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Original Article

Effect of a Continuous Aerobic Exercise Session on Flow-Mediated Dilation in Women with Prehypertension

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Abstract

Introduction: Hypertension is defined by a chronic elevation of arterial pressure above a certain threshold value (140/90 mmHg). Pre-hypertension is the harbinger of systemic hypertension. Brachial artery flow-mediated dilation (FMD) that measured by high-resolution ultrasound is used to assess endothelial dysfunction in humans. The purpose of this study was to investigate the acute effects of a continuous aerobic session on FMD and blood pressure in women with prehypertension (SBP=120-139 mmHg or DBP=80-89 mmHg).
Methods: The study method was laboratorial with counter-balanced crossover design. Subjects included 12 women with prehypertension (age: 29.4±3.6 yrs.), without exercise activities or any cardiovascular disease, were participated in two control and aerobic exercise conditions. Continuous aerobic exercise concluded 45 minutes with 65 to 70 percent of maximum heart rate running on the treadmill. Flow mediated dilation was measured before and 1 hour after the sessions. In addition, blood pressure was measured pre, immediately post and every ten minutes to 60 minutes after the sessions. For data analysis, independent t-test and paired t-test were used.
Results: Flow-Mediated Dilation increased significantly 1 hour after the aerobic exercise (p=0.000). Also blood pressure levels decreased significantly from 30 to 60 minutes after the exercise.
Conclusion: Performing continuous aerobic exercise, with improving in FMD and blood pressure in women with prehypertension, can be helpful for these patients.

Introduction

Hypertension is the most common risk factor associated with cardiovascular diseases and mortality (1, 2).

The seventh report of the Joint National Committee (JNC 7) on prevention, detection, evaluation, and treatment of high blood pressure defines a systolic blood pressure of 120-139 mmHg or a diastolic blood pressure of 80-89 mmHg as prehypertension. Evidence suggests that prehypertension is associated with increased risk factors of the cardiovascular diseases, the damage to target organs, atherosclerosis which cannot be diagnosed by clinical examinations, as well as mortality. In fact, prehypertension is defined as a normal blood pressure which is high or higher than the optimal threshold (3). High levels of physical fitness are associated with a reduced risk of hypertension in healthy individuals with normal blood pressure. In addition, physical exercise has acute and chronic positive effects on the resting blood pressure in hypertensive patients (3-5). A session of physical exercise has been reported to reduce blood pressure after the exercise in healthy individuals and in hypertensive patients. This phenomenon is referred to as Post Exercise Hypotension and is characterized by a sustained blood pressure reduction following a session of sports activity (6 , 7).

Endothelium is a dynamic organ of the human body that maintains the hemostasis of blood vessels and protects them against atherogenesis by regulating vascular tone (8). Vascular endothelium plays a key role in secreting vasomotor tone mediators (9, 10). Assessing brachial artery endothelial function is an acceptable non-invasive alternative to evaluating coronary artery endothelial function. Evidence suggests that endothelial dysfunction is a major factor contributing to a cascade in atherosclerosis (8 , 11). Flow-Mediated Dilation (FMD) is a standard test of the brachial artery which is performed using high-precision ultrasound. This test is a non-invasive tool that is widely used to investigate endothelial function and develop of vascular health in human (12). Research has shown that impaired brachial artery FMD is significantly associated with cardiac complications and mortality (8 , 13).

The FMD response describes an interaction between vasodilator and vasoconstrictor factors derived from vascular endothelium (11 , 14). The principle of FMD is that an increased blood flow in an artery in a response to a period of blood obstruction increases shear stress on the endothelium. An increase in shear stress activates potassium channels and causes calcium to penetrate the endothelial cells. The intracellular activity of calcium activates nitric oxide synthase, which results in nitric oxide-dependent vasodilation (11, 15-16). Currie et al. (2012) investigated the acute effects of a session of moderate-intensity endurance training and high-intensity interval exercise on endothelial function in patients with coronary artery disease and observed improvements in endothelial function within one hour after both types of exercise (11). Hwang et al. (2012) reported that an exercise session could reduce FMD in women and physically inactive subjects (17). Hallmark et al. (2014) examined the effects of different exercise intensities on acute FMD variations in obese and lean adults and showed that FMD increases in lean rather than in obese subjects after high-intensity exercise (13). Sales et al. (2013) studied the acute effects of aerobic exercise and found that this exercise can prevent endothelial dysfunction caused by mental stress in patients with metabolic syndrome (18).

Given the discussed matters, the vital role of endothelial function in controlling blood pressure, the effect of exercise on endothelial health and FMD as well as the high risks of developing hypertension throughout life, initial preventive measures are recommended to be taken to minimize or reduce the risk of factors affecting hypertension. Moreover, to the best of the authors' knowledge, no studies have so far investigated the acute effects of continuous aerobic exercise on FMD and blood pressure in patients with prehypertension. The present study was thus conducted to examine these effects on factors affecting the cardiovascular health in women with prehypertension.

Materials and Methods

The present experimental study used a crossover design to recruit women with prehypertension presenting to Imam Ali Hospital (a university heart center) in Kermanshah, Iran. The disease status of the subjects was confirmed by a cardiologist. Twelve cases were randomly selected from those who volunteered to cooperate. The inclusion criteria comprised having prehypertension, i.e. a systolic blood pressure of 120-139 mmHg or a diastolic blood pressure of 80-89 mmHg which was measured at least three times and confirmed by a specialist, an age range of 18-35 years, no history of sports activities at least within the previous six months, avoiding medications that affect the endothelial function and blood pressure, no diabetes or acute cardiovascular, pulmonary and neuromuscular diseases, no pregnancy, being able of following the desired exercise protocols and no smoking.

The objectives, conditions and method of performing different stages of the study were explained to all the subjects and the measurements were described and their questions were responded in a session. The subjects then signed written consent forms approved by the Medical Ethics Committee of Kermanshah University of Medical Sciences. In this session, the general details of the subjects, including age, weight and height, were recorded, as shown in Table 1.

Table 1. The subjects' descriptive details (Mean±SD)

Age	Height (cm)	Weight (kg)	Body Mass Index (kg/m^2)
29.3±4.6	162.4±4.8	65.4±7.6	24.1±9.5

The present research used a crossover design. The subjects were examined at two randomly selected stages, including control conditions and continuous aerobic exercise. In fact, every subject was included in the study as controls one day and as those participating in the exercise the other day. All the measurements were made at the same time of day, i.e. 16:00 to 18:00. Given that only one subject could be assessed at a time, every subject had to be investigated on a separate day. The aerobic exercise protocol and control conditions were at least three days apart so as to ensure the repeated measurements did not affect the dependent variables. Moreover, the participation schedule of the subjects was adjusted such that every participant was examined outside her menstrual period.

The initial measurements of FMD and blood pressure were made before doing aerobic exercise and after about 20 minutes of rest. The posttest values were also obtained by measuring blood pressure over 60 minutes immediately and every minute after the exercise and by measuring FMD one hour after the exercise. All these measurements were repeated on the control day when the subject was at rest sitting on a chair rather than doing exercise. The subjects were recommended to note their diet within 48 hours up to the day of the first session and do their best to follow the same diet within 48 hours up to the day of the second session. They were also asked to inform about their use of medicines and try to avoid exposure to mental and physical stress during the study.

Before beginning the continuous aerobic exercise, the program started with a 10-minute warm-up including stretching movements and a fast walk on the treadmill. In addition, the exercise ended with five minutes of recovery, including a fast walk on the treadmill which gradually slowed down. The continuous aerobic exercise included a 45-minute run in which the heart rate was 65-70% of its maximum. The intensity and duration of continuous aerobic exercise were selected between 64% to 94% of the maximum heart rate as per the recommendations of the American College of Sports Medicine (19). Given that the study women were physically inactive, the lowest amplitude recommended was considered for the intensity of the activity. The exercise intensity was controlled by monitoring the subjects' heart rate using heart rate monitors (Polar, Finland), and the maximum heart rate was estimated using the "220-age" formula.

Blood pressure was measured at a sitting position in the left arm with the hand lying at the heart level. Before measuring resting blood pressure, the subjects were given at least 10 minutes of rest and they were advised to empty their bladder before the measurements. All the blood pressure measurements were made using a digital sphygmomanometer (Beurer blood pressure monitor BM20, Germany), with a systolic and diastolic accuracy of ±3 mmHg. The mean arterial pressure was calculated using the following formula.

$$Mean\ Arterial\ Pressure = \frac{Systolic\ Blood\ Pressure + 2(Diastolic\ blood\ pressure)}{3}$$

FMD measurement: After at least 10 minutes of rest, the baseline artery diameter was measured in the right hand 5-10 cm proximal to the cubital fossa and this site was marked for post-occlusion measurements. To create an occlusion in the lower part, a cuff was positioned at the upper third of the forearm and inflated to 200 mmHg for 5 minutes. Brachial artery was monitored at least 30 seconds before deflating the cuff and continued for 3.5 minutes. The maximum vessel diameter and the time to reach this diameter were recorded. These measurements were taken using a Doppler ultrasound (Medison Samsung, V20, PROB: 7-10 MH, South Korea). FMD was ultimately calculated as the percent change from the baseline diameter using the following formula.

$$FMD = \frac{Maximum\ vessel\ diameter - Baseline\ vessel\ diameter}{Baseline\ vessel\ diameter} \times 100$$

The data were presented in this study as mean ± standard deviation. After examining the normality of the data distribution, the independent t-test was used to investigate intergroup differences in the pretest. The dependent t-test was used to examine intragroup differences from the pretest to the posttest. The data collected were analyzed in SPSS-18 with $P<0.05$ being set as the level of statistical significance.

Findings

No significant differences were observed in FMD between two conditions, namely continuous aerobic exercise and controlled condition ($P=0.938$ and $t_{22}=-0.79$). A significant increase was observed in FMD after continuous aerobic exercise ($P<0.001$ and $t_{11}=-5.310$), although no significant changes occurred to the control condition ($P=0.733$ and $t_{11}=0.350$) (Figure 1).

Systolic blood pressure

The pretest values of systolic blood pressure suggested no significant differences between the two conditions ($P=0.744$ and $t_{22}=0.331$). Figure 2 shows the results of investigating intragroup changes using the dependent t-test, suggesting no significant changes in systolic blood pressure in any of the measurement time

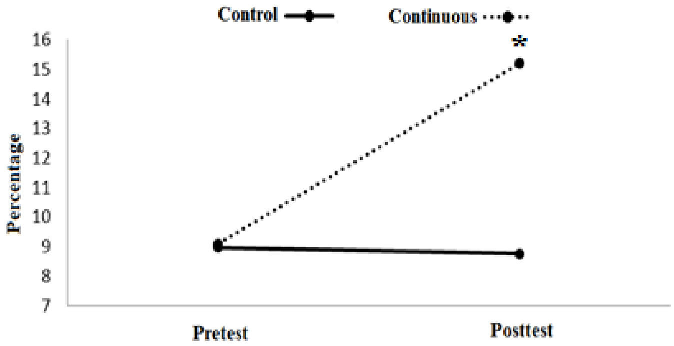

Figure 1. Variations in FMD from the pretest to the posttest under two conditions
*: A significant increase compared to the pretest (p<0.05)

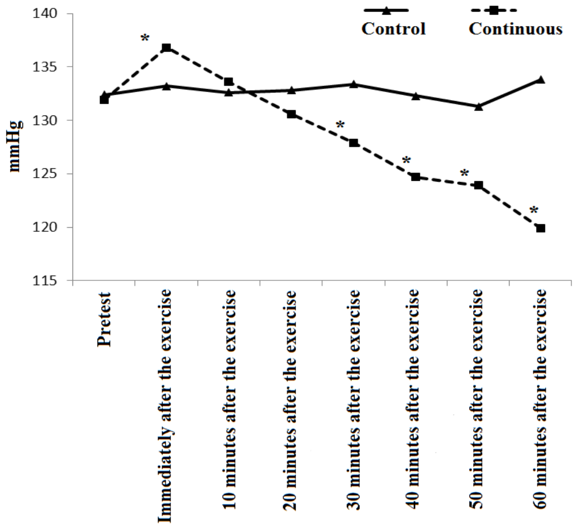

Figure 2. Variations in systolic blood pressure from the pretest to the posttest in two conditions
*: Significant changes compared to the pretest (p<0.05)

points of the control condition. In the continuous exercise condition, a significant increase was observed in systolic blood pressure immediately after the exercise, whereas a significant reduction was observed from 30 minutes after the exercise up to the last measurement time, i.e. minute 60.

The results of the independent t-test between the two conditions indicated a significant increase in systolic blood pressure immediately after the exercise compared to the control day (P=0.022), although no significant differences were observed 10 minutes (P=0.375) and 20 minutes (P=0.129) after the exercise. However, the two conditions exhibited significant differences from minute 30, e.g. p was 0.006 at minute 30, 0.001 at minute 40 and <0.0001 at minutes 50 and 60.

Diastolic blood pressure

The pretest values of diastolic blood pressure suggested no significant differences between the two conditions (P=0.613 and t_{22}=0.513). Figure 3 presents the results of investigating intragroup changes using the dependent t-test, suggesting no significant changes in diastolic blood pressure in any of the measurement time points of the control condition. In the continuous exercise condition, diastolic blood pressure showed a decrease from 20 minutes after the exercise and this reduction was significant at the 50^{th} and 60^{th} minutes.

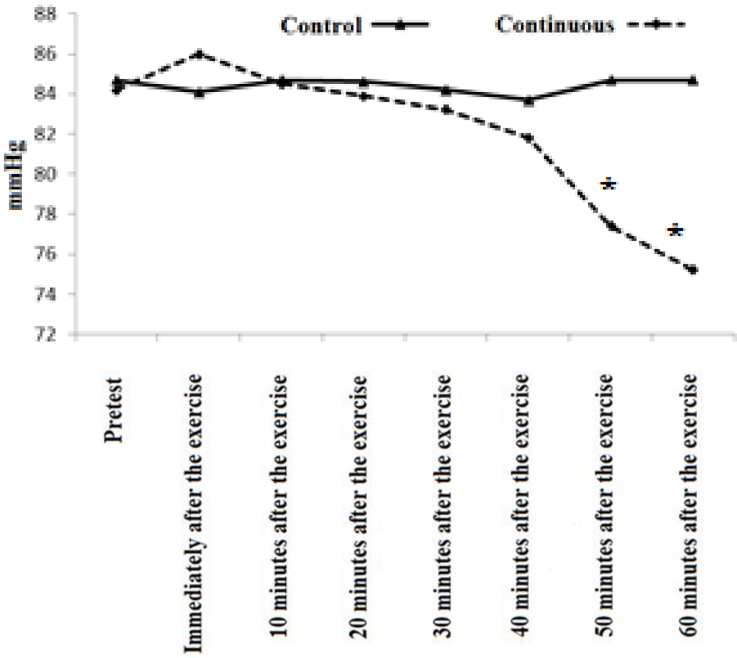

Figure 3: Variations in diastolic blood pressure from the pretest to the posttest in two conditions
*: Significant changes compared to the pretest (p<0.05)

The results of the independent t-test between the two conditions indicated a significant difference in diastolic blood pressure 50 minutes and 60 minutes after the exercise, although no significant differences were observed 0 (P=0.117), 10 (P=0.776), 20 (P=0.469), 30 (P=0.282) and 40 minutes (P=0.209) after the exercise.

Mean arterial pressure

The pretest values of mean arterial pressure suggested no significant differences between the two conditions (P=0.597 and t_{22}=0.536). Figure 4 shows the results of investigating intragroup changes using the dependent t-test, suggesting no significant changes in mean arterial pressure in any of the measurement time points of the control condition; however, in the continuous exercise condition, mean arterial pressure showed a significant reduction from 30 to 60 minutes after the exercise.

The results of the independent t-test between the two conditions indicated a significant increase in mean arterial pressure immediately after the continuous exercise (P=0.035). No significant differences were observed in mean arterial pressure 10 minutes (P=0.801) and 20 minutes (P=0.125) after the exercise. Significant differences were, however, observed between the two conditions from 30 minutes after the exercise, including minutes 30 (P=0.006), 40 (P=0.001), 50 (P<0.0001) and 60 (P<0.0001).

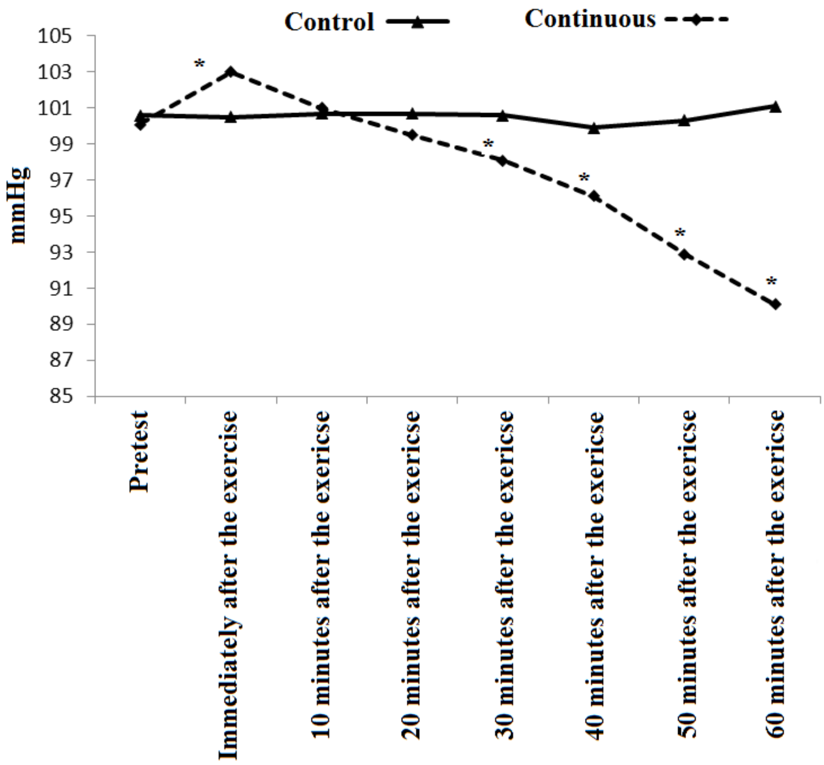

Figure 4. Variations in mean arterial pressure from the pretest to the posttest in two conditions
*: Significant changes compared to the pretest ($p<0.05$)

Discussion

The most important finding of the present research was the significant effect of a session of continuous aerobic exercise on elevating FMD in the study subjects one hour after the exercise. To the best of the authors' knowledge, no studies have so far been conducted in Iran to investigate the acute effects of physical activity on FMD, and the present study is therefore the only domestic research on this subject. An effective mechanism in the increase in FMD is that in response to an increase in metabolic needs during exercise, blood flow increases to support the active muscles, and this augments the shear stress along the endothelium and increases the secretion of vasodilators such as nitric oxide. Nitric oxide secretion contributes to smooth muscle relaxation and vasodilation and ultimately increases FMD. A trigger of nitric oxide production from the endothelium is an increase in blood flow or specifically an increase in the frictional force along the endothelium membrane, which is known as shear stress. Frequent periodic increases in blood flow and shear stress, caused by the exercise sessions, resemble a key mechanism for adaptation and positive changes in vascular function. The results of the present study are consistent with those found by Currie et al. (2012). These researchers investigated the acute effects of a session of moderate-intensity endurance training and high-intensity interval exercise on endothelial function in patients with coronary artery disease and observed improvements in endothelial function within one hour after both of the cited exercises (11). The present findings are also consistent with those obtained by Sales et al. (2014), who studied the effects of aerobic exercise on preventing endothelial dysfunction in patients with metabolic syndrome (18). Hallmark et al. (2014) examined the effects of different exercise intensities on acute FMD variations in obese (BMI>30) and lean (BMI<24) adults and reported an increase in daily values of FMD in lean rather than obese subjects after high-intensity exercise (13), which was consistent with the present findings. Hwang et al. (2012) investigated the acute effects of exercise as per the Bruce protocol on FMD in healthy young subjects according to gender and exercise habit. They found acute exercise to cause a decrease in FMD in females and subjects without regular exercise, which is inconsistent with the present results (17). This discrepancy in results can be explained by factors such as the difference in the subjects' characteristics, exercise type and FMD measurement settings. The disparity in results can be better clarified by the fact that proper exercise intensities for making useful changes in blood pressure and endothelial function depend on the initial value of endothelial function in the study population while the present study included women with prehypertension.

Post-exercise variations in blood pressure: The results obtained from the present study suggested no significant changes in blood pressure in the control group at any time points, although significant reductions were persistently observed in blood pressure between 30 minutes and 60 minutes after continuous aerobic exercise. These findings are consistent with the results obtained by Emmanuel (2012) and Gomes et al. (2013) (1 and 6). Improved endothelial function through an increase in shear stress during exercise is the main factor that justifies the benefits of exercise for blood pressure control. Different gradients of shear stress caused by continuous aerobic exercise can increase FMD and ultimately cause a blood pressure drop. A major cause of a post-exercise drop in blood pressure in hypertensive patients is a reduction in both resting heart rate and the number of circulating catecholamines, which directly reduces the activity of the sympathetic nervous system. Furthermore, a post-exercise decrease in cardiac output and total peripheral resistance causes a post-exercise drop in both blood pressure and mean arterial pressure. In addition, the reduced activity of the sympathetic nervous system, which is associated with the reduced activity of the postganglionic sympathetic nervous system, results in a post-exercise drop in blood pressure. In fact, the main factor contributing to post-exercise hypotension is a reduction in the peripheral resistance caused by the automatic nervous system and vasodilators (15). According to the present and previous results, aerobic exercise appears to play an undeniable role in reducing systolic blood pressure in patients with prehypertension. Continuous aerobic exercise caused a significant increase in blood pressure immediately after the exercise. An increase in the activity of the sympathetic nervous system during exercise can increase the heart rate and the resistance of peripheral vessels and therefore causes an increase in blood pressure immediately after the exercise. On the other hand, a while after stopping the exercise and with a decrease in the activity of the sympathetic nervous system and an increase in the activity of the parasympathetic nervous system, blood pressure is reduced as a cause of a reduction in resting heart rate and an increase in the stroke volume (1). Moreover, oxidative stress increases after exercise and causes a reduction in bioavailability of nitric oxide immediately after exercise (11), which can also be a potential cause of increased blood pressure immediately after exercise. The activity of antioxidant enzymes increases a while after exercise, which can also justify a reduction in blood pressure at the following time points, as blood pressure began to decrease 20 minutes after continuous aerobic exercise and a significant reduction appeared in systolic blood pressure from minute 30 following the exercise. The shear stress at the vessels bed appears to be one of the major causes of improving endothelial function after continuous aerobic exercise. In addition, during the recovery period after the exercise, an elevation in the stimulants caused by the exercise and an increase in vasodilators cause a systemic reduction in the resistance of vessels and therefore blood pressure (20). Local metabolites most probably contribute to the length of post-exercise hypotension until the blood pressure return to resting values. Post-exercise reductions in the activity of the sympathetic nervous system have been observed in patients with prehypertension. Vasodilators that potentially affect post-exercise reductions in blood pressure can include nitric oxide, prostaglandins, adenosine, ATP, potassium, hydrogen ions, increased carbon dioxide and reduced oxygen. A complex matrix of central and peripheral regulating agents can potentially affect the post-exercise hypotension. Given the numerous factors contributing to blood pressure regulation, the interaction between facilitators and inhibitors of blood pressure regulation can elucidate the difficulty of identifying the main mechanism responsible for post-exercise hypotension (6).

Conclusion

The results obtained from the present research suggest that continuous aerobic exercise, including a 45-minute run with 65-70% of maximum heart rate in women with prehypertension, causes an increase in FMD one hour after the exercise, indicating an improvement in endothelial function. Moreover, continuous aerobic exercise is associated with a significant post-exercise hypotension, which demonstrates the beneficial effects of this type of exercise on patients with prehypertension.

References

1. Ciolac EG. High-intensity interval training and hypertension: maximizing the benefits of exercise. Am J Cardiovasc Dis. 2012; 2(2):102-110.
2. Aalatab S, Baqeri A, Sharifi F, Mirarefin M, Badamchi Z, Hashemi A, et al. [Carotid intima-media thickness (CIFT) and the flow mediated dilation (FMD) in women with a previous history of gestational diabetes (persian)]. Iranian Journal of Diabetes and Lipid Disorders. 2012; 11(2):168-175.
3. Erdogan D, Yildirim I, Ciftci O, Ozer I, Caliskan M, Gullu H, et al. Effects of normal blood pressure, prehypertension, and hypertension on coronary microvascularfunction. Circulation. 2007;115(5):593-9.
4. Lamina S, Okoye GC. Therapeutic effect of a moderate intensity interval training program on the lipid profile in men with hypertension: A randomized controlled trial. Niger J Clin Pract. 2012;15(1):42-7.
5. Velez R, Ramirez J, Aguilar C. Effect of prolonged strenuous exercise on endothelial function in non-elite runners. Rev Bras Cardiol. 2010; 23(3):157-161.
6. Cardoso CG Jr, Gomides RS, Queiroz AC, Pinto LG, da Silveira Lobo F, Tinucci T, et al. Acute and chronic effects of aerobic and resistance exercise on ambulatory blood pressure. Clinics (Sao Paulo). 2010;65(3):317-25.
7. Faselis C, Doumas M, Kokkinos JP, Panagiotakos D, Kheirbek R, Sheriff HM, et al. Exercise capacity and progression from prehypertension to hypertension. Hypertension. 2012;60(2):333-8.
8. Inaba Y, Chen J, Bergmann SR. Prediction of future cardiovascular outcomes by flow-mediated vasodilatation of brachial artery: a meta-analysis. Int J Cardiovasc Imaging. 2010; 26(6):631-40.
9. Harrison DG, Widder J, Grumbach I, Chen W, Weber M, Searles C. Endothelial mechanotransduction, nitric oxide and vascular inflammation. J Intern Med. 2006;259(4):351-63.
10. Black MA, Cable NT, Thijssen DH, Green DJ. Impact of age, sex, and exercise on brachial artery flow-mediated dilatation. Am J Physiol Heart Circ Physiol. 2009;297(3):H1109-16.
11. Currie K, Mckelvie RS, Macdonald MJ. Flow-mediated dilation is acutely improved after high-intensity interval exercise. Med Sci Sports Exerc. 2012;44(11):2057-64.
12. McCully KK. Flow-mediated dilation and cardiovascular disease. J Appl Physiol (1985). 2012;112(12):1957-8.

13. Hallmark R, Patrie JT, Liu Z, Gaesser GA, Barrett EJ, Weltman A. The effect of exercise intensity on endothelial function in physically inactive lean and obese adult. PLoS One. 2014;9(1):e85450.
14. Stoner L, Erickson ML, Young JM, Fryer S, Sabatier MJ, Faulkner J, et al. There's more to flow-mediated dilation than nitric oxide. J Atheroscler Thromb. 2012;19(7):589-600.
15. Ruivo JA, Alcântara P. Hypertension and exercise. Rev Port Cardiol. 2012;31(2):151-8.
16. Giles TD, Materson BJ, Cohn JN, Kostis JB. Definition and classification of hypertension: an update. J Clin Hypertens (Greenwich). 2009;11(11):611-4.
17. Hwang IC, Kim KH, Choi WS, Kim HJ, Im MS, Kim YJ, et al. Impact of acute exercise on brachial artery flow-mediated dilatation in young healthy people. Cardiovasc Ultrasound. 2012; 10:39-49.
18. Sales AR, Fernandes IA, Rocha NG, Costa LS, Rocha HN, Mattos JD, Aerobic exercise acutely prevents the endothelial dysfunction induced by mental stress among subjects with metabolic syndrome: the role of shear rate. Am J Physiol Heart Circ Physiol. 2014;306(7):H963-71.
19. Roitman L, Tom F. The Exercise professional's puide to optimizing health: strategies for preventing and reducing chronic disease. Lippincott Williams & Wilkins, 2011; Chapter 8.
20. Zhu W, Zeng J, Yin J, Zhang F, Wu H, Yan S, et al. Both flow-mediated vasodilation procedures and acute exercise improve endothelial function in obese young men. Eur J Appl Physiol. 2010;108(4):727-32.