

ORIGINAL ARTICLE

Effects of continuous vs. interval exercise training on blood pressure and arterial stiffness in treated hypertension

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Exercise is an effective intervention for treating hypertension and arterial stiffness, but little is known about which exercise modality is the most effective in reducing arterial stiffness and blood pressure in hypertensive subjects. Our purpose was to evaluate the effect of continuous vs. interval exercise training on arterial stiffness and blood pressure in hypertensive patients. Sixty-five patients with hypertension were randomized to 16 weeks of continuous exercise training ($n=26$), interval training ($n=26$) or a sedentary routine ($n=13$). The training was conducted in two 40-min sessions a week. Assessment of arterial stiffness by carotid–femoral pulse wave velocity (PWV) measurement and 24-h ambulatory blood pressure monitoring (ABPM) were performed before and after the 16 weeks of training. At the end of the study, ABPM blood pressure had declined significantly only in the subjects with higher basal values and was independent of training modality. PWV had declined significantly only after interval training from 9.44 ± 0.91 to 8.90 ± 0.96 m s^{-1} , $P=0.009$ (continuous from 10.15 ± 1.66 to 9.98 ± 1.81 m s^{-1} , $P=\text{ns}$; control from 10.23 ± 1.82 to 10.53 ± 1.97 m s^{-1} , $P=\text{ns}$). Continuous and interval exercise training were beneficial for blood pressure control, but only interval training reduced arterial stiffness in treated hypertensive subjects. *Hypertension Research* (2010) 33, 627–632; doi:10.1038/hr.2010.42; published online 9 April 2010

Keywords: arterial stiffness; blood pressure; exercise

INTRODUCTION

A sedentary lifestyle has been characterized as an independent risk factor for cardiovascular disease.¹ Studies have shown the inverse association between physical activity level and the incidence of cardiovascular diseases.^{2,3,4} Various mechanisms could be involved in the cardiovascular protective effects of physical activity, including improvement in endothelial function, a decrease in sympathetic neural activity and a reduction in arterial stiffness. Increased arterial stiffness has been associated with hypertension in elderly subjects^{5,6} and with cardiovascular risk in middle-aged hypertensive patients. Several studies have shown the beneficial effects of exercise on arterial stiffness in different diseases. However, the best exercise modality for better control of hypertension and improved arterial function has not been well established.

Continuous exercise training is the type of physical activity most frequently recommended to hypertensive subjects.⁷ However, some studies have shown that interval exercise training may have greater effects on exercise capacity in healthy subjects^{8,9} and those with cardiovascular disorders.¹⁰ Interval training promotes greater gradients of shear stress because patients fluctuate between high and low

intensities.¹¹ We have recently shown that interval exercise acutely decreases blood pressure in hypertensive patients.¹² We therefore hypothesized that interval exercise has a better effect on arterial stiffness and blood pressure control than continuous exercise does in hypertensive subjects.

The aim of this study was to compare the impact on arterial stiffness of a continuous exercise protocol with one involving interval exercise training, as evaluated by pulse wave velocity (PWV) measurement and 24-h blood pressure control in treated hypertensive subjects.

METHODS

Study population

We studied 65 sedentary hypertensive subjects (23 male, 42 female) on anti-hypertensive medication and controlled office blood pressure (systolic blood pressure <140 mm Hg and diastolic blood pressure <90 mm Hg on anti-hypertensive drugs) without complications for at least 3 months. Subjects were recruited from the hypertension department of a tertiary hospital and randomized into three groups: continuous, interval and control. The characteristics of the population are listed in Table 1. We excluded subjects with diagnosed coronary artery disease or an abnormal electrocardiogram during the exercise

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Table 1 Subjects' characteristics

	Continuous	Interval	Control
Number of subjects	16	16	11
Sex (F/M)	9/7	12/4	9/2
Age (years)	50 ± 8	45 ± 9	47 ± 6
BMI (kg m ⁻²)	28 ± 4	29 ± 5	26 ± 5
Waist (cm)	92 ± 12	91 ± 10	84 ± 11
W/H	0.91 ± 0.07	0.88 ± 0.07	0.87 ± 0.06
PWV (m s ⁻¹)	10.15 ± 1.66	9.44 ± 0.91	10.23 ± 1.82
Blood pressure			
Systolic	124 ± 9	125 ± 9	128 ± 9
Diastolic	81 ± 9	81 ± 5	83 ± 9
Current medication			
Diuretics	62%	69%	45%
ACE inhibitors	50%	25%	45%
β-blockers	44%	38%	19%
CCI	12%	0%	0%

Abbreviations: ACE inhibitors, angiotensin convertor enzyme; CCI, calcium channel inhibitor; F, female; M, male; PWV, pulse wave velocity; W/H, waist/hip.
P > 0.05 for all variables between groups.

test as well as patients with non-cardiovascular functional limitations such as osteoarthritis. Subjects participating in regular physical activity (more than once a week) for the previous 6 months were also excluded.

This protocol was approved by the ethics committee of the study institution. All patients provided informed consent before participation.

Study design

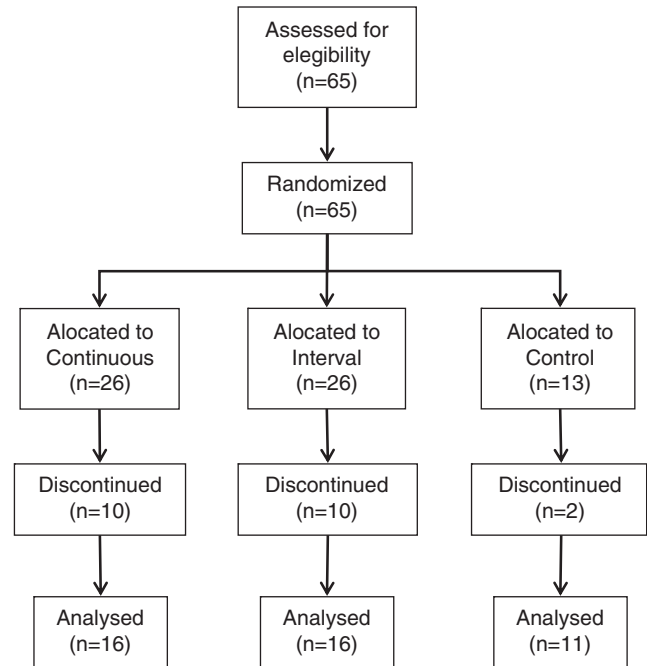
This was a randomized, controlled trial to investigate the effects of continuous and interval exercise training on arterial stiffness and blood pressure in hypertensive subjects. First, all subjects underwent an exercise test to exclude electrocardiographic abnormalities. After 2 days, we performed PWV measurements by using a non-invasive device and 24-h ambulatory blood pressure monitoring (ABPM). Referred patients with no exclusion criteria were randomized in a 2:2:1 ratio between the continuous, interval and control groups, respectively. A computer-generated randomization list was created by the statistician. The 2:2:1 randomization sequence was developed in blocks of five, including two continuous, two intervals and one control. The order of training and control within each block was also randomly assigned. Two days after the last session of the exercise training protocol (16 weeks), subjects were evaluated again for comparison, and the measurements were carried out by an investigator blinded to the exercise modality (Figure 1).

Exercise test

All subjects were asked to refrain from both strenuous physical activities and the consumption of any stimulants (for example, coffee, tobacco and alcohol) that might influence heart rate for 24 h before the exercise test and not to eat at least 2 h before the start of the test. They underwent exercise testing on a programmable treadmill (Quinton, Quinton, Seattle, WA, USA) with a standard 12-lead continuous electrocardiography monitor (TAB-SM 310), in a temperature-controlled room (21–23 °C) between 10:00 a.m. and 3:00 p.m. Blood pressure monitoring was performed by the auscultatory method. Resting heart rates were computed as the mean of the final 30 s of the resting period, and peak heart rates were the mean values of the final 30 s of effort before exhaustion. A satisfactory exercise test (modified Bruce protocol) was defined by symptoms of maximum effort. The maximum exercise heart rate predicted for age was calculated by subtracting the subject's age from 220.

Exercise training protocol

All subjects performed the exercise training protocol in a room with temperature controlled at 20 ± 1 °C for 16 weeks, three times per week (two supervised

**Figure 1** Study design.

and one non-supervised session). Supervised exercise sessions consisted of 10 min of warm-up stretching exercises, 40 min of exercise training on a treadmill (either continuous or interval exercises), 20 min of submaximal strength training and 10 min of cool-down exercises. During non-supervised exercise sessions the patients were instructed to follow the same protocol carried out during supervised sessions. The control group was advised to maintain their daily activities without exercise training during the 16-week period.

Exercise intensity was determined according to the workload reached during the maximal graded exercise test and was calculated to promote the same cardiovascular workload for both continuous and interval training. Continuous exercise was 40 min on a treadmill at 60% of reserve heart rate. Interval exercise was 40 min on a treadmill with intensity alternating between 50% (2 min) and 80% (1 min) of reserve heart rate, resulting in a mean workload of 60% ((50% × 2) + 80% / 3). Reserve heart rate was calculated as the difference between peak and resting heart rate, multiplied by the intensity of exercise and added to resting heart rate, according to the Karvonen method. Peak and resting heart rates were obtained during the graded exercise test. Each individual's heart rate was monitored during all exercise sessions with a heart rate monitor (Polar Beat, Polar Eletro, Kempele, Finland). Subjects were excluded if they did not perform more than 70% of the exercise sessions.

Ambulatory blood pressure monitoring

Twenty-four hour ABPM was performed on the non-dominant arm using an oscillometric device (SpaceLabs Redmond, Issaquah, WA, USA). The device was set to take readings every 15 min during the day and every 20 min during the night, and a new measurement was obtained after 2 min if the first one was unsuccessful. The software automatically edited values outside the normal physiological ranges and spurious readings because of external factors such as arm movement. Awake and asleep periods were determined by the patient before the examination. All subjects were instructed to maintain their usual activities and medications. The ABPM was set a day before each maximal cardiopulmonary exercise test. Data were accepted only if at least 75% of the measurements were successfully taken.

Arterial stiffness

Arterial stiffness was evaluated using carotid–femoral PWV measurements by a non-invasive automatic device (Complior; Colson, Garges les Gonesses, France)

obtained by an experienced observer blinded to the patients' clinical characteristics and exercise modality. Briefly, common carotid artery and femoral artery pressure waveforms were recorded non-invasively by a pressure-sensitive transducer (TY-306-Fukuda; Fukuda; Tokyo, Japan). The distance between the recording sites (*D*) was measured, and PWV was automatically calculated as $PWV=D/t$, where *t* represents pulse transit time.¹³ Measurements were repeated over 10 cardiac cycles, and the mean was used for the final analysis. Patients were told not to take anti-hypertensive medications on the day of the procedure. All of the tests were performed in the afternoon between 3 p.m. and 4 p.m. by the same physician who was blinded to the patient's group.

Statistical analysis

Descriptive analyses are presented as means with standard deviation. The blood pressure and PWV measurements were normally distributed. The two-way ANOVA (group×time) with repeated measures was used to compare the data. Bonferroni *post hoc* analysis was performed to evaluate the differences among groups. As systolic blood pressure has a direct influence on PWV measurements, we adjusted the values for the mean systolic blood pressure when comparisons among groups were done. Pearson's correlation was used to analyze associations between age and PWV decline in all groups.

Data were analyzed using the *Statistical Package for Social Sciences* for Windows, 11.5 (SPSS, Chicago, IL, USA). Statistical significance was defined as $P<0.05$.

RESULTS

The three groups had similar age, body mass index, office blood pressure, PWV values and current medication distribution (Table 1). Of the 65 randomized subjects, 43 completed the protocol. Seven subjects from the continuous group and seven from the interval group dropped out of the study for personal reasons. Two subjects were excluded because of changes in their medication (one in the continuous exercise and one in the control group) and five because they performed <70% of the exercise sessions (two from the continuous group). One subject from the control group became pregnant (Figure 1). The protocol was well tolerated, and there were no differences in the training session between the continuous and interval groups (82 ± 9 and $81 \pm 10\%$, respectively). Three women were postmenopausal (two in the interval group and one in the control group).

After 16 weeks of intervention, mean 24 h, daytime and nighttime systolic and diastolic blood pressure did not change significantly in any of the three groups (Table 2). When we analyzed the two exercise groups together, exercise training significantly decreased the mean 24 h and daytime diastolic blood pressure, whereas diastolic blood pressure at nighttime and mean 24 h, daytime and nighttime systolic blood pressure did not change (Figure 2). The decrease in blood pressure on ABPM was more significant in subjects whose office blood pressure was above median values (24 h 126/80, daytime 131/84 and nighttime 117/73 mm Hg) at study inclusion (Figure 3).

Interval exercise training significantly decreased the carotid to femoral PWV values after 16 weeks, whereas no significant changes were observed in the continuous and control groups (Figure 4). The heart rate, systolic and diastolic blood pressure before and after 16 weeks, measured before PWV evaluation, did not differ among the three groups (Table 3). Moreover, there was no correlation between age and PWV decline for all groups (continuous $r=0.11$ and $P=0.34$, interval $r=0.30$ and $P=0.12$, and control $r=0.30$ and $P=0.18$).

Body mass index and waist circumference were unchanged after completion of the protocol in the three groups.

DISCUSSION

This is the first trial to evaluate the effects of interval exercise training on 24-h blood pressure and arterial stiffness in hypertensive subjects

Table 2 Ambulatory blood pressure monitoring pre- and post-16 week of intervention

	Continuous		Interval		Control	
	Pre	Post	Pre	Post	Pre	Post
24 h						
SBP	124 ± 8	124 ± 9	125 ± 8	123 ± 9	128 ± 8	127 ± 9
DBP	80 ± 9	79 ± 9	80 ± 5	78 ± 6	83 ± 8	82 ± 8
Daytime						
SBP	129 ± 10	128 ± 9	128 ± 9	126 ± 9	131 ± 9	131 ± 9
DBP	84 ± 9	82 ± 9	84 ± 6	81 ± 6	86 ± 9	86 ± 9
Nighttime						
SBP	113 ± 7	112 ± 9	116 ± 9	115 ± 8	119 ± 10	116 ± 10
DBP	71 ± 7	70 ± 8	72 ± 6	71 ± 5	74 ± 8	73 ± 8

Abbreviations: DBP, diastolic blood pressure in mm Hg; SBP, systolic blood pressure in mm Hg. No significant difference between groups pre×post intervention as analyzed by two-way ANOVA.

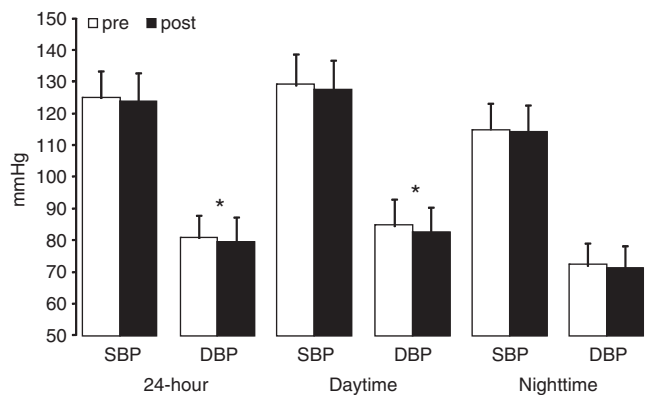


Figure 2 Average 24-h daytime and nighttime ABPM before and after 16 weeks of exercise training (continuous+interval groups). *Denotes $P<0.05$.

receiving long-term treatment. The main finding was the observation that exercise training, independent of the exercise training method, decreased blood pressure on ABPM. Moreover, only interval training improved arterial stiffness as evaluated by a decrease in carotid-femoral PWV.

Blood pressure

It is well known that aerobic exercise decreases blood pressure, mainly in the daytime. These blood pressure-lowering effects are more pronounced in hypertensive patients.^{14,15,16,17}

One meta-analysis demonstrated that aerobic exercise decreases systolic and diastolic blood pressure by 6.9 and 4.9 mm Hg, respectively, in hypertensive patients vs. 2.4 and 1.6 mm Hg in normotensive subjects.¹⁵ Another meta-analysis, which included ambulatory blood pressure measurements, demonstrated that aerobic exercise decreases systolic/diastolic blood pressure by 4.5/2.4 mm Hg during the daytime and 1.7/0.7 mm Hg during the nighttime.¹⁸ Our study is in agreement with these results; blood pressure in our subjects decreased during the daytime, mainly in those with higher blood pressure values.

A few studies have analyzed the effects of different intensities of exercise training on blood pressure. These studies showed that

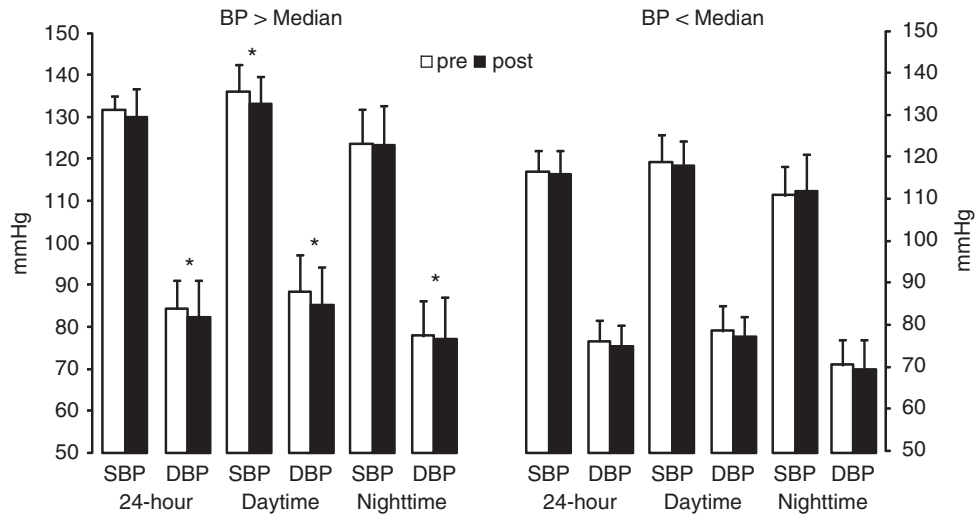


Figure 3 Average 24-h daytime and nighttime ABPM before and after 16 weeks of exercise training (continuous+interval groups) in the patients with control BP above and below the median value. *Denotes $P < 0.05$.

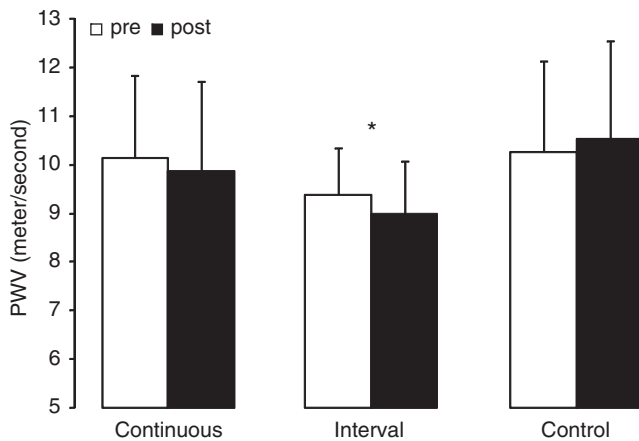


Figure 4 PWV before and after 16 weeks of exercise training. *Denotes $P < 0.05$.

Table 3 Blood pressure and heart rate levels before pulse wave velocity evaluation

	Continuous	Interval	Control
<i>Systolic blood pressure (mm Hg)</i>			
Pre	136 ± 10	134 ± 11	134 ± 13
Post	129 ± 10	128 ± 10	130 ± 10
<i>Diastolic blood pressure (mm Hg)</i>			
Pre	89 ± 9	90 ± 8	89 ± 11
Post	86 ± 7	86 ± 7	86 ± 6
<i>Heart rate (b.p.m.)</i>			
Pre	78 ± 7	80 ± 11	80 ± 7
Post	76 ± 9	78 ± 12	79 ± 7

No significant difference between groups pre×post follow-up as analyzed by two-way ANOVA.

exercise intensity does not influence the level of blood pressure decline.^{7,18} Our study is in agreement with those findings and shows that exercise intensity does not influence the decrease in blood pressure.

Several factors are involved in the blood pressure decline mediated by exercise training, but the improvement in peripheral vascular resistance seems to have the most important role. The decrease in sympathetic nervous system activity,¹⁹ effects on baroreflex control²⁰ and improvement in nitric oxide production and action (endothelial function)²¹ are probably involved in the anti-hypertensive effects of exercise. Moreover, effects on arterial remodeling,²² angiogenesis²³ and arterial distensibility²⁴ might be related to the blood pressure decline after aerobic exercise training.

Arterial stiffness

The aging process leads to a progressive increase in arterial stiffness, especially in large arteries, as has been clinically observed in elderly patients. Indeed, in hypertensive subjects this increase is more pronounced.²⁵ Aerobic exercise training seems to attenuate arterial stiffness in healthy subjects, but the results in hypertensive patients are controversial.²⁵ Twelve weeks of aerobic exercise training, at 70–75% of the maximum heart rate, increased the carotid compliance of healthy subjects to the same values as endurance-trained men.² However, 8–12 weeks of aerobic exercise training at 65–70% of the maximum heart rate did not improve arterial stiffness in patients with systolic hypertension.^{24,26} In our study, after 16 weeks of training, arterial stiffness, measured by PWV, decreased only in the aerobic interval training group. The exercise intensity and the severity of disease could explain these conflicting results.

The mechanisms involved in arterial stiffness are degradation of the elastic matrix, endothelial dysfunction, hypertrophy and hyperplasia of the smooth muscle cells and increase in collagen content.^{27,28} These mechanisms seem to be more accelerated in hypertensive subjects.^{28,27} On the other hand, an experimental study showed that the magnitude of wall distension promoted by a given shear stress affects the change in arterial stiffness through mechano-biochemical signaling that compromises vasorelaxation.²⁹ Thus, aerobic exercise training with increased intensity or duration should be required to better improve arterial stiffness in hypertensive subjects. Nevertheless, in healthy subjects with less stiff arteries, a short duration and low intensity of exercise could be sufficient to improve arterial function.^{2,4} In this context, aerobic exercise with increased intensity could be required to improve arterial stiffness in hypertensive subjects, as observed in our study. As younger subjects may have less stiff arteries, and they may

react with a greater PWV drop, one might argue that a 5-year difference between continuous and interval training may have influenced the results. However, this age difference was not statistically significant. Moreover, we did not find significant correlation between age and PWV drop.

Clinical implications

The reduction in blood pressure after both training protocols, although observed mainly in individuals with more elevated baseline levels, has important clinical implications because it has been documented that a reduction of only 2 mm Hg in systolic blood pressure decreases mortality from cerebral vascular accidents by 10% and cardiovascular disease by 7%.³⁰

Arterial stiffness has been shown to be an independent predictor of cardiovascular and all-cause mortality³¹ in hypertensive patients. Sedentary lifestyle and anti-hypertensive treatment resulted in an increase of 0.8 m s^{-1} of PWV in 6 years.²⁷ Our study shows that only 16 weeks of interval training caused a drop in PWV of 0.41 m s^{-1} in a similar population.

Regular physical activity is an effective intervention with respect to these factors, decreasing the mortality rate for cardiovascular disease and all causes of diseases in hypertensive patients,³² attenuating the increase in the arterial stiffness associated with age,² as well as reducing genetic susceptibility to this increase.³³ In addition, physical activity helps to control the metabolic variables related to hypertension and arterial stiffness.³⁴

Study limitations

This study has several limitations. The percentage of adherence to exercise training was 61% for both the interval and the continuous groups, which is a low level of adherence. There were two supervised training sessions per week; however, the patients were instructed to perform a non-supervised exercise session. Still, it has been shown that there is no significant difference in blood pressure reduction between an exercise training program requiring two sessions per week as compared with three sessions.³⁵ In addition, we do not know whether our results would have been different for those whose hypertension was controlled compared with those with uncontrolled hypertension.

Perspectives

Interval and continuous exercise training were well tolerated in chronic hypertensive subjects treated with anti-hypertensive drugs. Blood pressure control improved with exercise training, but only interval exercise improved arterial stiffness, measured by PWV analysis, which re-affirms the need for the inclusion of physical activity in the treatment of hypertensive patients.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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