FW: free wheights; CB: combined; EB: elastic bands; MA: machines; FB: full body; UT: upper train; LT: lower train; LI: low intensity; MI: moderate intensity; VI: vigorous intensity; NS: no strength; CT: continuous training; PT: periodic training; BF: blood flow restriction; ET: eccentric training; CT: concentric training; aPWV: aortic pulse wave velocity; AIx: augmentation index; cfPWV: carotid femoral pulse wave velocity; faPWV: femoral ankle pulse wave velocity; CAVI: cardio-ankle vascular index; ftPWV: femoral tibial pulse wave velocity; baPWV: brachial ankle pulse wave velocity.

Discussion

The aim of this review was to gather evidence, based on RCTs, about the effect of resistance training on arterial stiffness, for both acute and chronic interventions in healthy people. In general, a reduction in arterial stiffness was found as a chronic training effect at lower intensities (Au et al., 2017; Clark et al., 2011; Yasuda et al., 2014). Therefore, low- and moderate-intensity long-term resistance training do not significantly alter arterial stiffness. In contrast, in terms of acute effects, lower intensities imply greater changes (higher arterial stiffness) (Nitzsche et al., 2016; Okamoto et al., 2014) compared to higher intensities (lower arterial stiffness) (Augustine et al., 2014; Kingsley et al., 2017; Lefferts et al., 2015; Nitzsche et al., 2016).

Analyzing the type of training revealed that training based on weight machines and elastic bands did not alter arterial stiffness (Casey et al., 2007; Clark et al., 2011; Yasuda et al., 2015). The largest changes occurred in those studies that used combined resistance training (Au et al., 2017; Okamoto et al., 2009a; Yoon et al., 2010) or free weights (Nitzsche et al., 2016; Okamoto et al., 2014). The slight disparity in results could be due to the fact that although the studies used relatively common strength protocols, it was difficult to eliminate the existing differences between them. Gender differences in the samples could also account for these results, especially since most of the groups used both men and women in their samples. Greater changes were found in terms of acute effect measurements (Okamoto et al., 2014; Yoon et al., 2010).

With regard to the main muscle groups used in strength intervention (upper body, lower body or full body), Okamoto et al. (2009a) specifically compared the differences between vigorous-intensity combined resistance training protocols for the upper and lower body.

Table 3. Details about training interventions.

	Weeks	Days/ Week	Exercises	Sets	Repetitions	Intensity	Rest interval (sec)
				Chronic effects			
Au et al. (2017)	12	2	5	3	20-25* / 8-12**	30-50% RM* / 75-90% RM**	60
Casey et al. (2007)	12	3	7	2	8-12	To failure	-
Cortez-Cooper (2005)	11	4	12	6	5	To failure	-
Okamoto et al. (2015)	16	3	1	3	10	75% RM	120
Clark et al. (2011)	4	3	1	3	9-12* / 30-50**	80% RM* / 30% RM**	60-120
Fahs et al. (2014)	6	3	1	4	20	30% RM	60
Raj et al. (2012)	16	2	4	2* / 3**	10* / 5-10**	75% RM* / 50-100% RM**	180
Yasuda et al. (2015)	12	2	2	4	15-30	25-30% RM	30
Yasuda et al. (2014)	12	2	2	4	30* / 10**	20% RM* / 30% RM**	90
Okamoto et al. (2009a)	10	2	5	5	8-10	80% RM	120
				Acute effects			
Nitzsche et al. (2016)	-	-	5	3*/3**/4♮	30*/ 20**/10♮	30% RM*/50% RM**/70% RM♮	120
Kingsley et al. (2017)	-	-	3	3	10	75% RM	120
Lefferts et al. (2015)	-	-	2	5	5	To failure	90
Augustine et al. (2014)	-	-	2	5	5	To failure	180-300
Okamoto et al (2014)	-	-	1	3	To exhaustion	40% RM	120
Yoon et al. (2010)	-	-	8	2	15	60% RM	-

RM: maximum load in one repetition; * Group 1; ** Group 2; ♮ Group 3 (see table 2)

The results showed a large increase in arterial stiffness in the upper body, while in the lower body there was a trivial decrease. That can be explained by the fact that resistance training for the upper body muscle groups increased arterial stiffness as evidenced by a rise in noradrenaline concentration in the blood plasma (Okamoto et al., 2009a). A similar trend was shown in the upper body area in acute effect treatments at vigorous intensities (Lefferts et al., 2015), but a contrary result was found at lower intensities (Okamoto et al., 2014). However, trivial or small changes were found in the rest of the upper-body training groups (Okamoto et al., 2015; Yasuda et al., 2015). Differences in the number of weeks and days per week of training could explain these results for the chronic-effects oriented studies, while differences in the sample size may explain the disparities observed for acute effects.

In contrast, in those groups that performed an inferior train intervention, trivial or small changes were found, with the exception of two groups that showed moderate and large arterial stiffness reductions. The strongest reduction (Clark et al., 2011) may be related to the use of lower intensities or a blood restriction strategy. For studies involving both upper and lower body, most of the groups showed small or trivial changes in arterial stiffness, and only two displayed moderate decreases (Au et al., 2017, Casey et al., 2007). However, opposite findings were obtained in acute-effect treatments, with greater changes at lower intensities (Nitzsche et al., 2016; Yoon et al., 2010). Future research should aim to obtain more scientific evidence to clarify how resistance training in upper or lower body muscle groups compromises cardiovascular health. According to the data gathered in this review, it does not appear to be determinant.

According to the blood flow restriction, only one study compared a lower intensity with blood restriction to a higher intensity (Clark et al., 2011). Greater reductions were found in arterial stiffness in both cases, with a large effect in the blood restriction group. Moreover, while Yasuda et al. (2015) and Fahs et al. (2014) found that groups performing BFR intervention showed increased arterial stiffness (the maximum outcome being a moderate change), the intervention group in Clark et al.'s (2011) study showed a large decrease in arterial stiffness. This result may be because the latter study used short-term training close to an acute intervention (only four weeks). Therefore, more studies examining the effects of this type of resistance training on arterial stiffness is needed, especially in acute effects for which no information was found.

In terms of training intensity, resistance training performed at low or medium intensity does not appear to increase arterial stiffness (Au et al., 2017; Fahs et al., 2014; Raj et al., 2012). The same trend is seen at vigorous intensities, except for the studies by Casey et al. (2007) and Okamoto et al. (2009a), which showed a moderate decrease and a large increase in arterial stiffness, respectively. The differences in the training methodology (weeks and days per week) between studies are highlighted. Contrary findings are shown in acute effect studies, in which vigorous intensities produced smaller changes (Augustine et al., 2014; Kingsley et al., 2017; Nitzsche et al., 2016). Therefore, moderate or gentle intensity of resistance training could guarantee cardiovascular safety, especially in chronic effects. However, the vigorous intensity has not the same outcome, especially in upper body exercises. Future studies may provide greater insight. Data from this review indicate that vigorous intensity training, on its own, should not compromise cardiovascular health by increasing the stiffness of the arteries.

With regard to acute effects, as Kingsley et al. (2017) predicted, the results obtained in different studies are not uniform. However, there is a relative trend towards moderate or large increases in arterial stiffness occurring at lower intensities (Nitzsche et al., 2016; Okamoto et al., 2014; Yoon et al., 2010). Therefore, an isolated session of vigorous intensity resistance training should not be harmful to arterial stiffness, thus compromising cardiovascular health, or at least be no more harmful than applying an intervention of moderate or low intensity.

Other parameters of resistance training, such as continuous or periodic training (studied by Okamoto et al., 2015), and the use of mainly eccentric or concentric training (Raj et al., 2012), have been analyzed. Both studies involved a single intervention group and registered trivial or small changes. Therefore, it is difficult to draw conclusions about these parameters, although it could be very interesting to consider them in future studies.

The duration and frequency of resistance training interventions have also been taken into account in this review, but it is difficult to see their influence because there were pronounced differences between groups. Also, the age distribution of the groups was clearly inconsistent. The variability in outcomes could also be related to the gender distribution in the groups since most of the studies used gender-mixed samples. These confounding factors should be taken into account when comparing data in meta-analyses. No forest plots are presented, despite the importance of this statistical technique, because of the inappropriate models created with a limited number of studies and samples, with different goals. Therefore, more studies need to be undertaken to shed more light on this topic.

Finally, some limitations should be considered. Firstly, the included studies measured arterial stiffness in different ways (central, peripheral or systemic), and the values obtained differed depending on where the measurements were taken. In addition, there are some variables that may be confounders, including age, activities of daily living, usual diet and medication intake, all of which should be taken into account. Thus, the interpretations made in this review should be considered with caution when comparing the results with other studies, as arterial stiffness values may vary. Secondly, the main methodological shortages in the reviewed RCTs were found in the fifth point of the Testex scale, where it is stated unambiguously if the assessor of at least one primary outcome measure was blinded to group allocation. However, this could not be considered a high problem. Finally, a meta-analysis should be addressed in the future, when a higher background could be found.

Conclusion

The available scientific evidence suggests that resistance training, of at least four weeks duration and two days per week frequency, does not impair cardiovascular health in terms of altered arterial stiffness. Variables such as the type of training, the muscle groups involved, intensity, duration, frequency and other parameters analyzed do not seem to determine arterial stiffness variation. However, resistance training focused in the upper body and conducted at vigorous intensity may increase arterial stiffness in a chronic effect. Overall, resistance training may be safely added in terms of arterial stiffness to health-oriented physical activity programs in healthy population.

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Key points

- Resistance training is a safe component in health-oriented activity programs in terms of arterial stiffness.
- Resistance training does not impair cardiovascular health in chronic interventions, except in high intensity exercises with upper body muscles.
- More studies should be conducted in order to learn more about acute response to resistance training.

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