Potential benefits of exercise on blood pressure and vascular function

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Abstract

Physical activity seems to enhance cardiovascular fitness during the course of the lifecycle, improve blood pressure, and is associated with decreased prevalence of hypertension and coronary heart disease. It may also delay or prevent age-related increases in arterial stiffness. It is unclear if specific exercise types (aerobic, resistance, or combination) have a better effect on blood pressure and vascular function. This review was written based on previous original articles, systematic reviews, and meta-analyses indexed on PubMed from years 1975 to 2012 to identify studies on different types of exercise and the associations or effects on blood pressure and vascular function. In summary, aerobic exercise (30 to 40 minutes of training at 60% to 85% of predicted maximal heart rate, most days of the week) appears to significantly improve blood pressure and reduce augmentation index. Resistance training (three to four sets of eight to 12 repetitions at 10 repetition maximum, 3 days a week) appears to significantly improve blood pressure, whereas combination exercise training (15 minutes of aerobic and 15 minutes of resistance, 5 days a week) is beneficial to vascular function, but at a lower scale. Aerobic exercise seems to better benefit blood pressure and vascular function.

Introduction

High blood pressure has been associated with increased risk of coronary heart disease, stroke, and heart failure.\(^1\) Hypertension, defined as a systolic blood pressure (SBP) $\geq$130 and/or diastolic blood pressure (DBP) $\geq$85 mm Hg, is a criterion of the metabolic syndrome (MS)\(^2\) with its prevalence approaching 50% worldwide.\(^3\)

Physical activity plays an important role in reducing the risk of many chronic diseases and health problems.\(^4\)\(^-\)\(^7\) By definition, physical activity is any bodily movement caused by the contraction of skeletal muscle that greatly increases energy expenditure.\(^8\) Keeping a balance between energy consumption and energy expenditure is important to prevent weight gain.\(^9\) Energy intake estimation takes into consideration the energy density of food, serving size, and frequency of consumption, whereas energy expenditure relates to the frequency of exercise (how often), intensity (how hard), and duration (how long).\(^9\) Exercise is a planned, structured, and repetitive body movement which aims to ameliorate or maintain physical fitness.\(^8\)

Studies have shown that regular physical activity can improve cardiovascular fitness during the course of the life-cycle,\(^6\) reduce blood pressure,\(^10\) and decrease prevalence of hypertension.\(^11\)\(^,\)\(^12\) Consequently, being physically active in middle age is associated with a lower risk of coronary heart disease.\(^13\) Regular exercise has also been suggested to delay or prevent age-related increases in arterial stiffness.\(^14\) Exercise training has been shown to improve both baroreflex sensitivity,\(^15\)\(^,\)\(^16\) blood pressure, and augmentation index (AI; an index of arterial stiffness which measures the reflected wave at the aorta)\(^17\) in hypertensive individuals.\(^16\)

Although exercising has been shown to improve cardiovascular risk factors, it is unclear which specific exercise modes (aerobic, resistance, or combined) have a better effect on blood pressure and vascular function. Therefore, the aim of this review is to report the benefits of the exercise modes on blood pressure and vascular function.

This review was written based on previous original articles, systematic reviews, and meta-analyses indexed on PubMed from years 1975 to 2012. A literature search was...
conducted to identify studies on different types of exercise and its associations or effects on blood pressure and vascular function. The bibliographies of some of the articles used were also searched to locate further studies.

**Aerobic and Resistance Exercise Training**

Aerobic or endurance exercise training is designed to increase aerobic endurance performance and involves large muscle group masses, leading to an increase in whole body maximal oxygen uptake (VO\textsubscript{2 max}) over the resting level, which consequently enhances energy expenditure and heart rate. Unlike resistance training, aerobic training does not produce hypertrophy of skeletal muscle. Aerobic exercise training enhances cardiac output (the amount of blood pumped from the heart in 1 minute), the density of capillaries, and myoglobin levels in skeletal muscle, which consequently contributes to an augmentation of VO\textsubscript{2 max}.

Resistance training aims to increase muscular strength (generates force) and power (performance rate), as well as endurance (repetitive contractions against a resistance), by involving strength, weight, and static and/or isometric exercises. It usually does not enhance VO\textsubscript{2 max}. Resistance exercise training is generally short and intensive and incorporates repetitive movement and overload stimulus, which increases muscle strength and induces muscle hypertrophy (enlargement of muscle cells). In general, loads below 60% fail to achieve improvements in muscle strength. Effective resistance training leads the muscle to fatigue, such that each set or at least the last set of an exercise repetition fails to be satisfactorily performed.

**Continuous vs. Discontinuous Training**

Few studies have investigated the role of continuous vs. discontinuous exercise training on cardioprotection, finding little differences in the response between both types of exercises. Continuous and discontinuous (2-minute intervals) knee extension exercises (four sets of eight repetition maximum (RM)) were performed to compare the effects of both exercise formats on blood pressure in men. Although the authors found discontinuous exercise led to greater blood pressure responses, the authors advise that further studies are needed to support their findings, due to some limitations of the study protocol. Therefore, there is need for further investigation on this area before recommendations can be definitively made.

**Effects of Different Exercise Modes on Blood Pressure and Vascular Function**

**Blood Pressure**

Improvements in blood pressure have been seen after aerobic, resistance, and a combination of aerobic and resistance exercise training compared to controls (no exercise).

**Aerobic or Resistance Training on Blood Pressure**

Three months of mild (50% VO\textsubscript{2 max}) aerobic exercise training (30 minutes, 5 days per week) significantly decreased resting blood pressure in older (59–69 years; n = 15), sedentary, normotensive (<140/90 mm Hg) women. Compared with baseline, aerobic training significantly reduced SBP (124 ± 13 vs. 112 ± 9 mm Hg; P < .05) and DBP (73 ± 11 vs. 66 ± 6 mm Hg; P < .05). While blood pressure at rest significantly decreased after exercise training, plasma concentration of nitric oxide (NO) significantly increased, suggesting that even mild regular aerobic-endurance exercise increases NO production in previously sedentary older humans, which may have beneficial effects (ie, antihypertensive and anti-atherosclerotic effects by endogenous NO) on the cardiovascular system. Aerobic exercise training (3 days a week on a cycle ergometer for 30–50 minutes) for 20 weeks was found to improve the components of the MS in 30% of the 105 participants. Of the 30% who improved their metabolic profile, 38% presented a significant decrease in blood pressure (P < .05) after aerobic exercise training. In addition, 30 minutes of moderate intensity walking a day significantly decreased SBP (by 6 mm Hg after 12 weeks [142 ± 3 to 136 ± 2 mm Hg; P < .005] and by 5 mm Hg at 24 weeks; P < .005) from baseline in postmenopausal women with hypertension. A meta-analysis including 72 trials with 105 study groups and 3936 participants demonstrated a significant reduction of SBP associated with aerobic training (−3.3/−3.5 mm Hg; P < .01), with a more pronounced reduction found in 30 hypertensive study groups (−6.9/−4.9 mm Hg) than in those without hypertension (−1.9/−1.6 mm Hg; P < .001 for all). Study duration in this meta-analysis varied from 4 to 52 weeks (median, 16 weeks). Average training frequency ranged from 1 to 7 days/week (median, 3 days/week), and average intensity was between 30% and 87.5% of heart rate reserve (median, 65%) involving walking, jogging, running, and/or cycling. Each training session lasted an average of 40 minutes. In contrast, a study with healthy, sedentary subjects without hypertension, aged 45.7 ± 9.4 years found 60 minutes of walking (either single bouts of 20 minutes on 3 days per week, or accumulated bouts of two 10 minutes walks on 3 days per week) for 12 weeks was not sufficient to cause changes in blood pressure post-intervention or compared with control. The authors acknowledged that changes were unlikely to occur, as the subjects were normotensive.

The results from the above studies suggest that improvements to blood pressure from exercise training are dependent on the amount of exercise performed. The studies above demonstrate that most overweight and obese individuals...
can improve their SBP levels by approximately 3 to 5 mm Hg from baseline by engaging in 30 minutes of moderate-intensity exercise most days of the week, while a greater amount of exercise may lead to even greater improvements to blood pressure.

Although aerobic exercise seems to improve blood pressure in interventional studies compared with baseline or no exercise, it is still controversial whether aerobic exercise plays a major role in improving blood pressure when compared with resistance exercise training. Some studies have compared the effects of aerobic exercise with resistance training. In one of these studies, aerobic training included 30 minutes of treadmill walking at 65% of participant’s previously determined VO2max, 3 days per week, and resistance included three sets of 10 repetitions at 65% of their 10 RM, 3 days per week.

Blood pressure significantly decreased in a similar manner following both training modes (SBP resistance: pre 136 ± 2.9 vs. post 132 ± 3.4; SBP aerobic: pre 141 ± 3.8 vs. post 136 ± 3.4 mm Hg; P = .005; and DBP resistance: pre 78 ± 1.3 vs. post 74 ± 1.6; DBP aerobic: pre 80 ± 1.6 vs. post 77 ± 1.7 mm Hg; P = .001) for 4 weeks in pre- or stage-1 essential hypertensive (n = 31) men and women. A 12-week study with obese women with normal or slightly elevated blood pressure did not observe significant changes in both SBP and DBP after 12 weeks of either aerobic (15–45 minutes of brisk walking plus leg cycle ergometer, 3–5 days a week, at 50%–85% of heart rate reserve) or resistance training (one to three sets of 10 repetitions) compared with control (P > .05). The authors suggest that the lack of improvement in SBP and DBP was due to the fact that the participants were all normotensive at baseline (resistance: SBP 126 ± 11 and DBP 79 ± 9 mm Hg; aerobic: SBP 126 ± 19 and DBP 80 ± 10 mm Hg) and did not lose large amounts of weight throughout the intervention, which could have led to a greater decrease in blood pressure. Both SBP and DBP significantly decreased compared with baseline in both interventions. Another study evaluated the effects of aerobic (40 minutes at 60%–85% of predicted maximal heart rate) and resistance (three sets of 10 repetitions) training, three times a week in untrained male volunteers (n = 26) exhibiting android obesity (ie, a waist to hip ratio >0.95 and a body mass index >27 kg/m²). There was no significant change in mean arterial blood pressure in either group after 10 weeks. However, after analyzing a subgroup of individuals with elevated DBP (>90 mm Hg), only aerobic training significantly decreased DBP (pre-training 95.5 ± 11.0 and post-training 92.2 ± 6.5 mm Hg; P < .05), while resistance training did not (pre-training 95.0 ± 8.5 and post-training 94.5 ± 4.5 mm Hg; P > .05).

A meta-analysis of nine randomized controlled trials involving 341 participants found resistance training produced a decrease in DBP of 3.5 mm Hg and a non-significant reduction in SBP of 3.2 mm Hg. Interventions varied from 6 to 26 weeks (median, 14 weeks) of two to three weekly sessions with intensity ranging from 30% to 90% (median, 70%) of 1RM.

Collectively, both aerobic exercise and resistance training seem to improve blood pressure similarly in normotensive or slightly hypertensive adults compared with baseline. However, there seems to be no difference between the two types of exercise interventions. Thirty minutes of aerobic exercise for at least 3 days a week, as well as three sets of 10 repetitions of resistance exercise can decrease blood pressure in a similar manner in overweight/obese individuals with normal or slightly elevated blood pressure.

**Combined Training on Blood Pressure**

A limited number of studies have investigated the effects of combined aerobic and resistance exercise training on blood pressure. In addition, the findings of these studies are conflicting. Aerobic (rhythmic continuous movements according to the music) plus resistance (squats, side leg raises, inner thigh lifts, wall press-ups, triceps presses, and abdominal exercises) training combined (40 minute sessions twice a week) has been found to significantly decrease SBP and DBP compared with the control group (SBP, 79.3 ± 7 vs. 82.2 ± 10 mm Hg, and DBP, 134 ± 16 mm Hg vs. 138.8 ± 17 mm Hg, respectively; P < .05) in overweight, older (age 63 ± 4 years) participants (n = 13 exercisers, n = 13 controls) after 12 weeks of training. Likewise, a study of 24 postmenopausal women who were randomly assigned to a no exercise control (n = 12) or combined exercise training group (circuit of resistance training plus aerobic training at 60% of the predicted maximal heart rate 3 days per week; n = 12) for 12 weeks found SBP (−6.0 ± 1.9 mm Hg) and DBP (−4.8 ± 1.7 mm Hg) in the combined exercise group significantly decreased compared with control (0.2 ± 2.1 and 0.5 ± 1.5 mm Hg, respectively; P < .05). Interestingly a 12-week study of participants with type 2 diabetes who were randomly assigned to four groups (three times a week, 60 minutes per session): aerobic group (cycling at the heart rate corresponding to the lactate threshold), resistance group (seven-exercise circuit as follows: leg press, bench press, lat pull down, seated rowing, shoulder press, abdominal curls, and knee curls), combined (aerobic plus resistance) group, and control group, observed a similar reduction in blood pressure in all groups from baseline (SBP in control, 136 ± 16 vs. 124 ± 17 mm Hg; aerobic, 141 ± 14 vs. 131 ± 16 mm Hg; resistance, 135 ± 20 vs. 125 ± 14 mm Hg; combined, 132 ± 16 vs. 129 ± 12 mm Hg; all P < .05; and DBP in control, 85 ± 7 vs. 78 ± 10 mm Hg; aerobic, 89 ± 13 vs. 80 ± 10 mm Hg; resistance, 84 ± 14 vs. 81 ± 10 mm Hg; combined, 86 ± 9 vs. 79 ± 4 mm Hg; all P > .05).
The authors suggest that the lack of improvement in the exercise groups compared with control might have been due to the absence of weight loss in the exercise training groups. A 12-week study including overweight and obese individuals with and without hypertension, undertaking no exercise (control) or moderate intensity aerobic (30 minutes on a treadmill), resistance (four sets of 8-12 repetitions at 10 RM: level of leg press, leg curl, leg extension, bench press, rear deltoid row for 30 minutes) or combination (15 minutes of aerobic and 15 minutes of resistance) exercise training, 5 days a week, did not observe any changes on blood pressure levels when assessing all participants in the study; however, in a subgroup of individuals who significantly improved their SBP, all modes of exercise training significantly reduced SBP at 8 weeks compared with baseline (aerobic, –4%; P < .027; resistance, –5.1%; P < .04; combination, –6.3%; P < .0001). In addition, the combination exercise significantly decreased SBP (–6.3%; P < .005) at 12 weeks compared with baseline.

Collectively, 40 minutes of combined exercise, two to three times a week for 12 weeks appears to improve both SBP and DBP compared with control groups in overweight but otherwise healthy individuals. However, this was not demonstrated in a study with participants with type 2 diabetes, which might have been due to the absence of weight loss in those individuals.

### Training in Men versus Women

Although the impact of risk factors for cardiovascular disease is different in women and men, the beneficial effects of exercise training on cardioprotection according to gender it is still unknown.41 A recent study with men and women observed significantly greater reductions in women in SBP (men vs. women, –5.4 vs. –10.6 mm Hg; P = .021) and DBP (men vs. women, –3.4 vs. –6.1 mm Hg; P = .023) after adjusting for confounding factor age, and change in body weight.42 In addition, two meta-analyses also observed a greater blood pressure reduction in women caused by exercise training compared with men.41,43 In contrast, two studies, including a meta-analysis,3,39 reported no differences of exercise training on blood pressure between genders.

Some mechanisms have been proposed to explain the gender differences in reduction of blood pressure caused by exercise training. Considering older adults, the greater improvements in blood pressure seen in women could be due to the greater reduction in the activity of the sympathetic nervous system compared with men,44,45 as well as the existence of a closer link between blood pressure and sympathetic nervous activity in the female population.44,45 However, studies have also found exercise training to improve not only sympathetic nervous activity, but also the parasympathetic.46 Aerobic training seems to decrease blood pressure due to lower systemic vascular resistance involving the sympathetic nervous system and the renin-angiotensin system.42 Hormonal parameters may also be involved in the gender differences in the reduction of blood pressure as the female hormone estrogen can reduce vascular tone by modulating the renin-angiotensin system; whereas the main male hormone testosterone appears to stimulate it.48 Women may also present more significant changes in arterial stiffness and endothelial function, which could partly explain the changes between genders, although further studies are necessary to confirm the current findings.42

### Potential Mechanisms

The mechanisms by which exercise training in general improves blood pressure may be by influencing NO production.49 Regular exercise has been shown to significantly decrease the concentration of plasma endothelin-1 (ET-1), a potent vasoconstrictor peptide produced by vascular endothelial cells, which might contribute to the increased production of NO as shown in older women.50 Furthermore, the increased NO production may be due to increased blood flow velocity induced by exercise, as an in vitro study suggested that mechanical deformation of the endothelium by shear or cyclic stretching increases (eNOS) gene expression, proteins, and activity.51 However, the mechanisms of NO production by exercise training remain to be elucidated.

In summary, the improvements in blood pressure caused by aerobic exercise seem to be dose-related, as a 30-minute walk most days of the week, was enough to decrease blood pressure significantly. Greater amounts of aerobic exercise may lead to even greater improvements to blood pressure. Thirty minutes of resistance training ranging from two to three weekly sessions of median 70% RM, for an average of 12 weeks, seems to improve both DBP and SBP. Data on the effect of combined exercise on blood pressure are inconsistent, with some, but not all studies showing greater benefits of combination exercise training, compared with aerobic or resistance alone. The studies mentioned in this section are summarized in Table 1. Overall, regular exercise as a combination of aerobic and resistance training appears to decrease cardiovascular disease risk.38,52,53

### Vascular Function

The endothelium is an organ with multiple functions, playing an essential role on the normal vascular physiology of blood vessels, as it covers the interior of the vessels.54 Endothelial dysfunction is an early and integral marker of atherosclerosis,21 which is caused by the imbalance between relaxation and contraction factors of the endothelium.55 Cardiovascular diseases can be predicted by following the progression of endothelial dysfunction in coronary arteries to atherosclerosis.21 Endothelial dysfunction also plays an important role in hypertension and thrombosis56 and contributes to increased arterial stiffness of both larger and
<table>
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<tr>
<td>Banz et al. [34]</td>
<td>Untrained males (n = 26) exhibiting android-shaped obesity, with at least one clinically diagnosed risk factor associated with the MS, mean BP 133 ± 90 mm Hg</td>
<td>10 weeks</td>
<td>Aerobic (40 min of training at 60%–85% of each subject’s predicted maximal HR) and resistance (3 sets of 10 lifts including military press, leg extension, bench press, leg curl, lateral pull-down, triceps push-down, biceps curl, and sit-ups), 3 times a week</td>
<td>There were no significant changes in mean BP in either group. Aerobic training significantly reduced DBP (DBP pre-training 95.5 ± 11.0 vs. post-training 92.2 ± 6.5; P &lt; .05), in a subgroup of individuals with elevated DBP (&gt;90 mm Hg)</td>
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<td>Collier et al. [30]</td>
<td>Pre- or stage-1 essential hypertensive (n = 31) men and women, mean BP aerobic: 141 ± 80, resistance: 136 ± 78 mm Hg</td>
<td>4 weeks</td>
<td>Resistance (3 sets of 10 repetitions at 65% of their 10 RM, 45–50 minutes, 3 days a week), or aerobic (30 minutes of treadmill walking at 65% of their previously determined VO₂ peak, 3 days a week)</td>
<td>Both resistance and aerobic trainings significantly decreased SBP (resistance: pre 136 ± 2.9 vs. post 132 ± 3.4; aerobic: pre 141 ± 3.8 vs. post 136 ± 3.4 mm Hg; P = .005) and DBP (resistance: pre 78 ± 1.3 vs. post 74 ± 1.6; aerobic: pre 80 ± 1.6 vs. post 77 ± 1.7 mm Hg; P = .001)</td>
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<tr>
<td>Fagard [28]</td>
<td>Healthy sedentary normotensive and/or hypertensive adults (72 trials, 105 studies), mean BP 128 ± 82 mm Hg</td>
<td>Varied from 4 to 52 weeks</td>
<td>Aerobic physical training as the sole intervention. Median training sessions was 40 min, 3 days a week, and median intensity was 65% of HR</td>
<td>Aerobic training significantly reduced BP 3.3/3.5 mm Hg (P &lt; .01), with reduction being more pronounced in 30 hypertensive study groups (−6.9/−4.9) than in the others (−1.9/−1.6; P &lt; .001 for all)</td>
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<tr>
<td>Fagard [28]</td>
<td>Healthy sedentary normotensive and/or hypertensive adults (9 RCT, 12 studies), mean BP 131 ± 81 mm Hg</td>
<td>Varied from 6 to 26 weeks, median 14 weeks</td>
<td>Resistance training as the sole intervention. Frequency of sessions was twice weekly in 2 study groups and 3 times a week in 10 study groups and median intensity was 70% of one RM</td>
<td>Resistance exercise was associated with reduction of DBP (−3.5 mm Hg; P &lt; .01)</td>
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<td>Figueroa et al. [36]</td>
<td>Postmenopausal women (n = 24), mean BP approx 120/73 mm Hg</td>
<td>12 weeks</td>
<td>Combined exercise training (circuit of resistance training plus aerobic training at 60% of the predicted maximal HR), 3 days a week, or control</td>
<td>Combined exercise training significantly decreased (all P &lt; .05) SBP (−6.0 ± 1.9 mm Hg) and DBP (−4.8 ± 1.7 mm Hg) compared with control (0.2 ± 2.1 mm Hg and 0.5 ± 1.5 mm Hg, respectively)</td>
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<tr>
<th>Study</th>
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<tr>
<td>Grant et al.(^{31}) Randomized Parallel Study</td>
<td>Elderly participants (n = 13 exercisers, n = 13 controls), mean BP exercisers: 134/70 and control: 139/82 mm Hg</td>
<td>12 weeks</td>
<td>Combined aerobic (rhythmical continuous movements in time with the music) plus resistance (rhythmical continuous movements in time with the music), 40-min, twice a week</td>
<td>Combined training significantly decreased SBP (134 ± 16 mm Hg) compared to the control group (138.8 ± 17 mm Hg, (P &lt; .05)), as well as the DBP (79.3 ± 7 vs. 82.2 ± 10 mm Hg; (P &lt; .05), respectively)</td>
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<tr>
<td>Ho et al.(^{35}) Randomized crossover study</td>
<td>Sedentary overweight and obese women (n = 20), BP</td>
<td>Single bout of aerobic, resistance or combined exercise</td>
<td>Resistance (8-12 repetitions at 10 RM), aerobic (60% of each participant’s age-predicted maximum HR) or combined exercise at moderate-intensity (single 30-min bout)</td>
<td>SBP and DBP significantly decreased initially after consumption of a high fat meal consumed 14 hours after the exercise intervention ((P &lt; .05)) and gradually returned to baseline by 8 h following the meal ((P &gt; .05))</td>
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<tr>
<td>Ho et al.(^{38}) Randomized parallel study</td>
<td>Overweight and obese individuals without hypertension</td>
<td>12 weeks</td>
<td>Control group (no exercise) or moderate intensity aerobic (30 min on a treadmill), resistance (4 sets of 8–12 repetitions at 10 RM: level of leg press, leg curl, leg extension, bench press, rear deltoid row for 30 minutes) or combination (15 minutes of aerobic and 15 minutes of resistance) exercise training, 5 days a week</td>
<td>In individual who significantly improved SBP, all exercise training significantly reduced SBP at 8 weeks compared with baseline (aerobic, (-4%; P &lt; .027); resistance, (-5.1%; P &lt; .04); combination, (-6.3%; P &lt; .001)); Combination exercise significantly decreased SBP ((-6.3%; P &lt; .005)) at 12 weeks compared to baseline</td>
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<tr>
<td>Jorge et al.(^{37}) Randomized parallel study</td>
<td>Patients with type 2 diabetes (n = 48), approx mean BP 137/85 mm Hg</td>
<td>12 weeks</td>
<td>Aerobic: cycling at the heart rate corresponding to the lactate threshold; resistance: 7-exercise circuit; combined: aerobic plus resistance; or control, 60 minutes, 3 times a week</td>
<td>Aerobic, resistance and combined training reduced BP similarly in all groups</td>
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<tr>
<td>Katzmarzyk et al.(^{26}) Longitudinal study</td>
<td>Healthy sedentary participants (n = 621), BP &lt; 160/100 mm Hg</td>
<td>20 weeks</td>
<td>Aerobic exercise training (3 days a week of exercise on a cycle ergometer). Participants started at 55% (\text{VO}_2) max/30 minutes per session up to 75% (\text{VO}_2) max/50 minutes per session</td>
<td>Among those who improved their metabolic profile with aerobic exercise, 38% significantly decreased BP ((P &lt; .05))</td>
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<tr>
<td>Maeda et al.(^{27}) Randomized parallel study</td>
<td>Elderly (n = 15) untrained women, BP &lt; 140/90 mm Hg</td>
<td>3 months</td>
<td>Mild aerobic exercise training (cycling on a leg ergometer at 80% ventilatory threshold for 3 minutes, 5 days a week)</td>
<td>Aerobic exercise significantly decreased BP at rest (SBP 112 ± 9; DBP 66 ± 6 mm Hg) compared with baseline (SBP 124 ± 13, DBP 73 ± 11 mm Hg; (P &lt; .05)).</td>
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<td>Study</td>
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<tr>
<td>Moreau et al. 19 Randomized parallel study</td>
<td>Postmenopausal women (n = 24) with borderline to stage 1 hypertension, SBP/DBP 130–150/85–99 mm Hg</td>
<td>24 weeks</td>
<td>Aerobic exercise (30 minutes of moderate intensity walking 3 km/day above their daily lifestyle walking), or control group (did not change their activity)</td>
<td>SBP after 12 weeks by 6 mm Hg (142 ± 3 to 136 ± 2 mm Hg; P &lt; .005) and by 5 mm Hg at 24 weeks (P &lt; .005)</td>
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<tr>
<td>Murtagh 22 Randomized parallel study</td>
<td>Sedentary normotensive and/or hypertensive men and women (n = 48), BP &lt; 140/90 mm Hg</td>
<td>12 weeks</td>
<td>Single bout aerobic (20-minute brisk walk), or accumulated bouts (two 10-minute walks) 3 days a week, or control (no training)</td>
<td>Aerobic (1st month: 3 days a week for 12–15 minutes, 2nd month: 4 days a week for 20–30 minutes, 3rd month: 5 days a week for 30–45 minutes at target HR), or resistance (1st week: 1 set (10 repetitions) of 40–60% of 1RM; 2nd week: 2 sets; 3rd week: 3 sets, 4th to 12th weeks: 3 sets) of 75–80% of 1 RM or control</td>
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<tr>
<td>Sarsan et al. 29 Randomized parallel study</td>
<td>Obese women (n = 60), mean BP 126/79 mm Hg</td>
<td>12 weeks</td>
<td>Both SBP and DBP were not significantly different after 12 weeks of either aerobic or resistance training (P &gt; .05) compared with control</td>
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AI, augmentation index; BP, blood pressure; DBP, diastolic blood pressure; HR, heart rate; MS, metabolic syndrome; RCT, randomized controlled trial; RM, repetition maximum; SBP, systolic blood pressure; VO₂max, maximal oxygen uptake.
**Table 2**

Effects of different exercise trainings on vascular function

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Study Duration</th>
<th>Intervention</th>
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<tr>
<td>Casey et al. <strong>58</strong></td>
<td>Healthy sedentary normotensive postmenopausal women (n = 23), BP &lt; 140/90 mmHg</td>
<td>Aerobic but not resistance exercise (28.8 ± 2.1 to 25.1 ± 1.4%; P &lt; .05)</td>
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<tr>
<td>Cook et al. <strong>75</strong></td>
<td>Healthy habitual rowers (n = 15) and sedentary controls, BP &lt; 140/90 mmHg</td>
<td></td>
<td>Combined exercise improved central arterial compliance (0.16 ± 0.01) compared with sedentary controls (0.10 ± 0.01; P &lt; .001). There were no differences of peripheral arterial stiffness</td>
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<tr>
<td>Ferrier et al. <strong>73</strong></td>
<td>Elderly patients (n = 20) with isolated systolic hypertension, BP &gt; 150/90 mmHg</td>
<td>8 weeks</td>
<td>There was no change in large artery stiffness (P &gt; .05) in both groups</td>
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<tr>
<td>Goldberg et al. <strong>70</strong></td>
<td>Healthy, normotensive young men (n = 30) with a family history of hypertension, BP &gt; 140/90 mmHg</td>
<td>4 weeks</td>
<td>Aerobic exercise significantly decreased AI by 6% (pre: −9.2 ± 2.4%; post: −15.2 ± 3.9%, P = .03), compared to control (pre: −10.6 ± 2.8%; post: −3.4 ± 3.4%, P &gt; .05)</td>
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<tr>
<td>Ho et al. <strong>35</strong></td>
<td>Sedentary overweight and obese women (n = 20), BP Single bout of aerobic, resistance or combined exercise</td>
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<td>Resistance, aerobic and combined exercise similarly decreased AI initially; however levels returned to baseline by approximately 3 h</td>
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<tr>
<td>Ho et al. <strong>38</strong></td>
<td>Overweight and Obese Individuals without Hypertension</td>
<td>12 weeks</td>
<td>In a subgroup of individual who significantly improved their SBP, AI significantly decreased at 12 weeks (aerobic: −12%, P &lt; .047; resistance: −9.5%, P &lt; .036; combination: −12.7%, P &lt; .003) compared to baseline. Combination exercise significantly lowered AI at 12 weeks (−10.7%, P &lt; .047) compared with the control group (no exercise)</td>
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exercise training in overweight and obese men increased the central arterial distensibility.\textsuperscript{72} Interestingly, not all studies found aerobic exercise to improve arterial stiffness and AI. A crossover study\textsuperscript{73} found no changes in large artery stiffness after 8 weeks of moderate aerobic exercise training (cycling 40 minutes, three times per week at an intensity of 65\% of their predetermined maximum heart rate then sedentary activity) in elderly patients with isolated systolic hypertension. The authors believe this was due to the fact that patients with isolated systolic hypertension have stiffer aortas compared with controls, which made the large arteries more difficult to modify with the aerobic exercise. Although the effects of resistance training have not been studied as extensively as aerobic training, a current review indicates that there is a role of resistance exercise in improving endothelial dysfunction,\textsuperscript{74} as seen in a 3-month randomized control trial with patients with chronic heart failure.\textsuperscript{21}

### Combined Training on Vascular Function

The effects of combined exercise (aerobic and resistance)\textsuperscript{75} on arterial stiffness have also been investigated. A cross-sectional study\textsuperscript{75} observed that rowing, which has both aerobic and resistance exercise components, significantly improved central arterial compliance (0.16 ± 0.01) compared with sedentary controls (0.10 ± 0.01; \(P < .001\)), but no differences in peripheral arterial stiffness were observed. A single 30 minute bout of resistance, aerobic, or combined exercise led to a temporary decrease in AI in overweight and obese premenopausal women; however, AI levels returned to baseline value by approximately 3 hours.\textsuperscript{35} This was most likely a meal effect, as the control group presented similar results. A subgroup of overweight and obese individuals in a randomized controlled trial also demonstrated significantly reduced AI at 12 weeks (aerobic, −12\%; \(P < .05\); resistance, −9.5\%; \(P < .05\); combination, −12.7\%; \(P < .003\)) compared with baseline. Combination exercise significantly lowered AI at 12 weeks (−10.7\%; \(P < .047\)) compared with the control group (no exercise).\textsuperscript{38}

Arterial stiffness seems to influence blood pressure control. Exercise (60 minute sessions, three times a week for 4 months) has been suggested to improve baroreflex sensitivity along with a decrease in blood pressure in hypertensive individuals compared with baseline.\textsuperscript{16}

There is a relationship between blood pressure and vascular function, as endothelial function plays a major role in regulating peripheral vascular resistance and blood pressure\textsuperscript{76} and is a possible mechanism by which improvements in blood pressure are seen after exercise training. In addition, aging and hypertension lead to changes to the endothelium, possibly due to their influence on NO synthesis from L-arginine, or NO release by the endothelial cells.\textsuperscript{77} NO has potent vasodilator effects,\textsuperscript{78} with anti-atherosclerotic properties.\textsuperscript{71} Exercise training has been shown to increase
NO levels, possibly through increasing blood flow and endothelial stretching during exercise. The AI is an indicator of arterial stiffness and is increased in the presence of hypercholesterolaemia. Evidence suggests habitual aerobic exercise training improves arterial stiffness, as well as endothelium-dependent vasorelaxation through increasing NO release.

Table 2 summarizes the findings of the studies mentioned above.

Conclusions

Overall, aerobic exercise (30–40 minutes of training at 60%–85% of predicted maximal heart rate) most days of the week improves blood pressure, while resistance training (three sets of 10 repetitions at 10RM, three days a week) also appears to significantly improve blood pressure, with most studies finding aerobic exercise to have more consistent effects. A smaller number of studies have investigated the role of exercise on vascular function. Aerobic exercise training improves arterial stiffness, as well as endothelium-dependent vasorelaxation through increasing NO release. Aerobic exercise (30–40 minutes at 65% of VO2 max) three times a week improves blood pressure, while resistance training (three sets of 10 repetitions at 10RM, three days a week) appears to significantly reduce AI, improve carotid artery compliance, and can restore vascular endothelial function in adults. Resistance exercise (four sets of 8–12 repetitions at 10 RM) and combination exercise training (15 minutes of aerobic and 15 minutes of resistance) 5 days a week also appear to have some benefits for vascular function; however, further studies are necessary to strengthen those findings.

References


