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DOI: 10.1016/j.jash.2013.07.004

Potential benefits of exercise on blood pressure and vascular function

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Short-title: Exercise and blood pressure / vascular function

Word count: 3541

Number of tables: 2

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ABSTRACT

Background: Physical activity seems to enhance cardiovascular fitness during the course of the life-cycle, improve blood pressure and is associated with decreased prevalence of hypertension and coronary heart disease (CHD). 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.

Methods and Results: 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 its associations or effects on blood pressure and vascular function. In summary, aerobic exercise (30-40 min of training at 60%–85% of predicted maximal heart rate, most days of the week) appears to significantly improve blood pressure and reduce augmentation index (AI). Resistance training (3-4 sets of 8-12 repetitions at 10 repetition maximum, 3 days a week) appears to significantly improve blood pressure, whereas combination exercise training (15 min of aerobic and 15 min of resistance, 5 days a week) is beneficial to vascular function, but at a lower scale.

Conclusion: Aerobic exercise seems to better benefit blood pressure and vascular function.

Key-words: Aerobic, resistance, combination exercise training, blood pressure, vascular function, arterial stiffness

INTRODUCTION

High blood pressure has been associated with increased risk of coronary heart disease (CHD), stroke and heart failure.(1) Hypertension, defined as a systolic blood pressure (SBP) ≥130 and/or diastolic blood pressure (DBP) ≥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 CHD.(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 (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,(8) leading to an increase in whole body $VO_{2\ max}$ over the resting level,(18) which consequently enhances energy expenditure and heart rate.(19) Unlike resistance training, aerobic training does not produce hypertrophy of skeletal muscle.(20) Aerobic exercise training enhances cardiac output (the amount of blood pumped from the heart in 1 min), the density of capillaries and myoglobin levels in skeletal muscle, which consequently contributes to an augmentation of $VO_{2\ max}$.(21)

Resistance training aims to increase muscular strength (generates force) and power (performance rate), as well as endurance (repetitive contractions against a resistance),(8) by involving strength, weight, static and/or isometric exercises.(8) It usually does not enhance maximal oxygen uptake ($VO_{2\ max}$).(22) Resistance exercise training is generally short and intensive and incorporates repetitive movement and overload stimulus,(23) which increases muscle strength and induces muscle hypertrophy (enlargement of muscle cells).(19, 23) In general, loads below 60% fail to achieve improvements in muscle strength.(23) 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.(23)

Continuous versus Discontinuous Training

Few studies have investigated the role of continuous vs. discontinuous exercise training on cardioprotection,(24, 25) finding little differences in the response between both types of exercises. Continuous and discontinuous (2 minute intervals) knee extension exercises (4 sets of 8 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.(25) Therefor 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

1) Blood Pressure

Improvements in blood pressure have been seen after aerobic,(10, 26-28) resistance(29, 30) and a combination of aerobic and resistance exercise training(31) compared to controls (no exercise).

Aerobic or Resistance Training on Blood Pressure

Three months of mild (50% $VO_{2\ max}$) aerobic exercise training (30 min, 5 days per week) significantly decreased resting blood pressure in older (59–69 y, n=15), sedentary, normotensive (<140/90 mm Hg) women.(27) Compared to baseline, aerobic training significantly reduced SBP(124±13 vs. 112±9 mm Hg, P<0.05) and DBP(73±11 vs. 66±6 mm Hg, P<0.05).(27) 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 (*i.e.*, antihypertensive and anti-atherosclerotic effects by endogenous NO) on the cardiovascular system.(27) Aerobic exercise training (3 days a week on a cycle ergometer for 30-50 min) 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<0.05) after aerobic exercise training.(26) In addition, 30 min of moderate intensity walking a day significantly decreased SBP [by 6 mm Hg after 12 weeks (142±3 to 136±2 mm Hg, P<0.005) and by 5 mm Hg at 24 weeks, P<0.005] from baseline in postmenopausal women with hypertension.(10) 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<0.01), 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<0.001 for all).(32) 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 min.(32, 33) In contrast, a study with healthy, sedentary subjects without hypertension, aged 45.7±9.4 y found 60 min of walking (either single bouts of 20 min on 3 days of the week, or accumulated bouts of two 10 min walks on 3 days of the week) for 12 weeks was not sufficient to cause changes in blood pressure post-intervention or compared to control.(34)

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 3-5 mm Hg from baseline by engaging in 30 min 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 to 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.(29, 30, 35). In one of these studies,(30) aerobic training included 30 min of treadmill walking at 65% of participant`s previously determined $VO_{2\ max}$, 3 days per week and resistance included 3 sets of 10 repetitions at 65% of their 10 RM, 3 days per week, with each session taking approximately 45–50 min. 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=0.005; 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=0.001) for 4 weeks in pre- or stage-1 essential hypertensive (n=31) men and women.(30) 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 min of brisk walking plus leg cycle ergometer, 3-5 days a week, at 50-85% of heart rate reserve) or resistance training (1 to 3 sets of 10 repetitions) compared to control (P>0.05).(29) 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 to baseline in both interventions.(29) Another study(35) evaluated the effects of aerobic (40 min at 60–85% of predicted maximal heart rate) and resistance (3 sets of 10 repetitions) training, 3 times a week in untrained male volunteers (n=26) exhibiting android obesity (i.e., a waist to hip ratio >0.95 and a BMI >27 kg/m²). There was no significant change in mean arterial blood pressure in either group after 10 weeks. However, after analysing 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<0.05), while resistance training did not (pre-training 95.0±8.5 and post-training 94.5±4.5 mm Hg, P>0.05.(35)

A meta-analysis of 9 randomized controlled trials involving 341 participants found resistance training produced a decrease in DBP of 3.5 mmHg and a non-significant reduction in SBP of 3.2 mmHg. Interventions varied from 6 to 26 weeks (median 14 weeks)(32) of 2-3 weekly sessions with intensity ranging from 30 to 90% (median 70%) of 1RM.(32, 33)

Collectively, both aerobic exercise and resistance training seem to improve blood pressure similarly in normotensive or slightly hypertensive adults compared to 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 3 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.(31, 36-38) Aerobic (rhythmical 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 min sessions twice a week) has been found to significantly decrease SBP and DBP compared to the control group (SBP: 79.3±7 vs. 82.2± 10mm Hg, and DBP: 134±16 mm Hg vs. 138.8±17 mm Hg, respectively, $P<0.05$) in overweight, older (age 63±4 y) participants (n=13 exercisers, n=13 controls) after 12 weeks training.(31) 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 to control (0.2±2.1 and 0.5±1.5 mm Hg, respectively, $P<0.05$).(37) Interestingly a 12-week study of participants with type 2 diabetes who were randomly assigned to 4 groups (3 times a week, 60 min per session): aerobic group (cycling at the heart rate corresponding to the lactate threshold), resistance group (7-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 $P<0.05$; 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 $P>0.05$).(38)

The authors suggest that the lack of improvement in the exercise groups compared to 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 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 min) or combination (15 min of aerobic and 15 min 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 to baseline (aerobic: -4%, p<0.027; resistance: -5.1%, p<0.04; combination: -6.3%, p<0.0001). In addition, the combination exercise significantly decreased SBP (-6.3%, p<0.005) at 12 weeks compared to baseline.(39)

Collectively, 40 min of combined exercise, twice to 3 times a week for 12 weeks appears to improve both SBP and DPB compared to 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(40, 41) is different in women and men, the beneficial effects of exercise training on cardioprotection according to gender it is still unknown.(42) A recent study with men and women observed significantly greater reductions in women in SBP (men vs. women, -5.4 vs. -10.6 mmHg, P=0.021) and DBP (men vs. women, -3.4 vs. -6.1 mmHg, P=0.023) after adjusting for confounding factor age, and change in body weight.(43) In addition, two meta-analyses also observed a greater BP reduction in women caused by exercise training compared to men.(42, 44) In contrast, two studies, including a meta-analysis(3, 40) reported no differences of exercise training on BP 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 to men(45, 46), as well as the existence of a closer link between BP and sympathetic nervous activity in the female population.(45, 46) However, studies have also found exercise training to improve not only sympathetic nervous activity, but also the parasympathetic.(47) Aerobic training seems to decrease blood pressure due to lower systemic vascular resistance involving the sympathetic nervous system and the renin-angiotensin system.(33) Hormonal parameters may also be involved in the gender differences in the reduction of BP as the female hormone Estrogen can reduce vascular tone by modulating the renin-angiotensin system;(48) whereas the main male hormone testosterone appears to stimulate it.(49) 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.(43)

Potential Mechanisms

The mechanisms by which exercise training in general improves blood pressure may be by influencing NO production.(50) 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.(51) 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.(52) 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 min 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 2-3 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 to 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.(39)

2) 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.(53) 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.(54) 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 thrombosis(55) and contributes to increased arterial stiffness of both larger and smaller arteries.(56) Arterial stiffness is an independent risk factor for CVD(57, 58) and has been shown to be increased in elderly people (with insulin resistance and diabetes mellitus),(59) and obesity(60). Although exercise has a beneficial impact on several arterial stiffness risk factors, the role of aerobic, resistance or combination exercise in preventing and improving arterial stiffness in the short and long-term has yet to be fully elucidated.

Aerobic or Resistance Training on Vascular Function

Aerobic exercise training is associated with lower levels of stiffness in central arteries which suggests that regular exercise may be able to delay or prevent age-related increases in arterial stiffness.(14) The beneficial effects of aerobic training on arterial stiffness and endothelial function have been observed in different study groups.(61-65) Cross-sectional studies have found a relationship between habitual aerobic exercise and a lower AI or arterial stiffness.(63, 66, 67) The effect of short-term aerobic exercise on vascular function was investigated in young individuals with a family history of hypertension.(68) Subjects were randomly assigned to either an aerobic exercise (30 min of cycle training at 65% of their maximal oxygen uptake), 3 times per week or a control group (normal activity), for 4 weeks.(68) The aerobic exercise group showed a 6%

reduction in AI (pre: -9.2±2.4%; post: -15.2±3.9%, $P=0.03$), compared with the control group (pre: -10.6±2.8%; post: -3.4±3.4%, $P>0.05$), which suggests that short-term moderate-intensity aerobic exercise significantly reduces arterial stiffness. Healthy sedentary normotensive postmenopausal women were randomized to resistance (1 set of 12 repetitions, at 50% of their 1RM) or aerobic training (30-40 min of treadmill walking between 65-80% of their predicted HR reserve), 2 days a week for 18 weeks. Aerobic training, but not resistance exercise significantly improved AI (28.8±2.1 to 25.1±1.4%, $P<0.05$).(69)

A study examining the effects of aerobic exercise on a leg ergometer (70% $VO_{2\,max}$ for 1 hour, 3-4 days/week) for 8 weeks in healthy, young subjects (20.3±0.5 y) compared to a control group(70) suggests that chronic exercise increases the production of the vasodilator NO by vascular endothelial cells, and decreases the production of the potent vasoconstrictor peptide ET-1, which may cause beneficial effects (i.e., vasodilative and anti-atherosclerotic) on the cardiovascular system. Likewise, the effects of aerobic exercise training on central arterial distensibility and endothelial function was investigated in middle-age overweight and obese men over 12 weeks of aerobic exercise intervention (walking and jogging, 40 to 60 min, 3 days a week).(71) The concentrations of plasma ET-1 significantly decreased and plasma NO significantly increased after the weight-reduction exercise program.(71) The authors conclude that weight reduction by aerobic exercise training in overweight and obese men increased the central arterial distensibility.(71)

Interestingly, not all studies found aerobic exercise to improve arterial stiffness and AI. A crossover study (72) found no changes in large artery stiffness after 8 weeks of moderate aerobic exercise training (cycling 40 min, 3 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 to controls, which made the large arteries more difficult to modify with the aerobic exercise. Although the effects of resistance training has not been studied as extensively as aerobic training, a current review indicates that there is a role of resistance exercise in improving endothelial dysfunction,(73) as seen in a 3-month randomized control trial with patients with chronic heart failure.(21)

Combined Training on Vascular Function

The effects of combined exercise (aerobic and resistance)(74) on arterial stiffness have also been investigated. A cross-sectional study(74) 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<0.001), but no differences in peripheral arterial stiffness were observed. A single 30 min 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 h.(36) 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<0.05; resistance: -9.5%, p<0.05; combination: -12.7%, p<0.003) compared to baseline. Combination exercise significantly lowered AI at 12 weeks (-10.7%, p<0.047) compared with the control group (no exercise).(39) Arterial stiffness seems to influence blood pressure control. Exercise (60 min sessions, 3 times a week for 4 months) has been suggested to improve baroreflex sensitivity along with a decrease in blood pressure in hypertensive individuals compared to baseline.(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(75) 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.(76) NO has potent vasodilator effects,(77) with anti-atherosclerotic properties.(70) Exercise training has been shown to increase NO levels,(27, 70, 78) possibly through increasing blood flow and endothelial stretching during exercise.(27) The AI is an indicator of arterial stiffness and is increased in the presence of hypercholesterolaemia.(17) Evidence suggests habitual aerobic exercise training improves arterial stiffness,(66) as well as endothelium-dependent vasorelaxation through increasing NO release.(64)

Table 2 summarizes the findings of the studies mentioned above.

Conclusion

Overall, aerobic exercise (30-40 min of training at 60%–85% of predicted maximal heart rate) most days of the week improves blood pressure, while resistance training (3 sets of 10 repetitions at 10RM, 3 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 (30-40 min at 65% of $VO_{2\,max}$) 3 times a week appears to significantly reduce AI, improve carotid artery compliance and can restore vascular endothelial function in adults. Resistance exercise (4 sets of 8–12 repetitions at 10 RM) and combination exercise training (15 min of aerobic and 15 min of resistance) 5 days a week also appear to have some benefits for vascular function; however, further studies are necessary to strengthen those findings.

Acknowledgements

Dr. Pal has participated to the conception, design, writing and critical revision of this paper. Dr. Radavelli-Bagatini and Dr. Ho have participated in the writing and revision of the article.

REFERENCES

1 Australian Institute of Health and Welfare. Australia's health, 2006. Canberra: Australian Institute of Health and Welfare, 2006.

2 WHO. Nutrition: Controlling the Global Obesity Epidemic. World Health Organization 2002;

3 Kones R. Primary prevention of coronary heart disease: integration of new data, evolving views, revised goals, and role of rosuvastatin in management. A comprehensive survey. Drug design, development and therapy 2011;5:325-80.

4 Foreyt JP, Brunner RL, Goodrick GK, St Jeor ST, Miller GD. Psychological correlates of reported physical activity in normal-weight and obese adults: the Reno diet-heart study. International Journal of Obesity and Related Metabolic Disorders 1995;19 Suppl 4:S69-72.

5 Helmrich SP, Ragland DR, Paffenbarger RS, Jr. Prevention of non-insulin-dependent diabetes mellitus with physical activity. Med Sci Sports Exerc 1994;26:824-30.

6 King CN, Senn MD. Exercise testing and prescription. Practical recommendations for the sedentary. Sports Medicine 1996;21:326-36.

7 Kruk J. Physical activity in the prevention of the most frequent chronic diseases: an analysis of the recent evidence. Asian Pacific Journal of Cancer Prevention 2007;8:325-38.

8 Howley ET. Type of activity: resistance, aerobic and leisure versus occupational physical activity. Med Sci Sports Exerc 2001;33:S364-9; discussion S419-20.

9 Egger G, Pearson S, Pal S. Individualising weight loss prescription--a management tool for clinicians. Aust Fam Physician 2006;35:591-4.

10 Moreau KL, Degarmo R, Langley J, McMahon C, Howley ET, Bassett Jr DR, et al. Increasing daily walking lowers blood pressure in postmenopausal women. Med Sci Sports Exerc 2001;33:1825-31.

11 Wassertheil-Smoller S, Anderson G, Psaty B, M, Black HR, Manson J, Wong N, et al. Hypertension and its treatment in postmenopausal women: baseline data from the women's health initiative. Hypertension 2000;36:780-9.

12 Mora S, Cook N, Buring JE, Ridker PM, Lee I-M. Physical activity and reduced risk of cardiovascular events: potential mediating mechanisms. Circulation 2007;116:2110-8.

13 Conroy MB, Cook NR, Manson JE, Buring JE, Lee I-M. Past physical activity, current physical activity, and risk of coronary heart disease. Med Sci Sports Exerc 2005;37:1251-6.

14 Tanaka H, DeSouza CA, Seals DR. Absence of age-related increase in central arterial stiffness in physically active women. Arteriosclerosis, Thrombosis, and Vascular Biology 1998;18:127-32.

15 Sakuragi S, Sugiyama Y. Effects of daily walking on subjective symptoms, mood and autonomic nervous function. Journal of Physiological Anthropology 2006;25:281-9.

16 Laterza MC, de Matos LDNJ, Trombetta ID, Braga AMW, Roveda F, Alves MJNN, et al. Exercise training restores baroreflex sensitivity in never-treated hypertensive patients. Hypertension 2007;49:1298-306.

17 Wilkinson IB, Prasad K, Hall IR, Thomas A, MacCallum H, Webb DJ, et al. Increased central pulse pressure and augmentation index in subjects with hypercholesterolemia. Journal of the American College of Cardiology 2002;39:1005-11.

18 Booth FW, Thomason DB. Molecular and cellular adaptation of muscle in response to exercise: perspectives of various models. Physiological reviews 1991;71:541-85.

19 Sundell J. Resistance Training Is an Effective Tool against Metabolic and Frailty Syndromes. Advances in preventive medicine 2011;2011:984683.

20 Holloszy JO, Booth FW. Biochemical adaptations to endurance exercise in muscle. Annual review of physiology 1976;38:273-91.

21 Angell P, Chester N, Green D, Somauroo J, Whyte G, George K. Anabolic steroids and cardiovascular risk. Sports medicine (Auckland, NZ) 2012;42:119-34.

22 Andersen JL, Schjerling P, Andersen LL, Dela F. Resistance training and insulin action in humans: effects of de-training. The Journal of physiology 2003;551:1049-58.

23 Glass SC, Stanton DR. Self-selected resistance training intensity in novice weightlifters. Journal of strength and conditioning research / National Strength & Conditioning Association 2004;18:324-7.

24 Stohr EJ, Gonzalez-Alonso J, Shave R. Left ventricular mechanical limitations to stroke volume in healthy humans during incremental exercise. Am J Physiol Heart Circ Physiol 2011;301:H478-87.

25 Polito MD, Simao R, Lira VA, Nobrega AC, Farinatti Pde T. Discontinuous sets of knee extensions induce higher cardiovascular responses in comparison to continuous ones. Arq Bras Cardiol 2008;90:350-5.

26 Katzmarzyk PT, Leon AS, Wilmore JH, Skinner JS, Rao DC, Rankinen T, et al. Targeting the metabolic syndrome with exercise: evidence from the HERITAGE family study. Med Sci Sports Exerc 2003;35:1703-09.

27 Maeda S, Tanabe T, Otsuki T, Sugawara J, Iemitsu M, Miyauchi T, et al. Moderate regular exercise increases basal production of nitric oxide in elderly women. Hypertension Research 2004;27:947-53.

28 Fagard RH. Exercise is good for your blood pressure: effects of endurance training and resistance training. Clinical and Experimental Pharmacology and Physiology 2006;33:853-6.

29 Sarsan A, Ardic F, Özgen M, Topuz O, Sermez Y. The effects of aerobic and resistance exercises in obese women. Clinical Rehabilitation 2006;20:773-82.

30 Collier SR, Kanaley JA, Carhart Jr R, Frechette V, Tobin MM, Hall AK, et al. Effect of 4 weeks of aerobic or resistance exercise training on arterial stiffness, blood flow and blood pressure in pre- and stage-1 hypertensives. J Hum Hypertens 2008;22:678-86.

31 Grant S, Todd K, Aitchison TC, Kelly P, Stoddart D. The effects of a 12-week group exercise programme on physiological and psychological variables and function in overweight women. Public Health 2004;118:31-42.

32 Fagard RH. Exercise is good for your blood pressure: effects of endurance training and resistance training. Clin Exp Pharmacol Physiol 2006;33:853-6.

33 Fagard RH, Cornelissen VA. Effect of exercise on blood pressure control in hypertensive patients. European Journal of Cardiovascular Prevention and Rehabilitation 2007;14:12-7.

34 Murtagh EM, Boreham CAG, Nevill A, Hare LG, Murphy MH. The effects of 60 minutes of brisk walking per week, accumulated in two different patterns, on cardiovascular risk. Preventative Medicine 2005;41:92-1.

35 Banz WJ, Maher MA, Thompson WG, Bassett DR, Moore W, Ashraf M, et al. Effects of resistance versus aerobic training on coronary artery disease risk factors. Exp Biol Med (Maywood) 2003;228:434-40.

36 Ho SS, Dhaliwal SS, Hills A, Pal S. Acute exercise improves postprandial cardiovascular risk factors in overweight and obese individuals. Atherosclerosis 2011;214:178-84.

37 Figueroa A, Park SY, Seo DY, Sanchez-Gonzalez MA, Baek YH. Combined resistance and endurance exercise training improves arterial stiffness, blood pressure, and muscle strength in postmenopausal women. Menopause 2011;18:980-4.

38 Jorge ML, de Oliveira VN, Resende NM, Paraiso LF, Calixto A, Diniz AL, et al. The effects of aerobic, resistance, and combined exercise on metabolic control, inflammatory markers, adipocytokines, and muscle insulin signaling in patients with type 2 diabetes mellitus. Metabolism 2011;60:1244-52.

39 Ho SS, Radavelli-Bagatini S, Dhaliwal SS, Hills AP, Pal S. Resistance, aerobic, and combination training on vascular function in overweight and obese adults. J Clin Hypertens (Greenwich) 2012;14:848-54.

40 Arain FA, Kuniyoshi FH, Abdalrhim AD, Miller VM. Sex/gender medicine. The biological basis for personalized care in cardiovascular medicine. Circ J 2009;73:1774-82.

41 Mosca L, Barrett-Connor E, Wenger NK. Sex/gender differences in cardiovascular disease prevention: what a difference a decade makes. Circulation 2011;124:2145-54.

42 Hagberg JM, Park JJ, Brown MD. The role of exercise training in the treatment of hypertension: an update. Sports Med 2000;30:193-206.

43 Morita N, Okita K. Is gender a factor in the reduction of cardiovascular risks with exercise training? Circ J 2013;77:646-51.

44 Hagberg JM, Brown MD. Does exercise training play a role in the treatment of essential hypertension? J Cardiovasc Risk 1995;2:296-302.

45 Lambert E, Straznicky N, Eikelis N, Esler M, Dawood T, Masuo K, et al. Gender differences in sympathetic nervous activity: influence of body mass and blood pressure. J Hypertens 2007;25:1411-9.

46 Narkiewicz K, Phillips BG, Kato M, Hering D, Bieniaszewski L, Somers VK. Gender-selective interaction between aging, blood pressure, and sympathetic nerve activity. Hypertension 2005;45:522-5.

47 Amano M, Kanda T, Ue H, Moritani T. Exercise training and autonomic nervous system activity in obese individuals. Med Sci Sports Exerc 2001;33:1287-91.

48 Gallagher PE, Li P, Lenhart JR, Chappell MC, Brosnihan KB. Estrogen regulation of angiotensin-converting enzyme mRNA. Hypertension 1999;33:323-8.

49 Reckelhoff JF. Gender differences in the regulation of blood pressure. Hypertension 2001;37:1199-208.

50 Moncada S, Palmer RM, Higgs EA. Nitric oxide: physiology, pathophysiology, and pharmacology. Pharmacological reviews 1991;43:109-42.

51 Maeda S, Tanabe T, Miyauchi T, Otsuki T, Sugawara J, Iemitsu M, et al. Aerobic exercise training reduces plasma endothelin-1 concentration in older women. Journal of Applied Physiology 2003;95:336-41.

52 Nishida K, Harrison DG, Navas JP, Fisher AA, Dockery SP, Uematsu M, et al. Molecular cloning and characterization of the constitutive bovine aortic endothelial cell nitric oxide synthase. The Journal of clinical investigation 1992;90:2092-6.

53 Monnink SHJ, Tio RA, van Boven AJ, van Gilst WH, van Veldhuisen DJ. The role of coronary endothelial function testing in patients. International Journal of Cardiology 2004;96:123-9.

54 Herrmann J, Lerman A. The endothelium: dysfunction and beyond. Journal of Nuclear Cardiology 2001;8:197-206.

55 Maier JAM, Malpuech-Brugere C, Zimowska W, Rayssiguier Y, Mazur A. Low magnesium promotes endothelial cell dysfunction: implications for atherosclerosis, inflammation and thrombosis. Biochimica et Biophysica Acta 2004;1689:13-21.

56 Boos CJ, Lane DA, Karpha M, Beevers DG, Haynes R, Lip GYH. Circulating endothelial cells, arterial stiffness, and cardiovascular risk stratification in hypertension. Chest 2007;132:1540-7.

57 Casey DP, Pierce GL, Howe KS, Mering MC, Braith RW. Effect of resistance training on arterial wave reflection and brachial artery reactivity in normotensive postmenopausal women. European Journal of Applied Physiology 2007;100:403-8.

58 Qureshi G, Brown R, Salciccioli L, Qureshi M, Rizvi S, Farhan S, et al. Relationship between aortic atherosclerosis and non-invasive measures of arterial stiffness. Atherosclerosis 2007;195:E190-4.

59 Safar ME, Levy BI, Struijker-Boudier H. Current perspectives on arterial stiffness and pulse pressure in hypertension and cardiovascular diseases. Circulation 2003;107:2864-9.

60 Zebekakis PE, Nawrot T, Thijs L, Balkestein EJ, van der Heijden-Spek J, Van Bortel LM, et al. Obesity is associated with increased arterial stiffness from adolescence until old age. J Hypertens 2005;23:1839-46.

61 Harvey PJ, Morris B, Kubo T, Picton PE, Su WS, Notarius CF, et al. Hemodynamic after-effects of acute dynamic exercise in sedentary normotensive postmenopausal women. J Hypertens 2005;23:285-92.

62 Mustata S, Chan C, Lai V, Miller JA. Impact of an exercise program on arterial stiffness and insulin resistance in hemodialysis patients. Journal of the American Society of Nephrology 2004;15:2713-8.

63 Tabara Y, Yuasa T, Oshiumi A, Kobayashi T, Miyawaki Y, Miki T, et al. Effect of acute and long-term aerobic exercise on arterial stiffness in the elderly. Hypertension Research 2007;30:895-902.

64 Higashi Y, Sasaki S, Kurisu S, Yoshimizu A, Sasaki N, Matsuura H, et al. Regular aerobic exercise augments endothelium-dependent vascular relaxation in normotensive as well as hypertensive subjects: role of endothelium-derived nitric oxide. Circulation 1999;100:1194-202.

65 Padilla J, Harris RA, Fly AD, Rink LD, Wallace JP. The effect of acute exercise on endothelial function following a high-fat meal. European Journal of Applied Physiology 2006;98:256-62.

66 Seals DR, Moreau KL, Gates PE, Eskurza I. Modulatory influences on ageing of the vasculature in healthy humans. Experimental Gerontology 2006;41:501-7.

67 Kozakova M, Palombo C, Mhamdi L, Konrad T, Nilsson P, Staehr PB, et al. Habitual physical activity and vascular aging in a young to middle-age population at low cardiovascular risk. Stroke 2007;38:2549-55.

68 Goldberg MJ, Boutcher SH, Boutcher YN. The effect of 4 weeks of aerobic exercise on vascular and baroreflex function of young men with a family history of hypertension. J Hum Hypertens 2011;

69 Casey DP, Pierce GL, Howe KS, Mering MC, Braith RW. Effect of resistance training on arterial wave reflection and brachial artery reactivity in normotensive postmenopausal women. Eur J Appl Physiol 2007;100:403-8.

70 Maeda S, Miyauchi T, Kakiyama T, Sugawara J, Iemitsu M, Irukayama-Tomobe Y, et al. Effects of exercise training of 8 weeks and detraining on plasma levels of endothelium-derived factors, endothelin-1 and nitric oxide, in healthy young humans. Life Sciences 2001;69:1005-16.

71 Miyaki A, Maeda S, Yoshizawa M, Misono M, Saito Y, Sasai H, et al. Effect of habitual aerobic exercise on body weight and arterial function in overweight and obese men. The American journal of cardiology 2009;104:823-8.

72 Ferrier KE, Waddell TK, Gatzka CD, Cameron JD, Dart AM, Kingwell BA. Aerobic exercise training does not modify large-artery compliance in isolated systolic hypertension. Hypertension 2001;38:222-6.

73 Umpierre D, Stein R. Hemodynamic and vascular effects of resistance training: implications for cardiovascular disease. Arquivos Brasileiros de Cardiologia 2007;89:233-9.

74 Cook JN, DeVan AE, Schleifer JL, Anton MM, Cortez-Cooper M, Tanaka H. Arterial compliance of rowers: implications for combined aerobic and strength training on arterial elasticity. Am J Physiol Heart Circ Physiol 2006;209:H1596-600.

75 Rankinen T, Rice T, Pérusse L, Chagnon YC, Gagnon J, Leon AS, et al. NOS3 Glu298Asp genotype and blood pressure response to endurance training: the HERITAGE Family Study. Hypertension 2000;36:885-9.

76 Benetos A, Waeber B, Izzo J, Mitchell G, Resnick L, Asmar R, et al. Influence of age, risk factors, and cardiovascular and renal disease on arterial stiffness: clinical applications. Am J Hypertens 2002;15:1101-8.

77 Moncada S, Higgs EA. The discovery of nitric oxide and its role in vascular biology. British Journal of Pharmacology 2006;147:S193-S201.

78 Taddei S, Galetta F, Virdis A, Ghiadoni L, Salvetti G, Franzoni F, et al. Physical activity prevents age-related impairment in nitric oxide availability in elderly athletes. Circulation 2000;101:2896-901.

79 Miyachi M, Donato AJ, Yamamoto K, Takahashi K, Gates PE, Moreau KL, et al. Greater age-related reductions in central arterial compliance in resistance-trained men. Hypertension 2002;41:130-5.

80 Rakobowchuk M, McGowan CL, de Groot PC, Bruinsma D, Hartman JW, Phillips SM, et al. Effect of whole body resistance training on arterial compliance in young men. Experimental Physiology 2005;90:645-51.

List of Tables

Table 1. Effects of different exercise trainings on blood pressure

Study	Participants	Study Duration	Intervention	Results
Banz et al.(35) Randomized parallel study	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	10 weeks	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	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<0.05), in a subgroup of individuals with elevated DBP (>90 mmHg)
Collier et al.(30) Randomized parallel study	Pre- or stage-1 essential hypertensive (n=31) men and women, mean BP aerobic: 141 ± 80, resistance: 136±78 mm Hg	4 weeks	Resistance (3 sets of 10 repetitions at 65% of their 10 RM, 45–50 min, 3 days a week), or aerobic (30 min of treadmill walking at 65% of their previously determined VO_2 peak, 3 days a week)	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=0.005) 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=0.001)
Fagard(28) Meta-analysis	Healthy sedentary normotensive and/or hypertensive adults (72 trials, 105 studies), mean BP 128±82 mm Hg	Varied from 4 to 52 weeks	Aerobic physical training as the sole intervention. Median training sessions was 40 min, 3 days a week, and median intensity was 65% of HR	Aerobic training significantly reduced BP 3.3/3.5 mm Hg (P<0.01), with reduction being more pronounced in 30 hypertensive study groups (-6.9/-4.9) than in the others (-1.9/-1.6; P<0.001 for all)
Fagard(28) Meta-analysis	Healthy sedentary normotensive and/or hypertensive adults (9 RCT, 12 studies), mean BP 131±81 mm Hg	Varied from 6 to 26 weeks, median 14 weeks	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	Resistance exercise was associated with reduction of DBP (-3.5 mmHg, P<0.01)
Figueroa et al.(37) Randomized parallel study	Postmenopausal women (n=24), mean BP approx 120/73 mm Hg	12 weeks	Combined exercise training (circuit of resistance training plus aerobic training at 60% of the predicted maximal HR), 3 days a week, or control	Combined exercise training significantly decreased (all P<0.05) SBP (-6.0±1.9 mm Hg) and DBP (-4.8±1.7 mm Hg) compared to control (0.2±2.1 mm Hg and 0.5±1.5 mm Hg, respectively)

Table 1. Effects of different exercise trainings on blood pressure (cont.)

Grant et al.(31) Randomized parallel study	Elderly participants (n=13 exercisers, n=13 controls), mean BP exercisers: 134/70 and control: 139/82 mm Hg	12 weeks	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	Combined training significantly decreased SBP (134±16 mm Hg) compared to the control group (138.8±17 mm Hg, P<0.05), as well as the DBP (79.3±7 vs. 82.2±10 mm Hg, P<0.05, respectively)
Ho et al.(36) Randomized crossover study	Sedentary overweight and obese women (n=20), BP	Single bout of aerobic, resistance or combined exercise	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)	SBP and DBP significantly decreased initially after consumption of a high fat meal consumed 14 h after the exercise intervention (P<0.05) and gradually returned to baseline by 8 h following the meal (P>0.05)
Ho et al.(39) Randomized parallel study	Overweight and obese individuals without hypertension	12 weeks	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 min) or combination (15 min of aerobic and 15 min of resistance) exercise training, 5 days a week	In individual who significantly improved SBP, all exercise training significantly reduced SBP at 8 weeks compared to baseline (aerobic: -4%, p<0.027; resistance: -5.1%, p<0.04; combination: -6.3%, p<0.0001); Combination exercise significantly decreased SBP (-6.3%, p<0.005) at 12 weeks compared to baseline
Jorge et al.(38) Randomized parallel study	Patients with type 2 diabetes (n=48), approx mean BP 137/85 mm Hg	12 weeks	Aerobic: cycling at the heart rate corresponding to the lactate threshold; resistance: 7-exercise circuit; combined: aerobic plus resistance; or control, 60 min, 3 times a week	Aerobic, resistance and combined training reduced BP similarly in all groups
Katzmarzyk et al.(26) Longitudinal study	Healthy sedentary participants (n=621), BP < 160/100 mm Hg)	20 weeks	Aerobic exercise training (3 days a week of exercise on a cycle ergometer). Participants started at 55% $VO_{2\ max}$/30 min per session up to 75% $VO_{2\ max}$/50 min per session	Among those who improved their metabolic profile with aerobic exercise, 38% significantly decreased BP (P<0.05)
Maeda et al.(27) Randomized parallel study	Elderly (n=15) untrained women, BP <140/90 mm Hg	3 months	Mild aerobic exercise training (cycling on a leg ergometer at 80% ventilatory threshold for 30 min, 5 days a week)	Aerobic exercise significantly decreased BP at rest (SBP 112±9; DBP 66±6 mm Hg) compared to baseline (SBP 124±13, DBP 73±11 mm Hg, P<0.05)

Table 1. Effects of different exercise trainings on blood pressure (cont.)

Moreau et al.(10) Randomized parallel study	Postmenopausal women (n=24) with borderline to stage 1 hypertension, SBP/DBP 130-150/85-99 mm Hg	24 weeks	Aerobic exercise (30 min of moderate intensity walking 3 km/day above their daily lifestyle walking), or control group (did not change their activity)	Aerobic exercise significantly reduced SBP after 12 weeks by 6 mm Hg (142±3 to 136±2 mm Hg, P<0.005) and by 5 mm Hg at 24 weeks (P<0.005)
Murtagh(34) Randomized parallel study	Sedentary normotensive and/or hypertensive men and women (n=48), BP <140/90 mm Hg	12 weeks	Single bout aerobic (20-min brisk walk), or accumulated bouts (two 10-min walks) 3 days a week, or control (no training)	There was no significant changes in BP post-intervention or compared to control (P>0.05)
Sarsan et al.(29) Randomized parallel study	Obese women (n=60), mean BP 126/79 mm Hg	12 weeks	Aerobic (1st month: 3 days a week for 12-15 min, 2nd month: 4 days a week for 20-30 min, 3rd month: 5 days a week for 30-45 min 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	Both SBP and DBP were not significantly different after 12 weeks of either aerobic or resistance training (P>0.05) compared to control

Abbreviations: MS: Metabolic Syndrome; RM: Repetition maximum; HR: Heart rate; AI: Augmentation index; $VO_{2\,max}$: Maximal oxygen uptake; BP: Blood pressure; SBP: Systolic blood pressure; DBP: Diastolic blood pressure

Table 2. Effects of different exercise trainings on vascular function

Study	**Participants**	**Study Duration**	**Intervention**	**Results**
Casey et al.(69) Randomized parallel study	Healthy sedentary normotensive postmenopausal women (n=23), BP <140/90 mmHg	Healthy habitual rowers (n=15) and sedentary (n=15) controls, BP <140/90 mmHg		Aerobic but not resistance exercise significantly reduced AI (28.8±2.1 to 25.1±1.4%, P<0.05)
Cook et al.(74) Cross-sectional study			Rowers (Aerobic plus resistance exercise) who had been training an average of 5 days per week for 5.7±4.0 y	Combined exercise improved central arterial compliance (0.16±0.01) compared with sedentary controls (0.10±0.01, P<0.001). There were no differences of peripheral arterial stiffness.
Ferrier et al.(72) Randomized crossover study	Elderly patients (n=20) with isolated systolic hypertension, BP >150/<90 mm Hg	8 weeks	Aerobic exercise (moderate intensity cycling at an intensity of 65% of their predetermined maximum heart rate), 40 min, 3 times a week; then sedentary activity	There was no change in large artery stiffness (P>0.05) in both groups
Goldberg et al.(68) Randomized parallel study	Healthy, normotensive young men (n=30) with a family history of hypertension, BP >140/90 mmHg	4 weeks	Aerobic exercise (cycle training at 65% of their $VO_{2\ max}$, 30 min, 3 times a week, or control (maintain their normal levels of physical activity)	Aerobic exercise significantly decreased AI by 6% (pre:-9.2±2.4%; post: -15.2±3.9%, P=0.03), compared to control (pre: -10.6±2.8%; post: -3.4±3.4%, P>0.05).
Ho et al.(36) Randomized crossover study	Sedentary overweight and obese women (n=20), BP	Single bout of aerobic, resistance or combined exercise	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)	Resistance, aerobic and combined exercise similarly decreased AI initially; however levels returned to baseline by approximately 3 h

Table 2. Effects of different exercise trainings on vascular function (cont.)

Ho et al.(39) Randomized parallel study	Overweight and obese individuals without hypertension	12 weeks	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 min) or combination (15 min of aerobic and 15 min of resistance) exercise training, 5 days a week	In a subgroup of individual who significantly improved their SBP, AI significantly decreased at 12 weeks (aerobic: -12%, $p<0.047$; resistance: -9.5%, $p<0.036$; combination: -12.7%, $p<0.003$) compared to baseline. Combination exercise significantly lowered AI at 12 weeks (-10.7%, $p<0.047$) compared with the control group (no exercise)
Miyachi et al.(79) Cross-sectional study	Sedentary or resistance-trained, healthy normotensive young and middle-aged (n=82) men, BP <140/90 mmHg		Resistance-trained men who had been performing vigorous resistance training for >2 y were recruited from fitness clubs. Sedentary men were those who had not participated in a regular exercise program in the previous 2 y	In the resistance-trained middle-aged group, carotid arterial compliance was 30% lower ($P=0.01$) compared with their sedentary peers
Rakobowchuk et al.(80) Longitudinal study	Young healthy men (n=28), BP <140/90 mmHg	12 weeks	Resistance training (3-day split routine: pushing, pulling and leg exercises), up to 60 sessions, 5 times a week	Central arterial compliance was unaltered ($P>0.05$)

Abbreviations: RM: Repetition maximum; HR: Heart rate; AI: Augmentation index; $VO_{2\,max}$: Maximal oxygen uptake; BP: Blood pressure; SBP: Systolic blood pressure; DBP: Diastolic blood pressure.