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Abstract:	Purpose of Review To elucidate the hemodynamic, autonomic, vascular, hormonal, and local mechanisms involved in the blood pressure (BP) lowering effect of dynamic resistance training (DRT) in pre-hypertensive and hypertensive populations. Recent Findings The systematic search identified 16 studies involving 17 experimental groups that assessed the DRT effects on BP mechanisms in pre-hypertensive and/or hypertensive populations. These studies mainly enrolled women and middle-aged/older individuals. Vascular effects of DRT were consistently reported, with vascular conductance, flow-mediated dilation, and vasodilatory capacity increases found in all studies. On the other hand, evidence regarding the effects of DRT on systemic hemodynamics, autonomic regulation, hormones and vasoactive substances are still scarce and controversial, not allowing for any conclusion.

	Summary The current literature synthesis shows that DRT may promote vascular adaptations, improving vascular conductance and endothelial function, which may have a role in the BP lowering effect of this type of training in pre-hypertensive and hypertensive individuals. More studies are needed to explore the role of other mechanisms in the BP lowering effect of DRT.

Mechanisms of Hypertension and Target-Organ Damage (J. E. Hall & M. E. Hall, Section Editors)

Title: Potential mechanisms behind the blood pressure lowering effect of dynamic resistance training

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Abstract

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Keywords: “strength training”; “hypertension”; “hypertensives”; “vascular”; “endothelial function”; “autonomic nervous system”.

Declarations

Funding

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Availability of data and material

Not applicable.

Code Availability

Not applicable.

INTRODUCTION

Hypertension is estimated to affect 1 billion individuals worldwide. It is considered a major cardiovascular risk factor, causing 8 million deaths per year with most of them because of stroke, myocardial infarct or sudden death [1]. Regarding its pathophysiological mechanisms, hypertension is determined by high cardiac output (CO) in few specific cases (e.g. early disease stage), but its most common hemodynamic determinant is the increase in systemic vascular resistance (SVR) caused by mechanisms such as elevated sympathetic vasomotor tone, hyperactivity of the renin-angiotensin-aldosterone system (RAAS), and vascular dysfunction and remodelling [2].

Despite the expressive progress on the efficacy of pharmacological antihypertensive treatment, the rates of blood pressure (BP) control among the hypertensive individuals remains low (i.e. 43.5%) [3], highlighting the importance of non-pharmacological approaches. Additionally, these approaches also prevent hypertension development, which is relevant since the absolute hypertension burden has increased in the last decades [4]. Therefore, as part of the non-pharmacological approach, exercise training is recommended as a first line therapy for individuals with pre-hypertension and stage 1 hypertension and is indicated as a complementary intervention to pharmacological treatment for hypertensive individuals at the other stages [5,6].

Classically, guidelines recommend aerobic training in hypertension because of the high level of evidence regarding its BP lowering effect [3,5,6]. However, more recently, dynamic resistance training (DRT) was also included as a non-pharmacological intervention for hypertension prevention and treatment, as highlighted in the American College of Cardiology and American Heart Association Guideline for High Blood Pressure Management [3**]. DRT, also called strength training, is composed by exercises in which force is exerted against a resistance with alternated phases of muscle shortening and lengthening [7]. A meta-analysis [8**] including 64 controlled trials (n=2344 participants) reported significant reductions of systolic (SBP) and diastolic (DBP) BPs after DRT, with greater reduction associated with higher baseline BP [i.e hypertensive individuals: -5.7 (IC: -9.0, -2.7) / -5.2 (-8.4, -1.9); pre-hypertensive individuals: -3.0 (-5.1, -1.0) / -3.3 (-5.3, -1.4); normotensive individuals: 0.0 (-2.5, 2.5) / -0.9 (-2.1, 2.2) mmHg for ΔSBP/ΔDBP).

Despite the recommendation of DRT for hypertension prevention and treatment, little is known regarding the mechanisms responsible for the BP lowering effect of this type of training as most of the studies did not include any mechanistic measure [9]. However, some investigations have studied the effects of DRT on isolated mechanisms related to BP control, assessing markers of autonomic modulation, vascular function, hormonal regulation, or others. Therefore, it is interesting to join this information within a comprehensive literature synthesis about the possible mechanisms behind the BP lowering effect of DRT, exposing the strength and weakness of the current scientific evidence. This synthesis can drive future experimental and clinical trials on this subject, leading to a more precise development of the knowledge in this area of investigation.

Thus, this study reviewed the current literature about the effects of DRT on BP hemodynamic, autonomic, hormonal, and vascular mechanisms, aiming to synthetize them in a possible model for the BP lowering effect of DRT.

METHODS

Literature search

A systematic literature review was conducted in US National Library of Medicine and National Institutes of Health (i.e., PubMed) database. Multiple advanced searches were performed including key-terms related to the population ("hypertension" OR "hypertensive" OR 'hypertensives" OR "prehypertension" OR "prehypertensive" OR "prehypertensives" OR "pre-hypertension" OR "pre-hypertensive" OR "pre-hypertensives"), the intervention ("resistance exercise" OR "strength exercise" OR "resistance training" OR "strength training") and the outcome ("hemodynamic" OR "cardiac output" OR "stroke volume" OR "heart rate" OR "autonomic" OR "sympathetic" OR "parasympathetic" OR "vagal" OR "sympathovagal" OR "vasomotor" OR "baroreflex" OR "vascular" OR "endothelial" OR "arterial diameter" OR "nitric oxide" OR "flow-mediated dilation" OR "blood flow" OR "vasoactive" OR "vasodilation" OR vasodilatory capacity" OR "angiotensin" OR "renin-angiotensin" OR "endothelin" OR "catecholamines" OR "epinephrine" OR "adrenaline" OR "norepinephrine" OR noradrenaline). The search included all sources up to October 9th, 2020. Manual searches upon the reference lists of the identified articles were also performed to complement database search.

Selection criteria

Records identified by database and manual search were initial analysed based on their tittles and abstracts review and excluded if they did not attend the following criteria: 1) to be a clinical trial; 2) to be conducted with humans; 3) to have investigated pre-hypertensive and/or hypertensive individuals; 4) to have assessed the chronic effects of DRT; and 4) to have included at least one group that had performed only DRT (i.e. not in combination with aerobic training). The full texts of the remaining studies were assessed for eligibility and excluded due to the following criteria: 1) any exclusion criteria of the screening phase were not identified; 2) have not assessed a BP control mechanism; and 3) have performed sub-analyses or presented the same data of another included study.

Data were extracted by one author (R.Y.F) and checked by another (L.C.B) and discrepancies were resolved by critical discussion. Descriptive data regarding the characteristics of the sample (gender, age, clinical status and anti-hypertensive use), the DRT protocol (volume, intensity, frequency and intervention length) and the experimental design (study arms and sample size) were extracted from each included studied. Afterwards, the effects of DRT on BP mechanisms reported by each paper were analysed.

RESULTS

A flow diagram describing the search and screening process is shown in Figure 1. Initial database search identified 316 records and 2 other records were identified by manual search, totalizing 318 records. By titles and abstracts review, 290 studies were identified for not fulfilling this review criteria, and by full paper reading another 28 papers were excluded. Thus, 16 studies were included and analysed [10–25]. As one of them [22] compared two different protocols of DRT (i.e. non-periodized vs. periodized), this review included the effects of DRT in 17 different experimental groups.

Study characteristics

Studies characteristics are shown in Table 1. Half of the studies (n=8) involved samples composed by both men and women, while 6 (37.5%) studies included only women and two studies (12.5%) involved only men. The great majority (87.5%) of the

studies involved middle-age or older individuals, and all (except by one) that studied only women involved only older women. Pre-hypertensive individuals were included in 7 studies (43.8%), while hypertensive individuals (81.3%) were investigated in 13 studies. In five studies, pre-hypertension was defined based on the 7th Joint National Committee's cutoff point (i.e. SBP/DBP between 120/80 and 139/89) [26], while in two studies elevated BP was based on the criteria of the 6th Brazilian Guideline of Arterial Hypertension [27] or the consensus statement of the International Diabetes Federation [28] (i.e. SBP/DBP between 130/85 and 139/89). Considering the studies with hypertensive individuals, six studies defined hypertension by previous diagnosis or use of anti-hypertensive therapy, while other six considered hypertension as BP levels higher than 140/90 mmHg [26,27], and one used both criteria (i.e. anti-hypertensive drug use or BP > 140 mmHg). Anti-hypertensive medication use was cited in 11 (68.8%) studies.

DRT frequency varied from 2 to 3 sessions per week. Training period varied from 3 to 6 months with most of the studies presenting training periods between 8 to 12 weeks (n=10, 62.5%). Training protocol varied considerably among the studies. The number of exercises varied from 3 to 11, the number of sets from 1 to 4, and the number of repetitions from 8-10 to 15-20. Exercise intensity was established as 50 to 80% of 1RM in 5 studies, was based on 10-15 RM in 3 studies, was defined based on subjective effort in 3 studies, used other methods (number of repetitions or percentage of 10RM) in 4 studies, and was not reported in 1 study.

DRT effects

Results from each study and a summary of results for each variable are presented, respectively, on Table 2 and Figure 2.

SBP and DBP responses to DRT evaluated in 16 experimental groups showed a decrease in SBP in 11 groups (68.8%) and a decrease in DBP in 9 groups (56.3%). Six of 8 (75.0%) experimental groups that assessed MBP showed a reduction after DRT. In only 4 experimental groups, DRT did not promote any BP lowering effect on SBP, DBP or MBP.

Systemic hemodynamic determinants of BP were only assessed in one experimental group in which DRT did not change CO, SVR nor BP. Additionally, HR

was assessed in 8 experimental groups and decreased after DRT in 4 (50.0%), did not change in 3 (37.5%), and increased in 1 of them (12.5%). Stroke volume (SV) was decreased in the only study that measured it.

Cardiac autonomic regulation was assessed in 3 experimental groups by means of HR variability. Almost all indexes assessed in these experimental groups did not change with DRT, except for the 0V% index that increased after DRT (33.3%). Vasomotor sympathetic modulation was assessed in only 1 experimental group through the low-frequency component of SBP variability and it decreased after DRT.

Pressor hormones (i.e. catecholamines, markers of renin-angiotensin-aldosterone system, vasopressin and kinins) were measured in 3 experimental groups, but they did not change in any of them.

Local hemodynamics were evaluated in 4 experimental groups. All of them assessed the upper limb (arm or forearm) and one experimental group had lower limb (calf) hemodynamics assessed. Upper limb vascular conductance increased in all experimental groups (3 studies) and blood flow increased in 2 of 3 groups (66.6%). Calf vascular conductance and blood flow increased after DRT in the only experimental group that had this variable assessed.

Regarding vascular function, vasodilatory capacity was assessed by plethysmography in 2 experimental groups and by flow mediated dilation using ultrasonography in another 4. These parameters increased in all the experimental groups. Brachial diameter was measured in 3 experimental groups and did not change in any of them after TRD.

Different vasoactive substances were measured in 7 experimental groups. Markers of nitric oxide (NO) were measured in all of them and did not change in 4 (50.0%), increased in 2 (28.6%), and decreased in one (14.3%). Endothelin and prostacyclin markers were assessed in two experimental groups, being unchanged in one (50.0%), whereas the other presented a decrease in endothelin 1 and an increase on prostacyclin (50.0%).

DISCUSSION

The current systematic review showed that mechanisms responsible for the BP lowering effect of DRT in pre-hypertensive and hypertensive individuals have been poorly investigated in literature, with results mainly sustained by studies with middle aged or older women. The most robust available evidence regarding these mechanisms is limited to local hemodynamics, suggesting that the BP lowering effect of DRT is accompanied by increased vascular conductance and vasodilatory responses, while there is poor or no evidence that DRT affects systemic hemodynamics, cardiovascular autonomic regulation, RAAS components or vasoactive substances (Figure 3).

The current review found scarce data regarding the hemodynamic determinant of the BP lowering effect of DRT. As BP is determined by the product between CO and SVR, and hypertension is caused by pathologic elevations in one or both of these factors [2], the effect of DRT lowering BP must involve a decrease of CO (central adaptation) and/or SVR (peripheral adaptation). Nevertheless, in line with previous reports in normotensives [29,30], the only study [12] that assessed these outcomes in hypertensive individuals did not observe any effect of DRT on BP, CO or SVR. Thus, more studies are required to reveal the systemic hemodynamic determinant of the BP lowering effect of DRT. However, based on the evidence revealed by this review regarding local hemodynamics and vascular function, an effect on peripheral mechanisms seems more probable.

Central adaptations

CO is determined by the product between SV or HR [30]. Studies with middle-aged and older normotensive individuals have consistently shown no change in SV after DRT. Similarly, classic findings suggest that DRT does not modify SV in healthy young subjects [29,30]. On the other hand, in the current review, the only study that assessed SV in hypertensive individuals [12] observed a significant decrease after 6 months of DRT. Nevertheless, despite this reduction, CO did not change because HR increased after DRT, suggesting that changes in SV may be compensated by HR changes. Additionally, in this specific study, BP did not decrease after training. Thus, an SV reduction may be obtained with DRT, but more studies are needed to verify this effect and they may also consider the HR responses. Moreover, it is important to keep in mind that hypertension is not

usually associated with an increase in SV [2], suggesting that a decrease in this parameter may not compensate the disease pathophysiological mechanisms.

Many studies have evaluated HR responses to DRT, but their results are controversial. A HR lowering effect was found in four experimental groups, with DRT decreasing HR in two of them [23,25] and preventing the increase in HR observed in the control group in the other two [22]. However, the other half of the studies did not observe any HR decrease after DRT [12,13,17,18]. Considering HR autonomic regulation, three studies evaluated HR variability [11,13,25] and in two of them [11,13], HR variability parameters did not change with DRT, suggesting no effect on central autonomic regulation. On the other hand, the third study [25] reported a reduction of HR (Cohen's d = 1.20; large effect) accompanied by a decrease in 0V% (Cohen's d = 0.88; moderate effect) that is a marker of cardiac sympathetic modulation. However, in this study, other indices related to cardiac sympathetic modulation (i.e LF_{R-R} and LF/HF) were not changed by DRT. Thus, the effects of DRT on HR and its autonomic regulation remain unclear and need future elucidation.

Therefore, together, the current evidence does not support a decrease in CO as the main hemodynamic systemic mechanism responsible for the BP lowering effect of DRT because DRT seems not to promote resting bradycardia as a hallmark response, and even when DRT decreases SV, a compensatory increase in HR may happen. Nevertheless, it is possible that DRT decreases CO in those hypertensive individuals with elevated CO as the main hypertensive mechanism, which should be assessed by future research.

Peripheric adaptations to DRT

SVR is determined by many mechanisms, such as local hemodynamics, vascular function, vasomotor autonomic regulation, hormonal influences, and vasoactive substances.

The current review revealed a consistent effect of DRT on local hemodynamics and vascular function. Along this line, baseline blood flow and vascular conductance increased after DRT in almost all studies that assessed these variables. Additionally, in one study [17], these variables were assessed in different vascular beds (forearm and calf)

and the increase was observed in both sites, which may reflect the whole-body DRT protocol employed in the study.

The current review also indicates an DRT effect improving vascular function of the resistance vessels. This effect was observed in two studies that reported an increased vasodilatory response to reactive hyperaemia when assessed by plethysmography [14,17]. In one of these studies [17], the improvement occurred on both arm and calf, showing a whole-body effect. Additionally, in pre-hypertensive individuals, the improvement obtained with DRT resulted in a vasodilatory capacity greater than observed in normotensive individuals. Finally, in pre-hypertensive and hypertensive individuals, the improvement has been shown to be greater than observed with aerobic training [14].

The present findings also suggest an effect of DRT on conduit vessels, improving endothelial function measured by FMD. Concerning these effects, a previous meta-analysis [31] involving 396 subjects with different clinical characteristics (e.g. congestive heart failure, coronary artery disease and peripheral artery disease, type 2 diabetes, and healthy individuals) has already reported an overall effect of DRT improving FMD. Thus, the current review confirmed this effect in individuals with high BP since all four studies [15,16,19,20] that have assessed FMD reported an increase after DRT. Interestingly, these studies involved different samples including young pre-hypertensive individuals [16], medicated hypertensive individuals [15*], a mix of pre-hypertensive and medicated hypertensive individuals [19*], and individuals with metabolic syndrome and elevated BP [20]. Among these studies, Beck et al. [16] reported that DRT was able to revert the endothelial dysfunction present in pre-hypertension. Additionally, these studies reported that DRT effects on FMD were similar to those reported for moderate continuous aerobic training [16,19], high-intensity interval training [20] and combined training [19,20].

The mechanisms explaining vascular function improvement induced by DRT are out of the scope of this review. However, it is possible to speculate that shear stress increase produced during exercise may be involved. Skeletal muscle contractions increase the production of vasodilatory factors (e.g. CO_2, adenosine, lactate/H^+ and K^+) [32]. However, during dynamic resistance exercise, the contracted muscle mass around the blood vessels imposes a mechanic restriction to blood flow increase [33]. Nevertheless, after each repetition and set, the cessation of contraction allows for the increase in blood flow, reflecting an ischemia/reperfusion condition that may acutely increase shear stress

and chronically improve vascular function [34,35]. Future studies, however, should confirm the role of shear stress on this improvement.

The vascular function improvements reported on both conduit and resistance vessels after DRT might reflect a more favourable vasoactive balance [34]. Along this line, Beck et al. [16] reported a favourable vasoactive balance after DRT characterized by concomitant increase on humoral markers of NO and prostacyclin with a decrease of endothelin 1. Additionally, another study [10] found NO increase after DRT to be inversely correlated with SBP decrease ($r=-0.63$; $p<0.05$). The increase of NO bioavailability with DRT could be a consequence from enhanced oxidant / antioxidant balance [24] after DRT. However, it is important to mention that the other 5 studies that measured NO markers and the other study that assessed prostaglandin and endothelin found different results. Thus, future studies should confirm the favourable effect of DRT over vasoactive balance. The dissociation concerning the controversial effect of DRT on NO and the well shown increase of endothelial function produced by this training might be explained by the fact that endothelial function was measured after a stimulus while NO markers were assessed in baseline conditions. Future studies should consider this aspect.

Despite the consistent effect on vascular function, the current literature review did not show any DRT effect on vascular structure as none of the studies reported brachial arterial diameter changes after training. This absence of effect might reflect the short length of the interventions (i.e. 8 to 12 weeks) given that structural adaptations might require longer periods to occur than functional adaptations [36]. Actually, a study with young health men [37] reported an increase in brachial arterial diameter and a decrease in wall-to-lumen ratio after 6 months of DRT. Future studies with longer periods of training should be designed to verify whether DRT can affect the hypertension-induced vessel remodelling.

Vascular function and structure is affected by neural and hormonal mechanisms, In the current review, the only study that evaluated the effects of DRT on vascular autonomic regulation reported a decrease in BP variability (low-frequency band in spectral analyses) similar to the reduction observed in a parallel group that performed aerobic training [13]. As BP variability is a marker of vasomotor sympathetic modulation, this result suggests that DRT may decrease muscle sympathetic nerve activity (MSNA)

in individuals with high BP. However, no study has directly assessed MSNA in individuals with elevated BP, and a study with normotensives reported no change [38]. Nevertheless, high BP levels are associated with altered MSNA, which may potentiate an effect of DRT decreasing this activity in individuals with elevated BP, which still need to be investigated.

Regarding vasoactive hormones, all the studies in the current review that focused on RAAS components found no significant effect. Moraes et al. [21] investigated hypertensive individuals employing a comprehensive evaluation including humoral concentrations of angiotensin I, angiotensin II, angiotensin 1-7 and ACE activity. Cononie et al. [12] evaluated angiotensin I and angiotensin II in pooled and separated analyses of normotensive and hypertensive individuals. Beck et al. [16] studied young pre-hypertensive individuals and measured angiotensin II plasma concentration. Therefore, there is no evidence of a DRT effect on RAAS. However, humoral concentrations of RAAS markers do not necessary reflect tissue (local) RAAS activity, and future studies should evaluate the effects of DRT on local angiotensin II.

Additional considerations

The present results add new information about the role of DRE in hypertension prevention and treatment. Despite the BP lowering effect of this type of training that supports its recommendation in pre-hypertension [39] and hypertension [8], the present review found vascular function improvement as the main mechanism for this effect. As vascular dysfunction is associated with increased risk for hypertension development (with a reduction of 0.62% in FMD associated with an increase of 20 mmHg in SBP) [40] and cardiovascular events in patients with cardiovascular diseases (with a reduction of 1 standard deviation in FMD doubling the risk of cardiovascular events) [41], the effect of DRT improving vascular function strengthens its recommendation for hypertension prevention and treatment.

It is important to mention some limitations of this review. The literature search was performed only in PubMed, and more data may be found in other databases. However, the execution of additional manual searches based on studies' references list might have attenuated this potential bias. Although only studies with pre-hypertensive and hypertensive individuals were included, there was a high heterogeneity among the

samples regarding BP levels (pre-hypertensive or controlled hypertensive or uncontrolled hypertensive individuals), BP status definition (based on different cut-off values or pre-participation diagnosis or anti-hypertensive use), and antihypertensive treatment (untreated or treated with different medication classes). Although this heterogeneity is common in literature, the mechanisms behind the BP lowering effect of DRT might differ among the specific groups, which need more data and standardized population definition to be investigated. Additionally, although age and sex are known to influence BP level [42] and its mechanisms, such as vascular function [43], very few data in the present review derived from studies with young adults or only with men. Despite these data pointed out for vascular benefits of DRT in young individuals [16,17] and in men [14,16,17], more studies are need especially because an improvement in these populations might have important impact on hypertension prevention. As many studies main outcome was the effects of DRT on BP, it is also possible that some of them were adequately powered to detect BP changes, but not BP mechanisms alterations. Therefore, it would be important to conduct future studies stablishing BP mechanisms as the main outcomes.

CONCLUSION

Based on the findings and discussion of this review, the need for more investigations regarding the mechanisms behind the BP lowering effect of DRT is clear. Nevertheless, the current literature synthesis indicates that DRT may promote vascular adaptations, improving vascular conductance and endothelial function, which may have a role in the BP lowering effect of to this type of training. On the other hand, there is no robust evidence to support that DRT decreases sympathetic activity nor RAAS activity, while its effects on vasoactive substances is controversial.

Compliance with Ethics Guidelines

Conflict of Interest

The authors declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent

This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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FIGURE LEGENDS

Fig. 1 Flow diagram of the study. BP = blood pressure; DRT = dynamic resistance training.

Fig. 2 Absolute number of experimental conditions from the reviewed studies with pre-hypertensive and/or hypertensive individuals that found changes that favour and do not favour a blood pressure lowering effect of dynamic resistance training. Variables analyses were: systolic blood pressure (SBP); diastolic blood pressure (DBP); mean blood pressure (MBP); cardiac output (CO); stroke volume (SV); heart rate (HR); systemic vascular resistance (SVR); vascular conductance; vasodilatory capacity; flow mediated dilation (FMD); nitric oxide (NO); arterial diameter; sympathetic vasomotor modulation (LF_SBP); and pressor hormones. Results favouring blood pressure lowering were defined by a significant decrease for CO, SVR, SV, HR, sympathovagal balance, LF_SBP and pressor hormones, and by a significant increase for vascular conductance, vasodilatory capacity, FMD and arterial diameter.

Fig. 3 Summary model showing the actual evidence regarding the possible mechanisms involved in the blood pressure lowering effect of dynamic resistance training (DRT) in pre-hypertensive and/or hypertensive individuals. NO, nitric oxide; RAAS, renin-angiotensin-aldosterone system. ? = available literature presents scare results (i.e. just one study was performed); → available literature indicates that DRT does not change this outcome; ↑ available literature indicates that DRT increases this outcome; ↓ available literature indicates that DRT decreases this outcome.

Figure 2

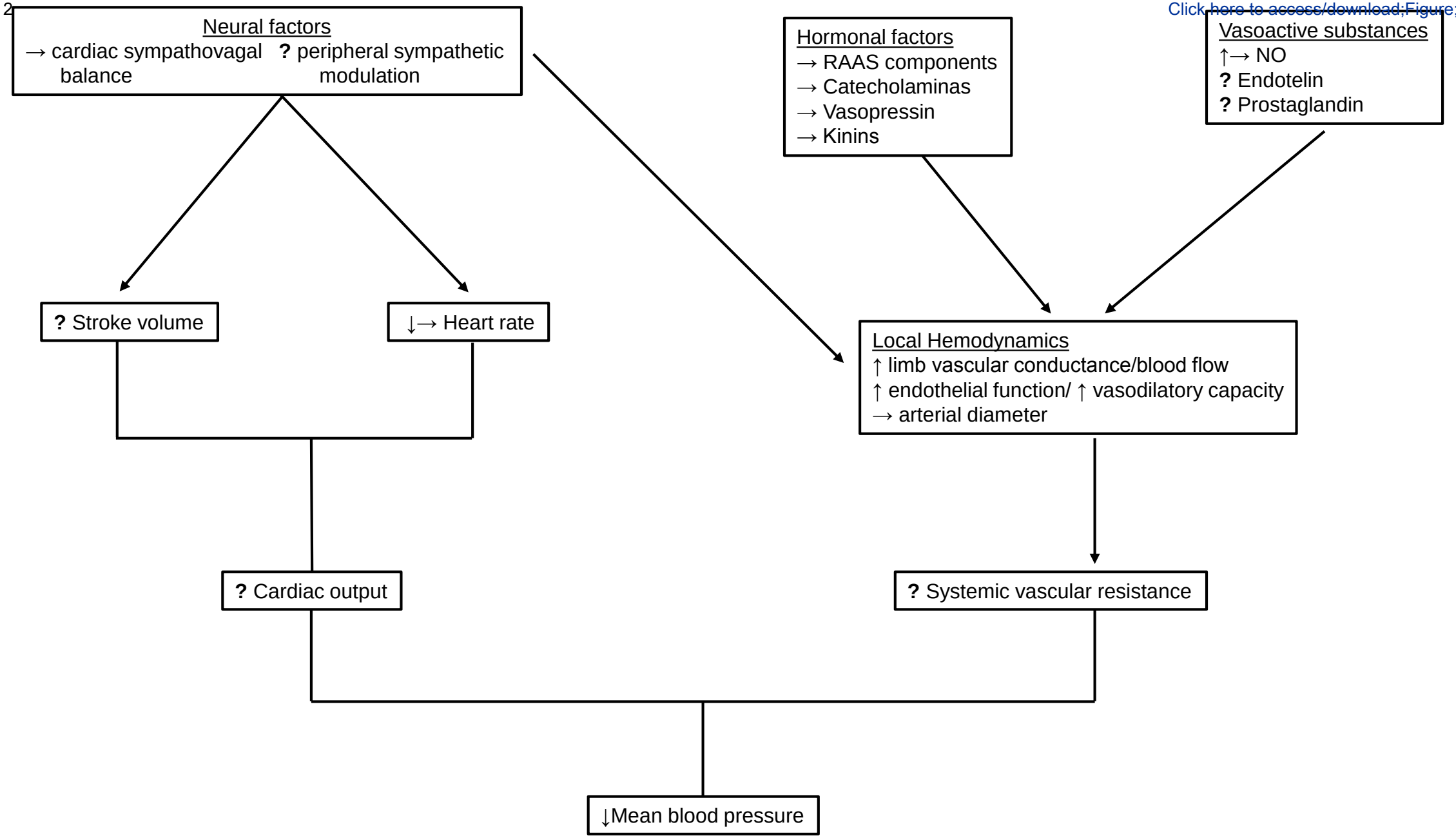

Figure 3

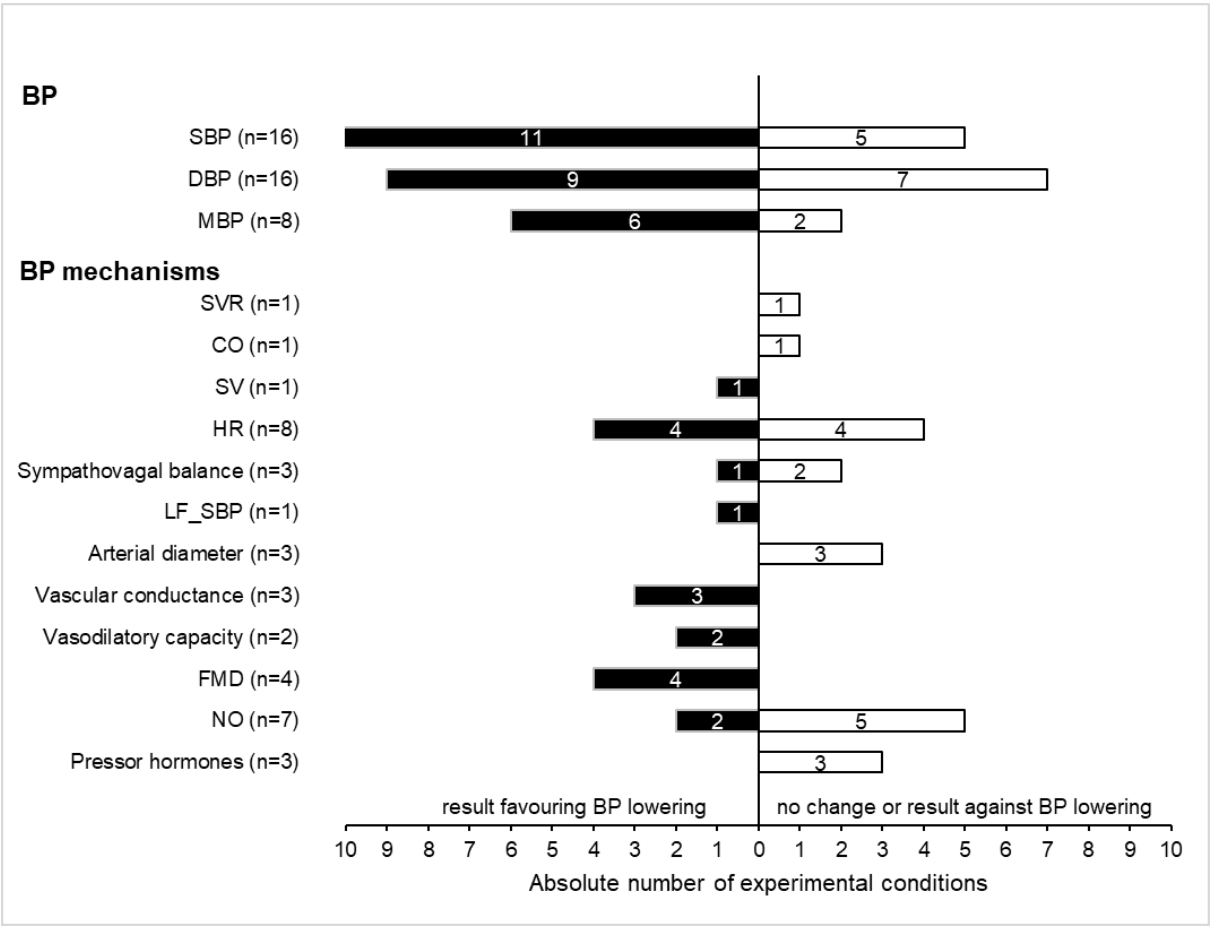

Figure 1

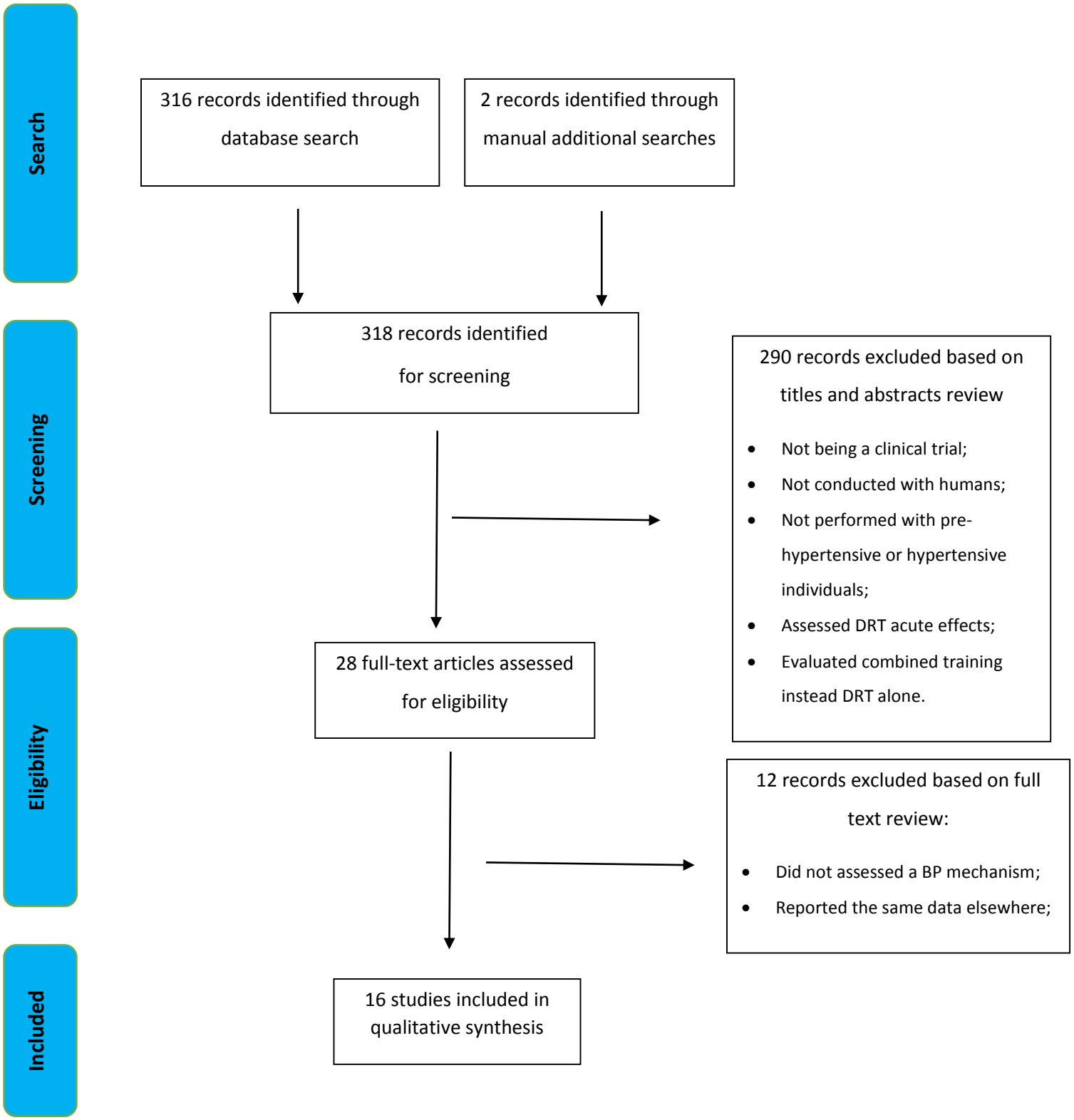

Table 1. Characteristics of the sample, experimental design, and dynamic resistance training (DRT) protocol of the studies that have evaluated the effects of DRT on blood pressure mechanisms in pre-hypertensive and hypertensive individuals.

Study	**Gender**	**Age (years)**	**Clinical status**	**Drug treatment**	**Medication type**	**Study arms (number of participants)**	**DRT protocol**	**DRT frequency (times/week)**	**DRT duration (weeks or months)**
Beck et al. (2013) [16]	Men and women	**DRT:** 21.1±2.5	Pre-hypertension	No	-	**DRT** (n=15) **C** (n=15)	**V** 7 ex, 2 sets, 8-12 rep; **I** progressed when 12 rep were performed.	3	8 weeks
Beck et al. (2014) [17]	Men and women	**DRT:** 21.1±0.6 (SEM)	Pre-hypertension	No	-	**DRT** (n=15) **C** (n=15)	**V** 7 ex 2 sets 8-12 rep; **I** progressed when 12 rep were performed.	3	8 weeks

Boeno et al. (2020) [15]	Men and women	**DRT:** 46.1±7.2	Hypertension	Yes	ARBs ACEi Diuretic CCB β-blocker	**DRT** (n=15) **C** (n=12)	**V** 8 ex, 2-3 sets, 8-20 rep; **I** maximum weight without concentric failure.	3	12 weeks
Collier et al. (2008) [14]	Men and women	**DRT:** 47.0±2.0 (SEM)	Pre-hypertension and hypertension	No	-	**DRT** (n=15)	**V** 9 ex, 3 sets, 10 rep; **I** 65% 10RM.	3	4 weeks
Collier et al. (2009) [13]	Men and women	**DRT:** 46.7±1.8 (SEM)	Pre-hypertension and hypertension	No	-	**DRT** (n=15)	**V** 9 ex, 3 sets, 10 rep; **I** NR.	3	4 weeks

Cononie et al. (1991) [12]	Men and women	**All sample**: 72±3	Hypertension and normotension	Yes (Some individuals)	ACEi Diuretic β-blocker vasodilator	**DRT** (n=20) **C** (n=12)	**V** 10 ex, 1 set, 8-12 rep; **I** progressed when 12 rep were performed.	3	6 months
Dantas et al. (2016) [24]	Women	**DRT**: 64.7±4.7	Hypertension	Yes	ARBs ACEi CCB diuretics β-blockers α2 agonist.	**DRT** (n=13) **C** (n=12)	**V** 9 ex, 1-3 sets, 9-11 to 13-15 rep; **I** 5-7 OMNI-RES scale	2 to 3	10 weeks
Dantas et al. (2020) [25]	Women	**DRT**: 64.7±4.7	Hypertension	Yes	ARBs ACEi CCB diuretics β-blockers α2 agonist.	**DRT** (n=13) **C** (n=12)	**V** 9 ex, 1-3 sets, 9-11 to 13-15 rep; **I**	2 to 3	10 weeks

							5-7 OMNI-RES scale		
De Sá et al. (2020) [23]	Women	**All sample:** 42 to 68	Hypertension	Yes	ARBs ACEi CCB β-blockers	**DRT** (n=16)	**V** 11 ex, 1-3 sets, 15 rep; **I** 15RM.	2	6 months
Coelho-Júnior et al. (2018) [22]	Women	**DRT_NP:** 67.5±4.4 **DRT_P:** 66.7±4.7	Hypertension and normotension	Yes (Some individuals)	ARBs ACEi CCB diuretics.	**DRT_NP** (n=10) only strength training **DRT_P** (n=12) intercalated strength and power training **C** (n=14)	**DRT_NP** **V** 9 ex, 3 sets, 8-10 rep; **I** 5-6 RPE. **DRT_P** = DRT_NP intercalating strength (**I:** 5-6 RPE) and power (**I:** 3 RPE; fast) training	2	18 weeks

Moraes et al. (2012) [21]	Men	**DRT:** 46±3 (SEM)	Hypertension	No – 6-week washout period	-	**DRT** (n=15)	**V** 8 ex, 3 sets, 12-20 rep; **I** 60% 1RM.	3	12 weeks
Stensvold et al. (2010) [20]	Men and women	**DRT:** 50.9±7.6	Metabolic syndrome compromising elevated BP.	Yes (some individuals)	ABRs ACEi CCB β-blockers.	**DRT** (n=11) **C** (n=11)	**V** 3-5 ex, 3 sets, 8-12 rep; **I** 60-80% 1RM	3	12 weeks
Pedralli et al. (2020) [19]	Men and women	**DRT:** 55.1±6.9	Pre-hypertension and hypertension	Yes (some individuals	ARBs ACEi diuretics β-blockers antiplatelet.	**DRT** (n=12)	**V** 6 ex, 4 sets, 8-12 rep; **I** 60-80% 1RM.	2	8 weeks

Terra et al. (2008) [18]	Women	**DRT:** 66.8±5.6	Hypertension	Yes	ACEi CCB diuretics β-blockers.	**DRT** (n=20) **C** (n=26)	**V** 10 ex, 3 sets, 8-12 rep; **I** 60-80% 1RM.	3	12 weeks
Trevizani et al. (2018) [11]	Men	**DRT:** 59.0±7.6	Hypertension	Yes (7 of 8 subjects)	ARBs CCB diuretics.	**DRT** (n=8)	**V** 8 ex, 2 sets, 15-20 rep; **I** 50% 1RM	3	12 sessions
Tomeleri et al. (2017) [10]	Women	**DRT:** 69.0±6.6	Pre-hypertension and hypertension	Some individuals	ARBs ACEi CCB β-blockers.	**DRT** (n=15) **C** (n=15)	**V** 8 ex, 1 set, 10-15 rep; **I** 10-15 RM.	2	12 weeks

ACEi angiotensin-converting enzyme inhibitors; *ARB* angiotensin II receptor blocker; *C* control group; *CCB* calcium channel blockers; *DRT_NP* non-periodized dynamic resistance training; *DRT_P* periodized dynamic resistance training; *ex* exercises; *rep* repetitions; *V* volume; *I* intensity; *RM* = repetition maximum; *RPE*: rate perceived exertion; *SEM* standard error of the mean.

Table 2. Results of studies that evaluated the effects of dynamic resistance training (DRT) on blood pressure mechanisms in pre-hypertensive and hypertensive individuals.

Study	Blood Pressure	Systemic Hemodynamics	Autonomic Regulation	Hormonal Regulation	Local Hemodynamic	Local vascular function	Vasoactive substances
Beck et al. (2013) [16]	↓ SBP ↓ DBP	-	-	→ Ang II	-	**Brachial** ↑FMD → diameter.	↑NO_x ↓ET-1 ↑PGI_2x
Beck et al. (2014) [17]	↓ SBP ↓ DBP	→ HR	-	-	**Forearm** ↑ BF ↑ VC **Calf** ↑ BF ↑ VC	**Forearm** ↑ vasodilation **Calf** ↑ vasodilation	
Boeno et al. (2020) [15]	↓SBP →DBP ↓24h-SBP →24h-DBP	-	-	-	**Brachial** →BF	**Brachial** ↑FMD →diameter	→NOx →PGI_2x →ET-1 →VEGF
Collier et al. (2008) [14]	↓ SBP ↓ DBP	-	-	-	**Forearm** ↑ VC.	**Forearm** ↑ vasodilation	-

Collier et al. (2009) [13]	↓ SBP ↓ DBP	→ HR	→ LF_{R-R} → HF_{R-R} → LF/HF_{R-R} ↓ LF_{SBP} → cSBR.	-	-	-	-
Cononie et al. (1991) [12]	→ SBP → DBP →MBP	→ CO → SVR ↓ SV ↑ HR	-	→Ang I →Ang II → epinephrine → norepinephrine	-	-	-
Dantas et al. (2016) [24]	→SBP ↓DBP ↓ MBP	-	-	-	**Forearm** ↑ BF ↑ VC	-	↓ NOx
Dantas et al. (2020) [25]	↓ MBP.	↓ HR	↓ 0V% → 1V% → 2V% → S. entropy → LF_{R-R} → HF_{R-R} → $LF/HF_{R-R.}$	-	-	-	-

De Sá et al. (2020) [23]	↓SBP ↓DBP	↓HR	-	-	-	-	-
Coelho-Júnior et al. (2018) [22]	**DRT_NP** ↓ SBP* ↓ DBP ↓MBP	↓ HR*	-	-	-	-	→ NOx
	DRT_P → SBP → DBP →MBP	↓ HR*	-	-	-	-	→ NOx
Moraes et al. (2012) [21]	↓ SBP ↓ DBP ↓MBP	-	-	→ Ang I → Ang II → Ang 1-7 → ACE activity → vasopressin → kinins	-	-	→ NOx
Stensvold et al. (2010) [20]	→ SBP → DBP.	-	-	-	-	**Brachial** ↑ FMD	-

Pedralli et al. (2020) [19]	↓ 24h-SBP → 24h-DBP	-	-	-	-	**Brachial** ↑ FMD → diameter.	-
Terra et al. (2008) [18]	↓ SBP → DBP ↓MBP	→ HR	-	-	-	-	-
Trevizani et al. (2018) [11]	→ SBP → DBP		→ MMN → SDNN → RMSSD → LF_{R-R} → HF_{R-R} → LF/HF_{R-R}.	-	-	-	-
Tomeleri et al. (2017) [10]	↓ SBP ↓ DBP ↓MBP	-	-	-	-	-	↑ NOx

0V% - standard unchanged; 1V% - standard with 1 variation; 2V% - standard with 2 variations; ACE = angiotensin-converting enzyme; Ang = angiotensin; BF = blood flow; C = control; cBRS = cardiac baroreflex sensitivity; CO = cardiac ouput; DBP = diastolic blood pressure; NP = non-periodized; P = periodized; ET-1 = Endothelin 1; FMD = flow-mediated dilation; HR = heart rate; HF_{R-R} = high-frequency component of R-R

variability; LF_{R-R} = low-frequency component of the R-R variability; LF_{SBP} = low-frequency component of SBP variability; MBP = mean blood pressure; MMN = average duration of RR intervals; NOx = NO metabolite; RMSSD = root mean square of successive RR intervals; SBP = systolic blood pressure; SDNN = standard deviation of RR intervals; SVR = systemic vascular resistance; PGI_{2x} = prostacyclin metabolite; VC = vascular conductance. * DRT decreased this variable by preventing an increase observed in the control group.