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Acute Hemodynamic Responses in Women Older Than 40 Years Old Following Resistance Training with Blood Flow Restriction Compared To Resistance Training Alone: A Systematic Review

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ACUTE HEMODYNAMIC RESPONSES IN WOMEN OLDER THAN 40 YEARS OLD FOLLOWING RESISTANCE TRAINING WITH BLOOD FLOW RESTRICTION COMPARED TO RESISTANCE TRAINING ALONE: A SYSTEMATIC REVIEW

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Abstract

Introduction: Blood flow restriction (BFR) is a novel training method that has gained recent popularity given the benefits and similar results to resistance training (RT) with lower intensities. The authors of this systematic review sought to determine the acute hemodynamic effects of BFR plus RT compared to RT alone in women over 40 years old.

Methods: The databases searched included Pubmed, EBSCO (Cumulative Index of Nursing and Allied Health Literature (CINHAL), SPORTDiscuss, Medline, Academic Search Complete) and Cochrane. Keywords utilized included BFR, occlusion therapy, female, older female, women, older women, RT, hemodynamic, blood pressure, and the boolean phrase utilized was “AND.” Inclusion criteria included women aged 40 or older, BFR, RT, or a combination, assessment of cardiovascular responses, randomized controlled trial (RCT) or non-RCT for studies on acute responses. Exclusion criteria included chronic outcome measures, no data on subjects over 40 years old, different modes of exercise, and any confounding factors. After thorough screening by 4 independent reviewers, 15 articles were kept for qualitative synthesis. The Physiotherapy Evidence Database (PEDro) scale was utilized for methodological quality assessment.

Results: The main findings of this systematic review include BFR+RT having a significant decrease in systolic blood pressure up to 60 minutes for hypertensive subjects, with varying results for RT. No significant differences were found for BFR+RT and RT in diastolic blood pressure up to 60 minutes post-exercise for normotensive and hypertensive subjects. Mean arterial pressure showed significant increase in BFR+RT and RT in normotensive subjects immediately post-exercise.

Similar results were found for heart rate immediately post-exercise in hypertensive subjects for each intervention.

Discussion: This systematic review demonstrated that BFR+RT might promote post-exercise hypotension for up to 60 minutes, similar to RT. Given that high intensity RT can be contraindicated for certain cardiovascular conditions, this may provide an alternative way to maintain stable hemodynamic variables.

Conclusion: Continued research is warranted to examine the effects of BFR training on acute cardiovascular responses in this population to establish safe and effective parameters during physical therapy rehabilitation.

Introduction

Blood flow restriction (BFR) is an augmented strengthening method that is gaining popularity in physical therapy settings, starting with athletes and gaining popularity among older adults. This technique in combination with low intensity resistance exercise reaches favorable changes in the muscle with less energy expenditure compared to high intensity resistance training (RT).[1] Recent research has shown beneficial physiological improvements following the use of BFR when compared to RT alone. Resistance training is commonly linked to the development of muscle strength, improvement of cardiovascular health, increasing bone mineral density, improving mental health, and reversing aging factors.[2] Moreover, BFR has been shown to have similar benefits to RT, with the addition of faster muscle hypertrophy and reduced muscle damage while allowing an increase in training frequency.[3] However, there is limited research on the benefits of BFR application to enhance acute hemodynamic responses that may be used to treat various health conditions such as type 2 diabetes, hypertension (HTN), and cardiovascular diseases. Of particular interest, older women are at high risk for developing these conditions as they undergo physiological changes following menopause including arterial stiffness and increase in carotid atherosclerosis.[4] Investigating the acute effects of BFR training on older women could give an insight into the application of this novel training modality.

BFR training is performed by applying a tourniquet, pressurized cuff, or elastic band to the proximal portion of a limb.[5] Evidence suggests that the occlusion restricts venous outflow at the occluded limb while the arterial inflow is partially reduced.[5] According to Patterson et al[6] the recommended occlusion percentage for RT is 40 to 80 percent. Therefore, distal to the tourniquet the extremity experiences a hypoxic environment, due to the decrease in blood flow which is thought to induce a training effect that increases muscle mass and strength.[5] Due to the lack of venous return, blood pooling begins to occur at the capillaries and leads to visible erythema at the limb.[1] When muscular contractions begin under this hypoxic state, further intramuscular pressure occurs and leads to metabolic stress.[1] This metabolic stress facilitates a drastic decrease in phosphocreatine stores and a drop in muscle pH, which also occurs with high intensity resistance training.[7] Consequently, this decrease in phosphocreatine improves energy storage by enhancing phosphocreatine resynthesis.[8] Other contributors to the hypertrophic effects besides an increase in metabolic stress seen with the hypoxic environment include an increase in fast-twitch muscle fibers, elevation of systemic hormones, cell swelling, and an increase in production of reactive oxygen species such as nitric oxide and heat shock.[5] Although further research is required, it is thought that once the BFR is deflated, the immediate reperfusion triggers an increase in metabolites including reactive oxygen species, which promotes an increase in smooth and cardiac muscle growth, and muscle protein synthesis.[1,5]

Despite the hypertrophic effects, BFR is not widely used due to the potential negative side effects it can have on adults with cardiovascular disease. Contraindications for BFR+RT include venous thromboembolism, peripheral vascular compromise, sickle cell anemia, extremity infection, lymphadenectomy, cancer or tumor, or individuals that take medications that increase clotting risk.[9] One study by Patterson et al[6] concluded that BFR resistance training did not increase blood coagulation factors in older adults with ischemic heart disease. Among the main possible side effects of BFR training, there has been evidence that the incidence of deep vein thrombosis is <0.06%, pulmonary embolism <0.01%, and muscle damage <0.01%.[10] High amounts of physical activity (3h or greater per week) has been shown to increase the risk of venous thromboembolism in older and obese populations.[11] Of the articles included in a systematic review, 22% reported musculoskeletal-related side effects post-RT such as muscle strain, joint pain, and bruising.[12]

To combat the low risk of a deep vein thrombosis or pulmonary embolism from BFR, researchers can measure blood markers before or following BFR training such as D-dimer, c-reactive protein, fibrin degradation product, and plasminogen activator inhibitor.[6,13] The literature also suggests that BFR is shown to have none to minimal muscle damage demonstrated by the lack of an increase in blood biomarkers, short-term acute muscle swelling, and no evidence of diminishing muscle performance over a prolonged period.[14] Ultimately, it is best to monitor patients with heart conditions during BFR training to ensure their blood pressure (BP) stays within safe limits and to prevent any harmful side effects.[15] For this reason, there is a need to investigate the acute effects of BFR with RT compared to RT alone.

Research has shown that RT has beneficial and crucial effects on any age, including the older population. Benefits of RT include muscle strength, increased endurance, improvement of overall health and quality of life, and decreased risk for conditions such as diabetes, osteoporosis, and cognitive decline.[16] Over a period of 18 years, 32,002 subjects who participated in 150 minutes of RT per week decreased their risk for type 2 diabetes by 34%.[17] A study that involved a 12-month RT program increased the bone mineral density of the lumbar spine in postmenopausal women by a mean of 0.009 g/cm^2 compared to -0.019 g/cm^2 in the non-exercise group.[18] A randomized controlled trial involving 52 older women found a significant change (p<0.03) in cortical activation in the RT group compared to the control group, improving functional plasticity.[19] An additional benefit of RT is a momentary post-exercise hypotension effect is achieved in individuals with HTN.[20] This physiologic state is accomplished by an increase in parasympathetic activity and decrease in sympathetic activity, subsequently decreasing BP.[20]

Despite these benefits, there are factors that limit the exercise prescription of high intensity RT in adults with cardiovascular disease. Precautions for RT in this population include but are not limited to diabetes, major risk factors for cardiovascular disease, uncontrolled HTN (>160/>100 mmHg), low functional capacity (<4 metabolic equivalent of task), musculoskeletal limitation, and conditions requiring pacemakers or defibrillators.[21] General contraindications include unstable coronary heart disease, severe pulmonary HTN, uncontrolled HTN (180/110 mmHg), severe aortic stenosis, aortic dissection, and uncontrolled arrhythmias.[21] Due to these safety concerns, there is limited research on populations diagnosed with cardiovascular disease undergoing high intensity RT. Moreover, additional training methods are warranted to reach similar outcomes as those seen with RT.

There is a need to examine different modes of exercise, such as BFR, in order to account for the physiological changes seen in older women, given that cardiovascular disease remains one of the leading causes of death.[22] Physiological changes of the vascular system that are commonly found in older adults encompass a decrease in endothelial compliance in blood vessels causing the arteries to become stiffer and less adaptable to changes in BP, which can lead to an increase in cardiac work intensity and BP.[23,24] Premenopausal women have significantly lower arterial stiffness compared to age-matched men because estrogen, a vasodilator, has anti-atherosclerotic properties in vascular tissues.[25] However, due to a drastic decrease in estrogen, these protective properties in postmenopausal women decline which causes a large increase in arterial stiffness for this population.[25,26] For example, one study showed that postmenopausal women had a higher brachial-ankle pulse wave velocity ranging from 1275–2814 cm/s, indicating a higher risk of atherosclerotic cardiovascular disease compared to premenopausal women with 744–1065 cm/s.[26] The literature supports the use of RT in older women to combat the aforementioned age-related changes, where further research is required to determine the acute hemodynamic responses with BFR training. The purpose of this systematic review is to determine the acute hemodynamic effects of BFR in combination with RT compared to RT alone in women over 40 years of age.

Methods

This review is organized according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.

Data Sources and Search Strategy

A thorough search was done on multiple databases including Pubmed, EBSCO (Cumulative Index of Nursing and Allied Health Literature (CINHAL), SPORTDiscuss, Medline, Academic Search Complete), and Cochrane. For the purposes of this search, the boolean phrase utilized was “AND.” The search terms used included blood flow restriction, occlusion therapy, female, older female, women, older women, resistance training, hemodynamic, and blood pressure. A total of 6,283 articles were found through the search. After duplicates were removed, 2,951 articles were screened by title and abstract by four independent reviewers. Four reviewers independently analyzed 25 full-text articles and proceeded to discuss their eligibility. After reviewing each article, 10 articles were excluded because they did not meet the inclusion and exclusion criteria. Fifteen articles were kept for qualitative synthesis in this systematic review.

Study Selection

The inclusion criteria consisted of women aged 40 or older, blood flow restriction, resistance training, or a combination, and randomized controlled trial (RCT) or non-RCT for studies investigating acute cardiovascular responses. Exclusion criteria consisted of studies that reported only on chronic effects, different modes of exercise other than BFR and RT, no data on subjects over 40 years old, and confounding factors.

Analysis of the Methodological Quality and Data Extrapolation

The Physiotherapy Evidence Database (PEDro) scale was utilized to assess the quality of the experimental studies included in this systematic review. Each article was appraised using the 11 items on this scale and was scored from a 0 (poor quality) to an 11 (high quality). Each individual article was scored independently by four reviewers, the scores were subsequently compared, and in the presence of a discrepancy in scoring, the article was assessed a second time through discussion as a group. The articles' scores ranged from 5 to 9, with an average score of 6.25 indicating good quality of evidence. All 15 articles were included in this review regardless of scoring. Lastly, the four reviewers independently extracted data by analyzing the participant characteristics, interventions, outcome measures, results, and conclusions of the articles included in this review.

Results

Database/Study Selection

The initial database search resulted in 6,283 studies. After duplicates were removed, the researchers screened 2,951 articles by title and then by abstract. Twenty-five full-text articles were assessed for eligibility. Ten articles were excluded because they failed to include RT as an intervention, added a confounding factor to the experimental group, no data on individuals over 40 years old, or did not report on acute effects. A total of 15 articles are included in the qualitative analysis of this systematic review from Cochrane, EBSCO, and Pubmed databases. Refer to Figure 1 for the PRISMA Diagram.

Study Characteristics and Risk of Bias

Within the 15 studies included in this systematic review, there are 4 articles that directly examined BFR+RT, and all articles looked at RT. Two studies are quasi-experimental, 12 are randomized control trials, and 1 is a controlled clinical trial (refer to Table 2). All participants included in these articles were female with 86.6% of the participants having HTN (refer to Table 3). Each researcher reviewed all of the articles independently and came to an agreement on the scores. The PEDro score did not influence the articles' eligibility for the systematic review as 3 articles had a score of 5, 7 scored a 6, 4 scored a 7, and 1 scored a 9 (refer to Table 1). The authors acknowledge that a score of 5 is considered “fair,” but the lack of available studies proves to be a more important consideration. The major findings in the assessment of the risk of bias were the absence of concealed allocation, along with therapist, participant, and assessor masking.

Intervention Comparison

Blood Flow Restriction Training

The intervention protocols found in Table 2 for BFR varied and included intensities from 20% to 30% of 1RM, frequencies from 3 to 5 sessions, repetitions from 8 to 20, and sets from 1 to 3.[27-30] Two articles included the duration of rest breaks which ranged from 30 to 45 seconds.[27,30] These studies utilized a combination of modes of exercise using leg extension and leg press with BFR.[27-30] BFR was applied to the lower extremities across all articles, varying between bilateral[27-29] and single limb[30] application. When considering cuff pressure used for BFR, the measures included 50% arterial occlusion pressure,[30] 80% arterial occlusion pressure,[27,29] and one was not explicitly stated.[28]

Resistance Training

Resistance training was implemented across all studies. The 15 protocols detailed in Table 2 varied across all studies with frequencies from 1 to 4 sessions, intensities from 40-80% of 1RM, repetitions from 8 to 20, and sets from 1 to 3.[27-41] One study did not mention the exact RM intensity.[31] Rest periods in these articles ranged from 30 seconds to 2 minutes.[27-36] Most of the articles included 7-10 exercises targeting various muscle groups.[32,33,35-40] Common RT exercises found included leg press,[31-38,41] bench press,[35,37-41] leg curl,[32,33,35,37-40] lateral pulldown,[32,35,36,40,41] leg/knee extension,[27,31-33,35-38,40] biceps flexion and triceps extension,[31-33,36-40] plantarflexion of the leg,[32,33,35,36,39] row,[32,33,37,38]and abdominal exercise.[35,38,39] Lastly, other less common exercises included military press and ankle dorsiflexion,[36] overhead press,[37] frontal raise,[39] adduction chair and flying,[32,33] leg abductor chair, shoulder abduction, and trunk extension,[35] pull ups,[31] and chair squats.[39]

Outcome Measures

The primary outcomes were hemodynamic variables, which included systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR). These were assessed in most studies through the use of either a non-invasive, automated, or semi-automated BP monitor where HR would also be measured or manually taken using the auscultatory method with a mercury sphygmomanometer and a stethoscope.[27,30,31,34-41] HR was assessed with a digital heart rate monitor using a variation of Polar monitor models[27,30,36-38,41] and through electrocardiography.[32-34] Four studies measured BP and HR through the use of photoplethysmography with Finometer PRO.[28,29,32,33] Seven studies calculated mean arterial pressure (MAP).[30,32,33,35,38-40]

Summary of Studies Results/Outcomes

Outcomes measures in the results section of the systematic review include systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and heart rate (HR). The results presented under each outcome measure begin by reporting immediate post-exercise results for hypertensive and normotensive subjects after RT, followed by BFR+RT. Refer to Figure 2. Thereafter, each outcome measure reported results for up to 60-minutes for both RT and BFR+RT for hypertensive and normotensive subjects. Refer to Figure 3. Lastly, results post 60-minutes will be reported under each outcome measure when available. Refer to Table 4 for specific values.

Systolic Blood Pressure

In hypertensive subjects who underwent RT, 3 studies showed a significant increase in SBP immediately after exercise,[36,38,41] 3 studies showed no significant differences,[28,29,31] and 1 study showed a significant decrease in SBP[34] with RT intensities ranging from low to high. Regarding exclusively normotensive subjects, there were no differences found in SBP immediately after exercise in 1 RT study.[34] Moreover, a study with normotensive and hypertensive (mixed) subjects demonstrated no significant differences in SBP post-exercise.[39] An additional RT study on normotensive subjects demonstrated an increase in SBP in both high and low intensity groups.[30] The studies that used BFR+RT as its main intervention also varied in results seen in 2 studies that showed no significant differences in SBP immediately post-exercise in hypertensive subjects,[28,29] and another study showed a significant increase in SBP in normotensive subjects.[30] These BFR+RT articles utilized 20% of 1RM as their low intensity.

In 4 studies with RT as their intervention, there were statistically significant decreases in SBP in hypertensive subjects at different time points up to 60 minutes, with intensities ranging from moderate to high.[31-33,38] Additionally, in normotensive subjects, 2 articles that utilized RT demonstrated a significant decrease in SBP at 15 and 30 minutes at an unspecified exercise intensity[40] and 30 minutes of 80% of 10RM[34] post-exercise. Six moderate intensity RT studies with hypertensive subjects demonstrated no significant differences in SBP up to and including 60 minutes compared to baseline values.[27,34-37,41] Another moderate intensity RT with mixed subjects found no significant difference in SBP up to and including 60 minutes compared to rest.[39] Two articles demonstrated no significant differences in hypertensive subjects at the 120-minute, 180-minute, and 24-hour post-RT in SPB measurements,[37,41] and 2 studies showed significant decreases of SBP at the 70- and 90-minute mark.[32,33] Another study with normotensive subjects demonstrated no significant difference in SBP at 90 minutes post-exercise compared to baseline.[40] A BFR+RT study demonstrated a significant decrease in SBP at 15, 30, 45, and 60 minutes post-exercise compared to baseline values.[27]

Diastolic Blood Pressure

There were statistically significant increases in DBP immediately post-RT with hypertensive subjects in 2 studies,[36,38] and no significant changes in DBP in 5 studies[28,29,31,34,41] compared to the resting values with intensities ranging from low to high. A study that included normotensive subjects post-RT with low and high intensities found no significant differences in DBP compared to baseline.[30] Another study that observed DBP post-RT with mixed subjects found no significant changes compared to baseline.[39] Regarding normotensive subjects, there were no significant changes in DBP immediately following RT at a moderate level.[34] No significant difference in DBP values was found for a BFR+RT hypertensive group compared to rest in 2 studies.[28,29] Another study with a BFR+RT normotensive group had a significant increase in DBP after the third set compared to baseline.[30]

Three studies that used moderate to high intensity RT as their main intervention found significant reductions in DBP values in hypertensive subjects post-exercise up to 60 minutes.[31-33] In contrast, 7 studies that also used RT at similar intensities as a mode of intervention showed no significant changes in hypertensive subjects for DBP from resting values during this recovery period.[27,34-38,41] An additional moderate to high intensity RT study that included mixed subjects exhibited no differences in DBP post-exercise compared to baseline data.[39] Similarly, 2 studies observed the same result in normotensive subjects after undergoing high intensity RT.[34,39] Researchers that studied BFR+RT also found no significant changes from baseline values compared to DBP values up to 60 minutes post-exercise in hypertensive subjects.[27] Articles that included RT at 50-80% of 1RM demonstrated significant decreases in DBP up to 90 minutes post-exercise in hypertensive subjects.[32,33] Three studies with hypertensive subjects that utilized low to high RT intensities demonstrated no significant differences at 120 minutes, 180 minutes, and 24 hours post-exercise compared to rest.[37,41] The same result was observed in normotensive subjects in a RT study at 90 minutes post-exercise.[40] None of the BFR+RT studies analyzed in this systematic review included results consistent with these longer-term parameters.

Mean Arterial Pressure

One study that measured MAP immediately after a RT session found significant increases at both 40% and 80% 1RM compared to rest in hypertensive subjects. The researchers also observed significant decreases from 30 to 60 minutes post-exercise at the same intensity for hypertensive subjects.[38] Similarly, 2 different studies found significant decreases for MAP at all time points up to 90 minutes in hypertensive subjects post-exercise for moderate to high intensity RT.[32,33] In fact, the researchers found BP reductions to be significantly greater after exercise at 80% 1RM when comparing it to 50% 1RM.[32] However, no significant differences were found in acute changes in MAP in 2 studies where RT was used as the main intervention on hypertensive subjects.[35,39] In contrast, normotensive subjects had a significant decrease in MAP at 15 and 30 minutes post-RT.[40] A study showed a significant increase in MAP from pre- to post-intervention in both the low intensity and high intensity groups.[30] Furthermore, in Scott et al,[30] MAP was significantly higher in the BFR+RT group compared to the low intensity RT and high intensity RT groups after the last set of exercises. The MAP values were not different between high intensity RT and low intensity RT trials at any point.[30]

Heart Rate

Regarding HR, immediately post-RT with moderate to high intensities, 1 study demonstrated a significant increase in hypertensive subjects compared to baseline.[38] Five studies demonstrated no significant differences for HR in low to high intensity RT in hypertensive subjects.[28,29,34,36,41] Moreover, another RT study observed the same result in normotensive subjects following moderate intensity exercise.[34] A study with mixed subjects post-RT at a high intensity found a significant decrease in HR.[39] For a study that observed BFR+RT with hypertensive subjects found no significance for HR compared to baseline.[28] However, a study that observed BFR+RT with hypertensive subjects resulted in a significant decrease in HR.[29]

In reference to HR results, 3 studies that used RT as a mode of exercise with hypertensive subjects demonstrated a significant decrease in HR up to 60 minutes post-exercise at moderate to high intensity.[27,35,36] The same result was observed in a study with mixed subjects undergoing RT at a moderate intensity.[39] Furthermore, 2 RT studies that used moderate to high intensity exercise resulted in a significant increase in HR for hypertensive subjects up to 50 minutes post-exercise.[32,33] Conversely, 4 RT studies demonstrated no significant changes in HR in hypertensive subjects at different time points up to 60 minutes post-exercise at moderate intensity.[34,37,38,41] In accordance with this, a single RT study found no significant difference in normotensive subjects after exercising at high intensity.[34] A study that used BFR+RT also observed no significant change in HR for hypertensive subjects after 30 and 60 minutes post-exercise.[27] Lastly, 3 RT articles with moderate to high intensity demonstrated no significant changes in HR at 70, 90, 120, 180 minutes, and 24 hours post-exercise in hypertensive subjects compared to rest.[32,37,41] None of the BFR+RT articles reported HR after 60 minutes post-exercise.

Discussion

The aim of this systematic review is to determine the acute hemodynamic responses following BFR+RT versus RT alone in women older than 40 years old. Additionally, a comparison can be made on acute hemodynamic effects in hypertensive versus normotensive individuals post-RT and post-BF+RT. To our knowledge, this is the first systematic review that examines the acute effects of BFR+RT versus RT on the hemodynamic variables in this population. This systematic review demonstrated that BFR+RT could potentially promote post-exercise hypotension for up to 60 minutes, similarly to RT. The main findings of this systematic review are (1) BFR+RT showed no significant differences in SBP immediately post-exercise in hypertensive subjects, (2) BFR+RT showed a significant decrease in SBP up to 60 minutes post-exercise for hypertensive subjects, (3) BFR+RT and RT showed no significant differences in DBP up to 60 minutes post-exercise for both normotensive and hypertensive populations, (4) MAP had a significant increase immediate post-exercise for normotensive subjects under BFR+RT and RT, and (5) BFR+RT and RT demonstrated no significant differences in HR in hypertensive subjects immediately post-exercise. Due to the heterogeneity of the study designs, there was a wide range of findings. Hence, the interpretation of the results was based on trends for the purpose of this systematic review.

For SBP changes immediately after exercise, BFR+RT showed no significant differences in the hypertensive subjects, while it was significantly increased in the normotensive subjects. RT showed variable results, with the majority showing either a significant increase or no differences post-exercise in both normotensive and hypertensive subjects. Interestingly, Pinto and Polito[28] and Pinto et al[29] found no significant differences in SBP in BFR+RT and RT, which could be attributable to the study designs as they only included 1 exercise for their experimental protocols while the rest of the articles included at least 3 exercises. Therefore, the number of exercises seems to have an impact on outcomes following RT and BFR+RT.

Nevertheless, when looking at 60 minutes post-exercise, Aurajo et al[27] showed a significant decrease in SBP in hypertensive subjects after BFR+RT, while the majority of the RT articles resulted in no differences and less so showed a significant decrease. Most studies on RT that showed no significant differences included a minimal to moderate intensity. Half of the studies with a significant decrease in SBP were able to sustain longer periods of low SBP levels when using high-intensity RT compared to the studies that utilized moderate-intensity RT. A study by Figueiredo et al[42] on normotensive subjects showed a post-exercise hypotension response up to 60 minutes after moderate intensity RT. Our study showed that high intensity RT primarily had a post-exercise hypotension response, demonstrating that intensity affects SBP following RT. A systematic review by Domingos and Polito[15] also showed a significant decrease in SBP after BFR+RT compared to RT between 30 and 60 minutes in hypertensive men and women subjects. Finally, our systematic review shows that even as low as 1 session of BFR+RT could be used as an alternative mode of exercise to help manage HTN by lowering the SBP levels.

After examining DBP immediately post-exercise on hypertensive and normotensive subjects, no significant difference for BFR+RT and RT was observed. Most of these studies included low to high intensity for RT articles, while only low intensity was used for BFR+RT articles. Similar to the present systematic review results, Sardeli et al[43] found no significant differences in DBP immediately post-exercise compared to baseline after low intensity-RT, high intensity-RT, and BFR+RT in normotensive older adults. This study is consistent with our findings and correlates to having no changes in acute DBP immediate post-exercise. A study by Pereira et al[44] separated older women into 3 groups, including antihypertensive medicated subjects with controlled BP (control group), antihypertensive medicated subjects with uncontrolled BP (decompensated), and lastly, untreated hypertensive subjects. This study found no significant changes in DBP for the control group compared to baseline at both 2 and 5 minutes, consistent with our systematic review findings and controlled HTN subjects.[44] However, there was a significant decrease for untreated hypertensive subjects at 2 and 5 minutes and at 2 minutes for decompensated hypertensive subjects post moderate intensity RT.[44] These significant decreases may differ from our systematic review results due to subjects having lack of medications and uncontrolled BP.

Two RT studies, up to 60 minutes post-exercise, showed no changes in DBP for normotensive subjects. Consistent with this finding, at least one BFR+RT study and the majority of the RT studies demonstrated no significant differences in DBP in hypertensive subjects while training at low and moderate-high intensities, respectively. This systematic review shows that low to high intensities can result in a non-significant change in DBP in hypertensive subjects. Interestingly, a study by de Brito et al[45] reported significant decreases in DBP in elderly hypertensive men and women up to 60 minutes post-RT compared to the control session. Similarly, Domingos and Polito[15] reported a significant reduction in DBP under BFR+RT compared to RT for normotensive individuals during the 30 to the 60 minute recovery period. The results from Domingos and Polito[15] and Brito et al[45] opposed those found in this systematic review as it was able to demonstrate that both modes of exercise (BFR+RT and RT) have no adverse effects in DBP for normotensive and hypertensive subjects.

Results for MAP immediately post-exercise, in hypertensive subjects were mixed as 1 article demonstrated a significant increase and 2 demonstrated no change following RT. For normotensive subjects, at least one BFR+RT and one RT study demonstrated a significant increase. These results demonstrated a normal response to exercise.[46] The opposing findings between normotensive and hypertensive subjects may potentially be attributed to medication intake, as blood pressure may be reduced by beta-blockers.[47] An article by Bazgir et al, studied BFR+RT and reported that MAP stayed within normal range post-exercise, concluding that this form of training is a safe and ideal option for healthy individuals.[48] Four articles demonstrated significant decreases in MAP in both hypertensive and normotensive subjects up to 60 minutes post-RT with no data noted on BFR+RT. Although these articles demonstrated significant decrease, 3 of the results did not drop below 80 mmHg which is above the required minimum of 60 mmHg to maintain perfusion of vital organs.[49]

Immediately post-exercise, HR showed no significant differences compared to baseline in both normotensive and hypertensive women in the majority of RT articles. In 2 BFR+RT articles regarding hypertensive women, there were no significant differences in HR pre- to post-exercise immediately and 60 minutes post-exercise. However, up to 60 minutes post-RT, the results for HR were inconclusive. The exercise parameters did not seem to affect the HR responses when comparing the different study designs. However, a potential explanation is the antihypertensive medications the subjects were taking reduced the HR response during and post-exercise. Beta-blockers, a common cardiac medication taken for various heart conditions, reduces HR which in turn blunts HR response during exercise.[48,50] This medication makes it difficult to reach the target HR. Therefore, recommendations were made, such as performing a stress test to determine a new target HR or to have the individuals exercise to fatigue but not exhaustion.[48,50]

Supporting articles vary in results, as researchers in Pereira et al[44] observed no significant changes in HR for all 3 groups at 2 and 5 minutes post moderate intensity RT. These results correspond with most of the articles in this systematic review. However, 2 other articles found in the literature demonstrated the contrary. An article comparing low-volume versus high-volume RT in older adults found significant increases in HR immediately post-exercise in both protocols.[51] The high-volume group demonstrated larger increases which the authors associated with a larger increase in effort, mechanical stress, and neuromuscular fatigue.[51] The authors stated that low-volume RT is beneficial for older adults to improve their strength and prevent a substantial increase in acute hemodynamic responses.[51] Another article assessed HR responses in healthy elderly subjects following low intensity-RT, high intensity-RT, and low intensity-BFR.[43] Immediately post-exercise and 30 minutes post-exercise, all groups demonstrated significant increases in HR compared to baseline measurements.[43] The results of this systematic review show that BFR+RT might be as beneficial as RT and even safe for women with cardiovascular issues as there were no differences between groups in regards to HR immediately post-exercise.

Study Limitations and Future Research Directions

The main limitation in this study was the heterogeneity of the study designs. As explained in the results and Table 2, most studies had different intensities, frequencies, and number of exercises performed in a session. This variability may explain different findings among the results in these studies. Another important limitation is the limited number of RT articles and more so for BFR+RT reporting on cardiovascular responses for women 40 years and older. Because of this, a BFR+RT study had to be included with participants between the ages of 36 and 54 and a mean age of 45. Additionally, there was an absence of data on BFR articles that reported on HR as an outcome measure when observing normotensive individuals' responses to exercise. This systematic review was unable to make a comparison between hypertensive and normotensive subjects at 60 minutes because not a single article on BFR included normotensive subjects. Attributing to this scarcity of studies, only 1 BFR+RT reported on data up to 60 minutes post-exercise, and no BFR article reported beyond 60 minutes post-exercise. Therefore, no comparisons with RT were made beyond 60 minutes.

The methodological quality of the articles in this systematic review was assessed through the use of the PEDro scale. These articles varied in score from 5 to 9, with the majority being scored as fair to good quality and 1 as excellent quality. Due to scarce evidence in the literature, this systematic review included all of the studies that ranged from fair to excellent quality that met the inclusion criteria, potentially reducing the validity. Additionally, the use of limited keywords during the initial search for articles might have narrowed our results as the researchers did not search specific cardiovascular outcome measures, including “heart rate,” “systolic blood pressure,” and “diastolic blood pressure.”

Future research should aim to increase the volume and quality of information on women older than 40 regarding RT and BFR+RT. Individualized BFR+RT training in this population will need further investigation in order to establish safe and effective parameters that optimize clinical outcomes. Homogeneity of exercise parameters should be considered in future research to improve the generalizability to this population. Finally, to determine the long-term effects of post-exercise hypotension, further research is warranted to record outcome measures after BFR+RT up to 24 hours.

Conclusion

This systematic review demonstrated that BFR+RT could potentially help manage hypertension by safely lowering SBP levels up to 60 minutes post-exercise, similarly to RT. BFR is an emerging trend that has been shown to have health benefits including but not limited to improvements in cardiovascular health, muscle hypertrophy, reversing age factors, and other similar benefits to RT.[5] As previously stated, high intensity RT can be contraindicated for people with cardiovascular diseases. Therefore, BFR training should be considered as an alternative treatment mode as it implements low intensity resistance.[21] Further research on BFR+RT should focus on improved study designs and homogeneity in this population in order to provide adequate recommendations to improve quality of life and overall health.

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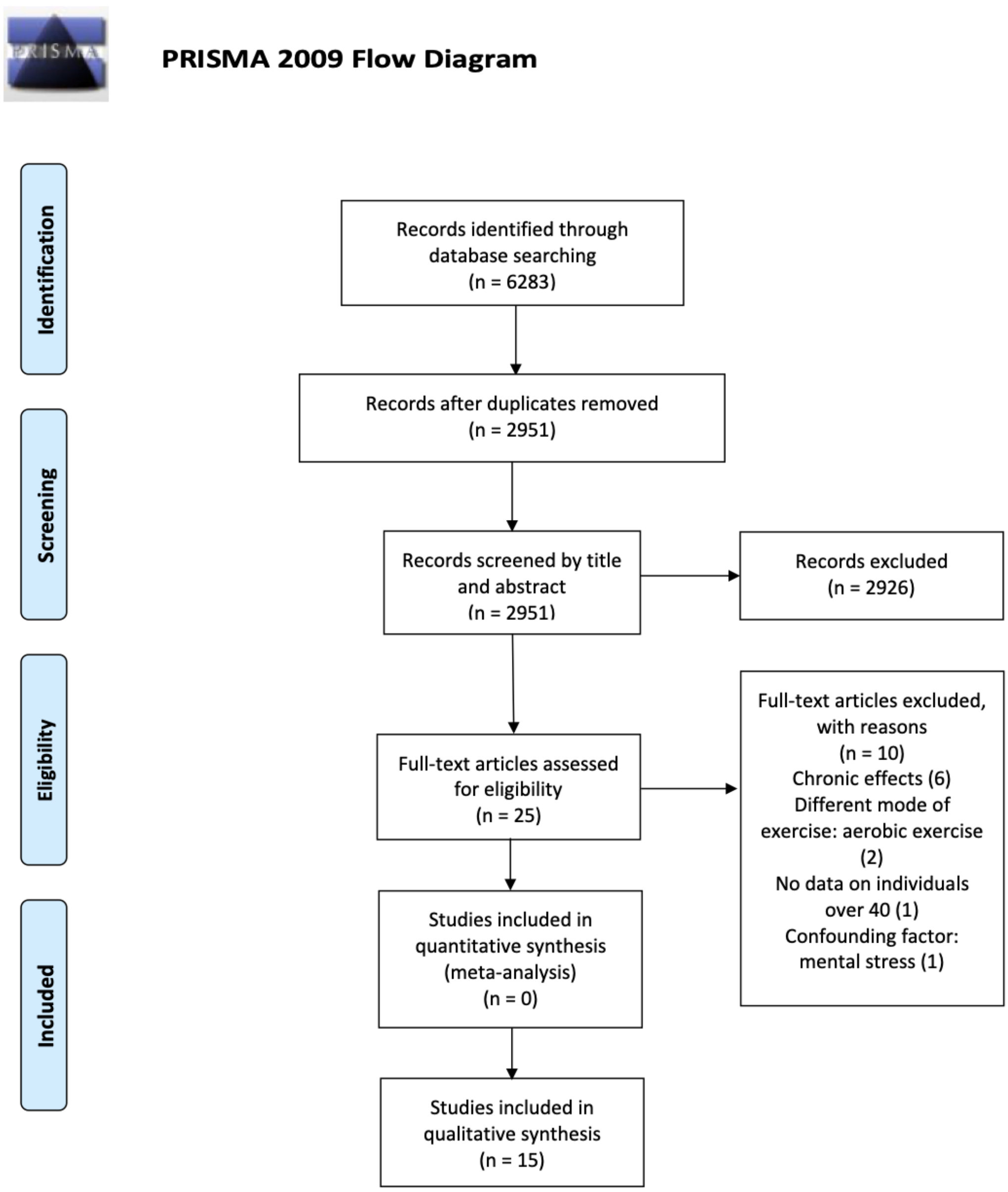
Appendix



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For more information, visit www.prisma-statement.org.

Figure 1. PRISMA Diagram

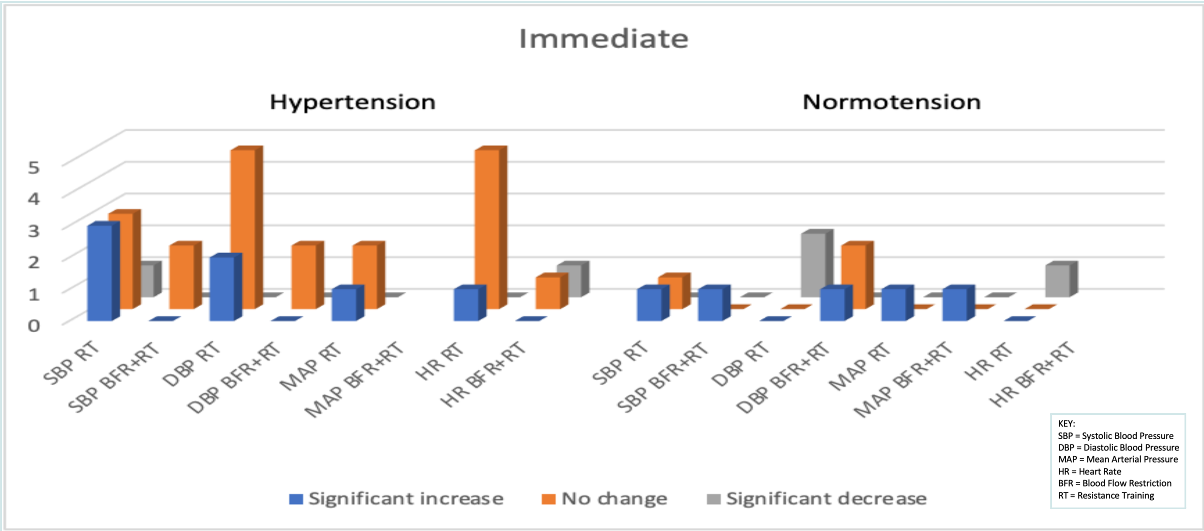

Figure 2. Immediate Hemodynamic Response for Hypertension versus Normotension

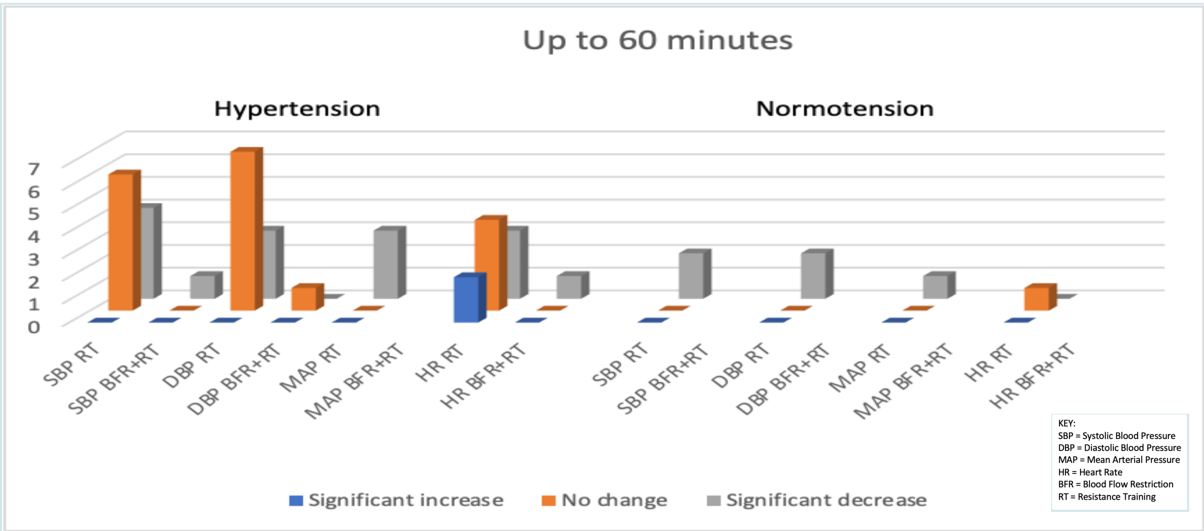

Figure 3. Up to 60 Minutes Hemodynamic Response for Hypertension versus Normotension

Table 1. Physiotherapy Evidence Database (PEDro) Scores for Included Experimental Studies

Study	PEDro											
	Eligibility Criteria Specified	Random Allocation	Concealed Allocation	Groups Similar at Baseline	Participant Masking	Therapist Masking	Assessor Masking	< 15% Drop-outs	Intention -to- Treat Analysis	Between Group Difference Reported	Point Estimate and Variability Reported	Total (0-11)
Anunciação et al (2016)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
Cavalcante et al (2015)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
Coelho-Junior et al (2017)	Y	Y	N	**Y**	Y	N	Y	Y	Y	Y	Y	9
Cunha et al (2012) delete for sure lol	Y	N	N	Y	N	N	N	N	Y	Y	Y	5
De Freitas Brito et al (2015)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	7
De Freitas Brito et al (2019)	Y	Y	N	**Y**	N	N	N	Y	Y	Y	Y	7
Gerage et al (2015)	Y	Y	N	Y	N	N	N	Y	Y	Y	N	6
Miguel et al (2012)	Y	N	N	Y	N	N	N	N	Y	Y	Y	5
Moreira et al (2014)	Y	N	N	Y	N	N	N	Y	Y	Y	Y	6
Orsano et al (2018)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
Vale et al (2018)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
Araujo et al (2014)	Y	N	N	Y	N	N	N	N	Y	Y	Y	5
Pinto et al (2016)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
Pinto et al (2018)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	6
Scott et al (2018)	Y	Y	N	**Y**	N	N	N	Y	Y	Y	Y	7

Y = yes, N = no.

Table 2. Study Characteristics

Author	Mode	Purpose	Study Design	Outcome measures	Interventions	PEDro score
Anunciação et al (2016)	Resistance training	To compare post isolated vs combined sessions of aerobic and RT in older hypertensive women.	Randomized control trial	-SBP -DBP -HR Other -HRV Measurements were taken at rest, 10, 30, 60, 120, and 180 minutes post-exercise.	4 random sessions dispersed by 48h intervals 3 experimental groups and 1 control group -Aerobic exercise session: 40 min, at 50-60% of HR reserve -RE: 8 exercises, 3 sets x 15 repetitions, at 40% 1RM. -Concurrent exercise session (A+R): AE followed by RE -Control session: 40 minutes in sitting	6
Cavalcante et al (2015)		To investigate the influence of RT sessions with different intensity on postexercise hypertension in older overweight women with controlled hypertension.	Randomized control trial	-SBP -DBP -HR Other -MAP -RPP Measurements were taken at rest, immediately after, 5, 10, 15, 30, 45, and 60 minutes post-exercise.	3 experimental sessions dispersed by 48h intervals 2 experimental groups and 1 control group -Light intensity (40%): 40 minutes, 3 sets x 10-12 repetitions -Heavy intensity (80%): 40 minutes, 3 sets x 10-12 repetitions -Control trial: 100 minutes in sitting	7
Coelho-Junior et al (2017)		To compare the acute effects of traditional moderate-intensity RT and low-to-moderate intensity power training (PT) on the hemodynamic parameters and nitric oxide (NO) bioavailability of older women.	Randomized control trial	-SBP -DBP -HR Other -MAP -DP -NO Measurements were taken at rest, immediately after, 5, 10, 15, 30, 45, and 60 minutes post-exercise.	1 single session each group 2 experimental groups and 1 control group, 50 minutes each -PT- 3 sets x 8-10 repetitions (3 Borg Scale) -RT- 3 sets x 8-10 repetitions (5-6 Borg Scale) -Control session- Resting	9
Cunha et al (2012)		To determine the subacute blood pressure behavior of pharmacologically- treated elderly hypertensive subjects after a session of resistance exercise.	Controlled clinical trial	-SBP -DBP Measurements were taken at rest, immediately after, and every 10 minutes up to 60 minutes post-exercise.	All participants underwent both conditions -Experimental control group- 3 sets x 8-10 repetitions, 10RM -Control Protocol- No exercise, but participants were allowed to sit, stand, drink water, go to the bathroom or talk.	5
De Freitas Brito et al (2015)		To determine how high-intensity RE affects BP, HR, cardiac autonomic modulation, and forearm blood flow in hypertensive older women.	Randomized control trial	-SBP -DBP -HR Other -MAP -HRV -Forearm blood flow	All participants underwent 3 randomized experimental sessions (20 minutes each) dispersed by 48 hours intervals 2 experimental and 1 control -RE at 50% 1RM, 10 exercises of 1 set x10 repetitions -RE at 80% 1RM, 10 exercises of 1 set x10 repetitions -Control session- Resting	7

				Measurements were taken at rest, 10, 30, 50, 70, and 90 minutes post-exercise.		
De Freitas Brito et al (2019)		To determine the effect of an exercise session with 1 set versus an exercise session with 3 sets on postexercise hypotension, forearm blood flow, and cardiac autonomic balance in hypertensive older women.	Randomized control trial	-SBP -DBP -HR Other -MAP -HRV -Forearm blood flow (FBF) Measurements were taken at rest, 10, 30, 50, 70, and 90 minutes post-exercise.	All participants underwent 3 randomized sessions dispersed by at least 7 days 2 experimental sessions and 1 control session -RE with 1 set: 50% 1RM, 10 exercises x10 repetitions -RE with 3 sets: 50% 1RM,10 exercises x10 repetitions -Control session: UNSPECIFIED	7
Gerage et al (2015)		To determine the effects of 12 weeks of resistance training on blood pressure in normotensive older women Reporting only on acute	Randomized control trial	-SBP -DBP Other -MAP Measurements were taken at rest,15, 30, 60, and 90 minutes post-exercise.	1 single session each group 1 experimental group, and 1 control -RE: 8 exercises, 2 sets x10-15 repetitions (unspecified intensity) -Control: stretching exercises, 2 sets x20 seconds each	6
Miguel et al (2012)		To compare the cardiovascular response during and after RT in mildly hypertensive women receiving 40 mg/day of propanolol with normotensive women.	Quasi-experimental	-SBP -DBP -HR Other -RPP Measurements were taken at rest, immediately after the first, second and third sets, and 5 and 30 minutes post-exercise.	1 single session each group -Normotensive: 3 sets x10 repetitions at 80% 10RM -Hypertensive: 3 sets x10 repetitions at 80% 10RM	5
Moreira et al (2014)		To assess the changes in BP before and after acute and chronic RE, and to analyze the relation between the acute changes in resting BP after a single bout of RE and the changes in resting BP after RE training. (Reporting only on acute)	Quasi-experimental	-SBP -DBP -HR Other -MAP -RPP Measurements were taken at rest, and 60 minutes post-exercise.	1 single session -RE: 10 exercises, 3 sets x12 repetitions at 60% 1RM.	6
Orsano et al (2018)		To compare the acute effects of traditional RE training versus HVRT on metabolic, cardiovascular, and psychophysiological responses in elderly hypertensive women.	Randomized control trial	-SBP -DBP -HR Other -RPP -NO -Blood lactate -Oxidative damage BP and HR measurements were taken at rest, after 15 minutes of seated rest (0) and at 5, 15, 30, and 45 minutes after the RE sessions.	2 groups completed 1 single session of each protocol 10 exercises, 3 sets x10 repetitions at 70% 10RM -RE: concentric/eccentric phase 2-3 sec each (moderate pace) -HVRT: concentric phase fast, eccentric phase 2-3 sec	6

				Blood samples were collected before, 3, 15, and 30 minutes post-exercise.		
Vale et al (2018)		To analyze and compare the effects of different protocols of high intensity of effort RE on autonomic cardiac modulation of hypertensive women.	Randomized control trial	-SBP -DBP -HR Other -HRV -DP Measurements were taken at rest, immediately after, 60 minutes, and 24h post-exercise.	All participants underwent 3 randomized sessions dispersed by 3 days 2 experimental sessions and 1 control. -RE 15RM: 3 exercises, lighter intensities and higher number of repetitions (3 sets x15 repetitions) -RE 6RM: 3 exercises, heavier intensities and lower number of repetitions (3 sets x6 repetitions) -Control trial: 20 minutes of rest	6
Araujo et al (2014)	Blood Flow resistance training and Resistance training	To examine the acute effects of low-intensity resistance training with blood flow restriction (LIBFR) and moderate-intensity resistance (MI) training on blood pressure and the heart rate before, during and after the exercise.	Randomized control trial	-SBP -DBP -HR Measurements were taken at rest, immediately after the first, second and third sets, and 15, 30, 45, and 60 minutes post-exercise.	2 experimental groups with 3 sets x15 repetitions each -MI: 50% 1RM intensity, 1 min rest periods between sets. -LIBFR: 30% 1RM, rest period of 45 seconds between sets.	5
Pinto et al (2016)		To compare the haemodynamic responses during low-resistance exercise with BFR to high-resistance exercise without BFR in hypertensive patients.	Randomized control trial	-SBP -DBP -HR Others: -CO -SV -Systemic vascular resistance Measurements were taken at rest, after the first, second and third set,and immediately post-exercise.	3 experimental conditions dispersed by 48h intervals 1 exercise for each condition -3 sets x15 repetitions, 20% 1RM, with BFR -3 sets x 8 repetitions, 65% 1RM -3 sets x15 repetitions, 20% 1RM	6
Pinto et al (2018)		To compare haemodynamic, rating of perceived exertion and blood lactate responses during RE with BFR compared with traditional high-intensity RE in hypertensive older women.	Randomized control trial	-SBP -DBP -HR Other -CO -SV -Rating of perceived exertion -Blood lactate Measurements were taken at rest, after the first, second and third set,and immediately post-exercise.	3 experimental conditions dispersed by 48h intervals 1 exercise for each condition -3 sets x10 repetitions, 20% 1RM with BFR -3 sets x10 repetitions, 65% 1RM -Control: BFR without exercise	6
Scott et al (2018)		To compare the acute hemodynamic and perceptual responses during low-intensity BFR exercise to unrestricted low-intensity and high-intensity exercise in older	Randomized control trial	-SBP -DBP -HR Other	3 experimental sessions -Low-intensity exercise: 20% 1RM, including 1 set x20 repetitions followed by 2 sets x15 repetitions -Low-intensity exercise with BFR: 20% 1RM, including 1 set x20 repetitions followed by 2 sets x15 repetitions	7

		women, and to determine whether these responses depend on the type of exercise performed.		-CO -SV -Muscle soreness 24 hrs after exercise -MAP HR, CO, SV, were measured during exercise at a beat-by-beat frequency Measurements were taken at rest, after the first, second, and third set post-exercise.	-High-intensity exercise: 70% 1RM, 3 sets x10 repetitions,	

Abbreviations: SBP (Systolic blood pressure), DBP (Diastolic blood pressure), MAP (Mean arterial pressure), HR (Heart rate), HRV (Heart rate variability), RPP (Rate pressure product), Cardiac output (CO), Stroke volume (SV), NO (Nitric oxide), Double product (DP) RM (repetition maximum), RE (resistance exercise), BFR (blood flow restriction)

Table 3. Participant Characteristics

Author/Publication year	**Number of Participants**	**Age (years)**	**Population**
Anunciação et al (2016)	21	63 ± 1.9	Sedentary and Controlled Hypertensive
Araujo et al (2014)	14	45 ± 9	Untrained and Hypertensive Stage 1
Cavalcante et al (2015)	20	65 ± 3	Untrained and Controlled Hypertensive
Coelho-Junior et al (2017)	21	67.1 ± 4.6	Untrained Mixed Hypertensive and Normotensive
Cunha et al (2012)	30	66.9 ± 4.63	Controlled Hypertensive
De Freitas Brito et al (2015)	16	56 ± 3	Controlled Hypertensive
De Freitas Brito et al (2019)	16	55.5 ± 3	Controlled Hypertensive
Gerage et al (2015)	28	Training group (TG): 65.5 ± 5.0 Control group (CG): 66.2 ± 4.1	Untrained and Normotensive
Miguel et al (2012)	20	Normotensive (N): 52.1 ± 10.7 Hypertensive (H): 56.5 ± 9.6	Untrained and Controlled Hypertensive (n = 10) Untrained and Normotensive (n = 10)
Moreira et al (2014)	20	66.8 ± 5.6	Sedentary and Controlled Hypertensive
Orsano et al (2018)	15	67.1 ± 6.9	Untrained and Sedentary Hypertensive Stage 1 or 2

			(33% not medicated, 60-70% medicated)
Pinto et al (2016)	12	57 ± 7	Sedentary and Controlled Hypertensive
Pinto et al (2018)	18	67.0 ± 1.7	Sedentary and Controlled Hypertensive
Scott et al (2018)	15	66.8 ± 3.8	Untrained and Normotensive
Vale et al (2018)	15	57.73 ± 6.11	Untrained and Hypertensive

Data presented as Mean±SD

Table 4. Outcome Measures

Author/Publication year	Systolic Blood Pressure (mmHg)	Diastolic Pressure (mmHg)	Heart Rate (BPM)
Anunciação et al (2016)	*Resting* Control: 132.6 ± 2.7 Resistance Exercise (RE): 136.0 ± 3.3 *10 minutes post-intervention* Control: 134.7 ± 3.1 RE: 131.2 ± 4.4 *30 minutes post-intervention* Control: 133.0 ± 2.9 RE: 131.7 ± 2.9 *60 minutes post-intervention* Control: 138.2 ± 3.1 RE: 135.5 ± 2.9 *120 minutes post-intervention* Control: 141.1 ± 2.9 RE: 137.5 ± 3.2 *180 minutes post-intervention* Control: 144.8 ± 3.4 RE: 136.9 ± 1.7	*Resting* Control: 77.1 ± 2.4 RE: 77.6 ± 3.6 *10 minutes post-intervention* Control: 78.2 ± 4.3 RE: 79.1 ± 2.9 *30 minutes post-intervention* Control: 77.6 ± 3.5 RE: 78.0 ± 3.9 *60 minutes post-intervention* Control: 79.5 ± 3.8 RE: 78.8 ± 2.9 *120 minutes post-intervention* Control: 92.3 ± 4.1 RE: 81.6 ± 4.1 *180 minutes post-intervention* Control: 93.5 ± 2.7 RE: 80.1 ± 3.4	*Resting* Control: 78.5 ± 3.1 RE: 79.4 ± 3.2 *10 minutes post-intervention* Control: 74.8 ± 2.5 RE: 76.7 ± 1.8 *30 minutes post-intervention* Control: 75.3 ± 2.8 RE: 74.2 ± 2.2 *60 minutes post-intervention* Control: 74.3 ± 2.7 RE: 75.7 ± 1.3 *120 minutes post-intervention* Control: 73.6 ± 2.7 RE: 74.6 ± 2.1 *180 minutes post-intervention* Control: 73.4 ± 2.7 RE: 75.1 ± 3.0
Cavalcante et al (2015)	*Resting* 40% 1RM: 123 ± 3 80% 1RM: 124 ± 4 *Immediately Post-exercise* 40% 1RM: 133 ± 4 80% 1RM: 139 ± 4	*Resting* 40% 1RM: 85 ± 3 80% 1RM: 84 ± 3 *Immediately Post-exercise* 40% 1RM: 92 ± 2 80% 1RM: 93 ± 3	*Resting* 40% 1RM: 80 ± 4 80% 1RM: 79 ± 4 *Immediately Post-exercise* 40% 1RM: 90 ± 3 80% 1RM: 92 ± 3
Coelho-Junior et al (2017)	*Resting** Control Session (CS): 129.8 ± 11.9 Resistance Training (RT): 137.4 ± 17.1	*Resting** CS: 77.2 ± 13.6 RT: 87.5 ± 21.5	*Resting** CS: 77.1 ± 11.4 RT: 79.3 ± 11.8

	Cohen's d *Immediately Post-exercise* CS: 0.40 (trivial) RT: -0.43 (trivial) *5 minutes post-exercise* CS: -0.15 (trivial) RT: 0.30 (trivial) *10 minutes post-exercise* CS: -0.26 (trivial) RT: 0.67 (small) *15 minutes post-exercise* CS: -0.40 (trivial) RT: 0.55 (small) *30 minutes post-exercise* CS: -0.26 (trivial) RT: 0.48 (trivial) *45 minutes post-exercise* CS: -0.32 (trivial) RT: 0.74 (small) *60 minutes post-exercise* CS: -0.22 (trivial) RT: 0.49 (trivial)	***Cohen's d*** *Immediately Post-exercise* CS: 0.66 (small) RT: -1.19 (small) *5 minutes post-exercise* CS: 0.12 (trivial) RT: -0.15 (trivial) *10 minutes post-exercise* CS: -0.36 (trivial) RT: 0.43 (trivial) *15 minutes post-exercise* CS: -0.14 (trivial) RT: 0.36 (trivial) *30 minutes post-exercise* CS: 0 (trivial) RT: 0.72 (small) *45 minutes post-exercise* CS: -0.13 (trivial) RT: 0.24 (trivial) *60 minutes post-exercise* CS: -0.41 (trivial) RT: 0.63 (small)	***Cohen's d*** *Immediately Post-exercise* CS: 0 (trivial) RT: 0.43 (trivial) *5 minutes post-exercise* CS: 0 (trivial) RT: 0.64 (small) *10 minutes post-exercise* CS: -0.18 (trivial) RT: 0.89 (small) *15 minutes post-exercise* CS: 0.25 (trivial) RT: 0.59 (small) *30 minutes post-exercise* CS: 0.18 (trivial) RT: 0.73 (small) *45 minutes post-exercise* CS: 0 (trivial) RT: 1.02 (small) *60 minutes post-exercise* CS: -0.31 (trivial) RT: 1.24 (small)
Cunha et al (2012)	*Baseline* Experimental protocol (EP): 134.41 ± 17.50 Control protocol (CP): 127.75 ± 16.93 *Immediately post-exercise* EP: 136.48 ± 16.16 CP: 129.96 ± 13.68 *10 minutes post-exercise* EP: 126.81 ± 16.16 CP: 124.25 ± 13.65	*Baseline* EP: 81.65 ± 10.57 CP: 80.38 ± 11.84 *Immediately post-exercise* EP: 80.03 ± 9.25 CP: 80.68 ± 11.07 *10 minutes post-exercise* EP: 76.35 ± 10.28 CP: 78.25 ± 10.50	*Not reported*

	20 minutes post-exercise EP: 123.73 ± 15.32 CP: 121.66 ± 14.34 *30 minutes post-exercise* EP: 123.36 ± 17.33 CP: 121.88 ± 13.33 *40 minutes post-exercise* EP: 124.46 ± 16.19 CP: 121.16 ± 13.11 *50 minutes post-exercise* EP: 124.43 ± 17.02 CP: 122.28 ±13.65 *60 minutes post-exercise* EP: 127.78 ± 15.89 CP: 125.83 ± 12.95	*20 minutes post-exercise* EP: 75.73 ± 10.76 CP: 77.16 ± 9.47 *30 minutes post-exercise* EP: 74.80 ± 10.52 CP: 77.31 ± 9.42 *40 minutes post-exercise* EP: 74.20 ± 10.58 CP: 77.36 ± 10.40 *50 minutes post-exercise* EP: 76.00 ± 9.71 CP: 77.90 ± 9.92 *60 minutes post-exercise* EP: 77.98 ± 9.72 CP: 76.96 ± 9.9	
De Freitas Brito et al (2015)	*Baseline Measurements for each session* control (CS): 145 ± 3 RE at 50% (EX50%) of 1 repetition maximum (1RM): 147 ± 4 RE at 80% (EX80%) of 1RM: 148 ± 4 *Not reported**	*Baseline Measurements for each session* CS: 92 ± 4 EX50% of 1RM: 93 ± 4 EX80% of 1RM: 90 ± 4 *Not reported**	*Baseline Measurements for each session* CS: 87 ± 4 EX50% of 1RM: 85 ± 4 EX80% of 1RM: 84 ± 4 *10 minutes post-exercise* CS: 86 ± 4 EX50% of 1RM: 90 ± 4 EX80% of 1RM: 96 ± 3 *30 minutes post-exercise* CS: 83 ± 4 EX50% of 1RM: 88 ± 4 EX80% of 1RM: 93 ± 3 *50 minutes post-exercise* CS: 85 ± 4 EX50% of 1RM: 89 ± 3 EX80% of 1RM: 90 ± 3

			70 minutes post-exercise CS: 82 ± 4 EX50% of 1RM: 84 ± 4 EX80% of 1RM: 86 ± 3 *90 minutes post-exercise* CS: 85 ± 4 EX50% of 1RM: 84 ± 3 EX80% of 1RM: 82 ± 2
De Freitas Brito et al (2019)	*Baseline* Control group: 145±3 S1 (RE with 1 set): 147±4 S3 (RE with 3 sets): 143±3	*Baseline* Control group: 92±4 S1 (RE with 1 set): 93±4 S3 (RE with 3 sets): 94±5	*Baseline* Control group: 85±4 S1 (RE with 1 set): 80±6 S3 (RE with 3 sets): 86±5
Gerage et al (2015)	*Not reported**	*Not reported**	*Not reported*
Miguel et al (2012)	*Resting* Normotensive (N): 129 ± 6.9 Hypertensive (H): 125 ± 10.8 *Set 1* N: 151 ± 9.0 H: 146 ± 11.7 *Set 2* N: 166 ± 7.2 H: 143 ± 8.2 *Set 3* N: 171 ± 6.7 H: 152 ± 9.2 *5 minutes post-exercise* N: 119 ± 10.7 H: 111 ± 9.9	*Resting* N: 89 ± 6.9 H: 83 ± 10.6 *Set 1* N: 90 ± 5.8 H: 90 ± 9.4 *Set 2* N: 100 ± 6.9 H: 89 ± 5.7 *Set 3* N: 103 ± 10.5 H: 88 ± 7.9 *5 minutes post-exercise* N: 81 ± 9.0 H: 74 ± 7.0	*Resting* N: 74 ± 5.3 H: 63 ± 5.8 *Set 1* N: 93 ± 8.5 H: 79 ± 8.7 *Set 2* N: 100 ± 7.0 H: 85 ± 10.4 *Set 3* N: 104 ± 10.5 H: 82 ± 11.8 *5 minutes post-exercise* N: 73 ± 8.0 H: 61 ± 4.4

	30 minutes post-exercise N: 119 ± 9.0 H: 117 ± 9.5	*30 minutes post-exercise* N: 80 ± 8.2 H: 79 ± 7.4	*30 minutes post-exercise* N: 71 ± 7.3 H: 59 ± 5.3
Moreira et al (2014)	*Resting:* 125.2 ± 9.3*	*Resting:* 72.0 ± 6.8	*Resting:* 72.2 ± 12.0
Orsano et al (2018)	*Resting:* 118.0±19.0*	*Resting:* 68.6±8.84	*Resting:* 77.26±12.70
Vale et al (2018)	*Resting* Control: 132.26±17.92 6RM: 128.33±17.07 15RM: 130.80±21.22 *Immediately Post-intervention* Control: 131.26±17.48 6RM: 140.33 ±16.99 15RM: 137.06±14.94 *1-hour post-intervention* Control: 133.73±18.39 6RM: 130.86±17.63 15RM: 130.00±17.55 *24-hours post-intervention* Control: 127.20±14.30 6RM: 129.93±16.07 15RM: 128.26±14.41	*Resting* Control: 78.06±7.30 6RM: 79.13±9.58 15RM: 77.00±7.21 *Immediately Post-exercise* Control: 78.26±8.31 6RM: 77.60±11.30 15RM: 76.20±11.02 *1-hour post-exercise* Control: 79.73±7.76 6RM: 77.86±10.82 15RM: 77.13±9.21 *24-hours post-exercise* Control: 75.00±8.76 6RM: 76.20±8.94 15RM: 77.73±9.35	*Resting* Control: 67.86±6.63 6RM: 66.00± 6.35 15RM: 68.70±9.17 *Immediately Post-exercise* Control: 65.98±7.26 6RM: 76.24±9.35 15RM: 85.32±13.21 *1-hour post-exercise* Control: 64.04±8.26 6RM: 68.59±8.66 15RM: 73.82±11.23 *24-hours post-exercise* Control: 70.67±8.36 6RM: 70.49±7.71 15RM: 72.06±9.54
Araujo et al (2014)	*Resting** Not reported Values during exercise *1st Set* Moderate Intensity (MI): 141 ± 6 Low-intensity with blood flow restriction (LIBFR): 167.4 ± 8 *2nd Set* MI: 147 ± 10 LIBFR: 183 ± 10	*Resting** Not reported Values during exercise *1st Set* MI: 87 ± 4 LIBFR: 96 ± 5 *2nd Set* MI: 86 ± 5 LIBFR: 107 ± 4	*Resting** Not reported Values during exercise *1st Set* MI: 93.5 ± 7.7 LIBFR: 107.2 ± 7.7 *2nd Set* MI: 100.5 ± 6.84 LIBFR: 115 ± 6.8

	3rd Set MI: 146 ± 10 LIBFR: 173.7 ± 9	*3rd Set* MI: 87 ± 5 LIBFR: 88 ± 6	*3rd Set* MI: 108.7 ± 7.3 LIBFR: 119.8 ± 7.3
Pinto et al (2016)	*20% 1RM with BFR* Resting: 146.2±19.6 1st set: 187.4±27.5 2nd set: 225.0±30.1 3rd set: 237.2±33.2 Post-exercise: 154.9±18.4 *20% 1RM* *Resting: 140.3*±18.2 1st set: 177.8±26.0 2nd set: 194.4±24.3 3rd set: 192.7±24.4 Post-exercise: 143.7±19.8 *65% 1RM* Resting: 145.0±23.8 1st set: 184.2±27.0 2nd set: 192.8±25.1 3rd set: 195.7±25.5 Post-exercise: 147.0±23.1	*20% 1RM with BFR* Resting: 82.2±12.5 1st set: 109.8±13.7 2nd set:130.2±16.4 3rd set: 139.4±22.2 Post-exercise: 86.3±10.7 *20% 1RM* *Resting: 76.9*±11.5 1st set: 98.3±15.2 2nd set: 108.0±14.3 3rd set: 109.4±13.5 Post-exercise: 78.9±11.7 *65% 1RM* Resting: 80.9±16.1 1st set: 107.6±20.1 2nd set: 111.5±17.7 3rd set:110.1±18.2 Post-exercise: 82.2±16.6	*20% 1RM with BFR* Resting: 76.0±10.4 1st set: 99.6±13.7 2nd set: 114.3±26.2 3rd set: 120.3±21.7 Post-exercise: 81.0±10.4 *20% 1RM* Resting: 75.2±10.3 1st set: 101.8±13.8 2nd set: 110.3±19.6 3rd set: 105.9±14.1 Post-exercise: 78.1±10.3 *65% 1RM* Resting: 75.3±10.5 1st set: 105.3±17.4 2nd set: 105.2±13.8 3rd set: 108.0± 17.5 Post-exercise: 77.6±11.7
Pinto et al (2018)	*Control (BFR without exercise)* Resting: 134.3±3.6 1st set: 143.2±5.7 2nd set: 139.7±4.9 3rd set: 140.2±4.9 Post-exercise: 133.7±4.4 *20% 1RM with BFR* Resting: 132.7±3.1 1st set: 179.8±5.4 2nd set: 210.7±6.8 3rd set: 212.2±7.5 Post-exercise: 129.8±2.9 *65% 1RM* Resting: 130.3±4.2	*Control (BFR without exercise)* Resting: 74.1±1.7 1st set: 81.2±3.1 2nd set: 81.3±2.8 3rd set: 81.3±2x8 Post-exercise: 75.7±2.3 *20% 1RM with BFR* Resting: 76.0±2.3 1st set: 100.9±3.2 2nd set: 120.9±4.5 3rd set: 123.6±5.5 Post-exercise: 74.2±2.5 *65% 1RM* Resting: 73.2±1.8	*Control (BFR without exercise)* Resting: 78.6±2.7 1st set: 78.6±2.4 2nd set: 81.2±2.5 3rd set: 81.5±2.4 Post-exercise: 82.9±2.4 *20% 1RM with BFR* Resting: 80.2±3.0 1st set: 96.1±2.6 2nd set: 99.8±3.2 3rd set: 97.9±2.9 Post-exercise: 73.7±2.0 *65% 1RM* Resting: 78.9±2.8

	1st set: 196.8±7.1 2nd set: 213.3±8.2 3rd set: 221.7±8.2 Post-exercise: 138.5±5.9	1st set: 108.8±3.5 2nd set: 119.5±4.5 3rd set: 122.6±3.9 Post-exercise: 71.1±2.4	1st set: 100.9±3.7 2nd set: 102.9±3.4 3rd set: 107.8±2.0 Post-exercise: 74.7±3.4
Scott et al (2018)	*Resting (baseline):* 120.2±13.5* *Cohen's d for higher SBP* Low intensity-BFR (LL-BFR) vs Low intensity (LL): 1.30-2.15 *p*<=0.021) LL-BFR vs high intensity (HL): .97-1.86 *p*<=0.016	*Resting:* 69.3±7.4 *Cohen's d for higher DBP* LL-BFR vs LL: 1.16-2.04; *p*<=0.001 LL-BFR vs HL: 1.21-1.82; *p*<=0.004	*Resting:* not reported *Cohen's d for lower HR* LL vs LL-BFR: 1.22-1.51; *p*<=0.002 LL vs HL: 1.51-1.58; *p*<=0.001

Data presented as Mean±SD

* = Post-exercise data shown in a figure. Exact values not provided.