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Comparison of the Effects of Aerobic and Resistance Exercises on Arterial Stiffness, Endothelial Function, Carotid Intima-Media Thickness, and Inflammatory Biomarkers in Obese Sedentary Females

Ziba Rahimianmashhad [1], Seyyed Reza Attarzadeh Hosseini [1,*], Amir Rashidlamir [1], Mohammad Ali Sardar [2], Sirous Nekooei [3], Ramesh Giti [3]

[1] Department of Exercise Physiology, Faculty of Physical Education and Sport Sciences, Ferdowsi University of Mashhad, Mashhad, IR Iran
[2] Department of General Courses, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, IR Iran
[3] Department of Radiology, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, IR Iran

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ABSTRACT

Background: Vascular stiffness, wall thickness, wave reflections, central hemodynamics, and endothelial function are the best indicators of arterial health. Numerous studies have evaluated the effect of exercise on the structure and function of the arteries in people with arteriosclerosis disorders. However, a limited number of studies have been carried out on healthy obese individuals.
Objective: This study aimed to compare the impacts of aerobic exercise and resistance training on arterial stiffness, endothelial function, and carotid Intima-Media Thickness (cIMT) in sedentary obese females.
Methods: In this study, 27 sedentary obese females (30 - 40 years old) with the mean body mass index of 30.47 kg/m2 were randomly assigned to two groups of aerobic exercise (n = 14) and resistance training (n = 13). The first group was subjected to 24 sessions of aerobic exercise in form of riding a stationary bike at the intensity of 50 - 70% of the maximum heart rate reserve for 35 - 50 min. In the second group, the participants performed progressive resistance training for 24 sessions with 60 - 85% intensity of one repetition maximum for 8 - 12 repetitions. Maximal oxygen uptake (VO2 max), vascular stiffness, endothelial function, and cIMT were measured by color Doppler ultrasound in the 1st, 12th, and 24th sessions.
Results: The results revealed a significant increase in VO2max of the two groups. However, the changes in weight, body mass index, endothelial function, cIMT, and Pulse Pressure (PP) were not statistically significant.
Conclusion: The eight-week (aerobic or resistance) training program could not exert positive effects on the structural properties of the arterial wall and reduce vascular stiffness in obese sedentary females. In addition, it seemed that diverse exercise methods had distinct effects on shear stress patterns and hemodynamics. Yet, further research is required to determine the most efficient exercise guidelines to maximize the effectiveness of exercise in the arterial wall thickness.

1. Background

From 1980 onward, the prevalence of obesity has nearly doubled. Today, approximately 500 million adults around the world have a Body Mass Index (BMI) equal to or greater than 30 kg/m2, which is indicative of obesity. This number has been expected to reach one billion people by 2030 (1). Obese people generally suffer from increased central and peripheral arterial stiffness, which might result in adverse cardiovascular events (2). Sedentary lifestyle can affect the risk of cardiovascular disease through exerting direct impacts on the structure and function of vessels (3). Thus, measurement and prevention of arterial stiffness are of paramount importance (4). Vascular stiffness, wall thickness, wave reflections, central hemodynamics, and endothelial function are the best indicators of arterial health (3). In total, 10-20% of heart attacks occur in individuals without

*Corresponding author: Seyyed Reza Attarzadeh Hosseini, Paradise Daneshgah, Azadi Square, Department of Exercise Physiology, Faculty of Physical Education and Sport Sciences, Ferdowsi University of Mashhad, Mashhad, Iran. Post code 91779-48979; Po BOX: 1574; Tel: +98-51-38833910, Fax: +98-51-38829580, E-mail: attarzadeh@um.ac.ir.

diabetes, hypertension, hypercholesterolemia, and smoking habits. They are informed about the presence of arterial stiffness and/or familial atherosclerosis when evaluated for their vascular health via stent or coronary angiography (4). Arterial stiffness leads to the progression of left ventricular hypertrophy and myocardial ischemia through increasing the cardiac load and reducing coronary distribution. Therefore, minimizing arterial stiffness seems to play a pivotal role in the prevention of cardiovascular diseases (5). Cardiovascular risk factors have been recommended to be managed through lifestyle changes, including healthy nutrition, increased physical activity, and weight control (6). Literature has shown that exercise as a non-pharmacological tool could be effective in improving cardiovascular and skeletal muscle adaptations. In addition, this measure has been demonstrated to exert anti-atherosclerotic effects (7). Evidence has also demonstrated that weight loss caused by exercise improved heart rate in obese adults. In other words, aerobic exercise and resistance training gradually enlarged the heart by inducing permanent stress and gradual adaptation in this organ, respectively (8). Indeed, the nature of the exercise can affect the alterations in vascular wall thickness. In terms of exercise, most studies have considered the impacts of aerobic exercise on the thickness of the arterial wall (9-11). Moreover, some studies have evaluated various types of interval training, such as resistance exercises (10, 12, 13). Nevertheless, there are limited studies comparing the nature of different exercises. In a recent study, Maiorana et al. compared the effects of aerobic exercise and resistance training on brachial arteries in patients with heart failure. They concluded that while there was no relationship between aerobic exercise and changes in the thickness of the brachial artery wall, resistance training significantly reduced the arterial intima-media thickness. This finding might be specific to the patients with congestive heart failure who can especially benefit from resistance training. Consequently, further studies are required to determine the optimal exercises for improving arterial wall thickness (10). Given the increased rate of cardiovascular diseases, importance of changes in vascular structure and function, and difference in response to various exercises, studies concerning the influences of diverse exercises on the modification of vascular structure and function and predictive inflammatory biomarkers of cardiovascular diseases are still of interest to researchers. On the other hand, the type, intensity, frequency, and duration of the exercises that are required to maintain and improve the vascular endothelial function have not been fully comprehended (14).

2. Objectives

The present study aims to evaluate the effects of aerobic exercise and resistance training on arterial structure and function. The main question of this research is whether the two aerobic and resistance training programs have comparable effects on arterial stiffness, endothelial function, and arterial intima-media thickness in sedentary obese females.

3. Patients and Methods

This clinical trial was performed in Mashhad, Iran in 2018. The study was approved by the Ethics Committee of Ferdowsi University of Mashhad, Iran (IR.MUM.FUM.REC.1396.15). The trial was also registered in the Iranian Registry of Clinical Trials (IRCT20190308042965N1).

3.1. Research Population

This study was conducted on 27 inactive obese females with a BMI range of 30 - 35 kg/m2. The study participants were selected from the volunteers who provided written informed consents for participation in the research. The participants' health status was assessed using the American College of Sports Medicine (ACSM) health/fitness questionnaire and the International Physical Activity Questionnaire (IPAQ) (r = 0.9) (15, 16). The inclusion criteria of the study were age range of 30 - 40 years, BMI range of 30 - 35 kg/m2 or whole body fat over 35%, and sedentary lifestyle (less than 150 minutes of moderate exercise or 75 minutes of more vigorous exercise in a week). The exclusion criteria were suffering from coronary artery disease, diabetes, renal failure, hepatic failure, or thyroid problems, consumption of any specific medicines, smoking habits, and having the history of regular exercise (30 minutes three or four times a week) during the past six months. The participants were selected via purposive and convenience sampling and were then randomly allocated to two groups (aerobic exercise and resistance training) each containing 14 participants). It should be noted that one individual in the resistance training group left the research on the first week of the exercise program. The flowchart of the study has been presented in Figure 1.

3.2. Training Design

In this study, two types of exercise schedules were executed, namely an aerobic exercise program and a resistance training program, in 24 sessions for eight weeks. Both groups completed three exercise sessions a week under the supervision of a coach and the researcher.

3.2.1. Aerobic Exercise

The aerobic exercise included riding a spin bike at an intensity of 50 - 70% of the maximum heart rate for 35 - 50 min per session. The workout consisted of three sections; i.e., warm-up including static and dynamic stretching (5 min), riding the spin bike (25 - 40 min), and cool-down (5 min) as stretching moves. It should be noted that the exercise intensity was controlled by the Polar wrist heart rate monitor throughout the exercise. The aerobic exercise program has been illustrated in Table 1.

3.2.2. Resistance Training

The plan for this group was designed similar to that of the research carried out by DeVallance et al. (2016) (17). In the first session, the participants were familiarized with the devices and the one Repetition Maximum (1RM) was measured for the exercises related to the upper and lower extremities. In each session, the upper-body exercises required the use of special devices, including vertical chest press, triceps extension, and biceps curl. In addition, leg curl, leg extension, and multi hip exercise were applied for lower-body workouts. The rest time between the sets

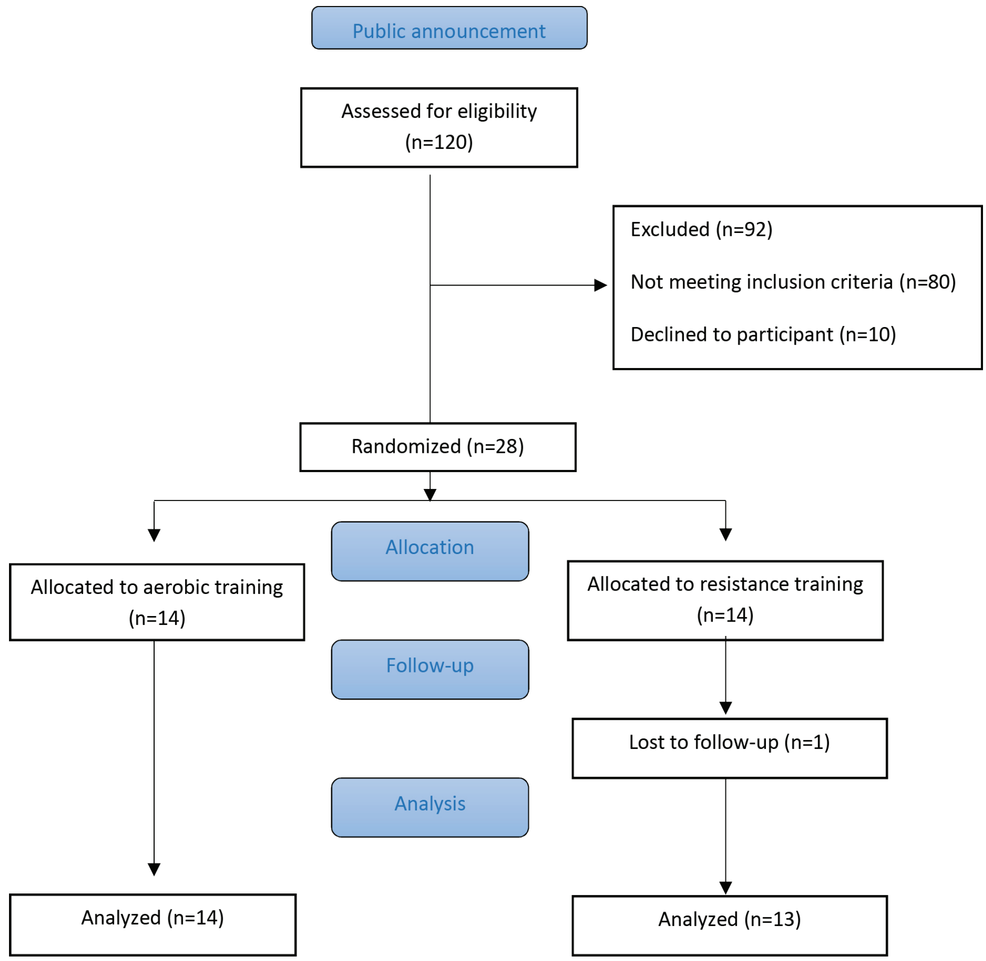

Figure 1. Flowchart of the Study

Table 1. The Aerobic Exercise Program

Week	1 and 2	3 and 4	5 and 6	7 and 8
Time (min)	35	40	45	50
Intensity (%MHR)	50% - 60%	50% - 60%	60% - 70%	60% - 70%

and movements were considered as two and three min, respectively. The resistance training program has been illustrated in Table 2.

3.3. Empirical Tests

3.3.1. Measurement of Maximal Oxygen Uptake

In order to estimate the maximal oxygen uptake (VO2 max), the Bruce protocol was applied on a Technogym treadmill. The test involved five three-minute stages, with the workload being augmented in each stage (the first step at 2.7 km/h with a 10% incline, the second step at 4 km/h with a 12% incline, the third step at 5.5 km/h with a 14% incline, the fourth stage at 6.8 km/h with a 16% incline, and the fifth step at 8 km/h with an 18% incline) (18). This device calculated the VO2 max as ml/min/kg of body weight.

3.3.2. Artery Wall Stiffness

Brachial Pulse Pressure (bPP) was employed to assess arterial stiffness. To this end, the participants were first asked to rest for 20 min in a lying position. Afterwards, the systolic and diastolic blood pressures of the left arm were measured twice using a digital barometric pressure sensor (OMRON M3, Vietnam), and the mean value of the two measurements was recorded as the final figure. In the next stage, the bPP was measured through subtracting the diastolic blood pressure from the systolic blood pressure.

3.3.3. Carotid Intima-Media Thickness

The measurement of carotid Intima-Media Thickness (cIMT) was accomplished using Doppler ultrasound with a 12-MHz probe (UGE WS80A, Samsung). Firstly, the patients lied on their backs while their heads were tilted 45° toward the region under examination. The scan was carried out in longitudinal and transverse sections by moving the probe to determine the areas with the highest thickness in the designated areas. The cIMT is usually measured from 10 mm proximal to the carotid sinus (19).

3.3.4. Flow-Mediated Dilation

The Flow-Mediated Dilation (FMD) was evaluated by the same high-resolution Doppler ultrasound device. The measurements were performed in a quiet room with a controlled temperature of 23 - 24°C after 15 min of rest

Table 2. The Resistance Training Program

Week	1 and 2	3 and 4	5 and 6	7 and 8
Intensity (%1RM)	60%	70%	80%	85%
Repetition	8 - 12	8 - 12	8 - 12	8 - 12
Set	3	3	3	3

Table 3. Anthropometric Data of Aerobic and Resistance Training Groups During Pretest, Midtest, and Posttest (Values Have Been Presented as Mean ± Standard Deviation) and Weighted Least Squares Results of the Mentioned Variables (Group Effect, Time Effect, And Group ± Time Effect)

Variables	AT group (n = 14)			RT group (n = 13)			Group			Time			Group*Time		
	Pre	Mid	Post	Pre	Mid	Post	F-value	P-value	ηp 2	F-value	P-value	ηp 2	F-value	P-value	ηp 2
BW (kg)	77.91 ± 6.76	78.55 ± 7.00	78.74 ± 7.05	78.45 ± 6.30	79.06 ± 6.6	79.66 ± 7.11	28.276	P<0.001 *	0.361	2.580	0.085	0.094	0.022	0.977	0.001
BMI (kg/m²)	29.73 ± 1.81	30.00 ± 1.87	30.04 ± 1.90	31.27 ± 3.41	31.51 ± 3.64	31.75 ± 3.69	463.092	P < 0.001 *	0.903	9.688	P < 0.001 *	0.279	0.170	0.843	0.007
BF (%)	41.54 ± 3.05	41.67 ± 2.66	41.63 ± 2.64	43.27 ± 5.54	42.93 ± 5.45	43.48 ± 5.55	100.094	P < 0.001 *	0.667	16.588	P < 0.001 *	0.399	1.120	0.334	0.043
SMM (kg)	24.87 ± 2.51	25.07 ± 2.52	25.12 ± 2.43	24.38 ± 3.13	24.71 ± 2.95	24.72 ± 3.21	130.552	P < 0.001 *	0.723	0.079	0.923	0.003	0.105	0.900	0.004

Abbreviations: AT, aerobic training; RT, resistance training; Pre, measured before each training; Mid, measured in the middle of each training; Post, measured after each training; BW, body weight; BMI, body mass index; BF, body fat; SMM, skeletal muscle mass

* Significantly different from Pre-Tr (P < 0.05)

for each individual. The participants were prohibited from performing physical activities and consuming caffeine-containing food and beverage products for 12 h before the test. When the participants were in the lying position with their arms placed in a fixed and comfortable position, the imaging of the brachial artery was carried out two cm above the elbow cavity in a longitudinal sheet. Thereafter, the brachial artery flow was occluded for five minutes by inflating a sphygmomanometer five cm below the elbow cavity at a pressure of 220 - 250 mmHg. Following ischemia, reactive hyperemia or increased blood flow was established by deflating the sphygmomanometer. Reactive hyperemia leads to endothelium-dependent dilation through creating shear stress. The diameter of the brachial artery was measured 60 - 180 seconds after removing the cuff, and the mean of the three measurements was calculated in the diastolic phase. The percentage of change in the arterial diameter during reactive hyperemia after occlusion was estimated using the equation below to estimate the FMD (20):

$$FMD = \frac{Mean\ diameter\ (mm) - Baseline\ diameter\ (mm)}{Baseline\ diameter\ (mm)} \times 100\%$$

3.4. Statistical Analysis

All data were analyzed using the SPSS software (SPSS Inc., Chicago, IL- version 16.0.0; sep 13, 2007). The means and standard deviations were calculated after checking the normal distribution of the data using Shapiro-Wilk test. Homogeneity of variances was also calculated by the Leven test. Repeated measures test (GLM-ANOVA) was used to compare the within-group and between-group differences. P-values less than 0.05 were considered to be statistically significant.

4. Results

The changes in the anthropometric measurements of the participants in the two aerobic and resistance training groups during the pretest, midtest, and posttest stages have been presented in Table 3. The results revealed no significant difference between the two groups in terms of weight, BMI, fat percentage, and skeletal muscle mass after eight weeks of aerobic and resistance training.

The alterations in VO2 max, PP, FMD, and cIMT of the participants in the aerobic and resistance training groups during pretest, midtest, and posttest have been demonstrated in Table 4. The results indicated that VO2 max increased significantly after eight weeks of both aerobic and resistance training exercises (P < 0.001). However, the elevation in VO2 max was more prominent in the aerobic group than in the resistance training group. In addition, the results indicated that the intragroup changes in cIMT were not significant in the two aerobic and resistance training groups (P = 0.973). Indeed, there was no significant difference between the two groups regarding cIMT (P = 0.42). Furthermore, the findings revealed no significant intragroup alteration in FMD after eight weeks of aerobic and resistance training (P = 0.095). Moreover, the intergroup comparison showed that the two groups were not significantly different concerning FMD (P = 0.101). Finally, the intra- (P = 0.100) and inter-group (P = 0.996) changes of PP were not significant after eight weeks of aerobic and resistance exercises.

5. Discussion

According to the results of the current research, eight weeks of aerobic exercise and resistance training led to a significant augmentation in the VO2 max and a significant decrease in the bPP of the inactive overweight females. Choudhary et al. (2015) evaluated the effect of aerobic exercise on cardiovascular parameters and concluded that three months of regular aerobic exercise improved cardiovascular function and diminished PP significantly. The latter change might be due to the reduced sympathetic

Table 4. Maximum Rate of Oxygen Consumption, Pulse Pressure, Flow Mediated Dilation, and Carotid Intima-Media Thickness in Aerobic and Resistance-Training Groups during Pretest, Midtest, and Posttest (Data Have Been Presented as Mean ± Standard Deviation) and Weighted Least Squares Results of the Mentioned Variables (Group Effect, Time Effect, and Group * Time Effect)

Variables							Group			Time			Group*Time		
	AT group (n = 14)			RT group (n = 13)			F-value	P-value	ηp 2	F-value	P-value	ηp 2	F-value	P-value	ηp 2
	Pre	Mid	Post	Pre	Mid	Post									
Vo2max (mL/kg-1/min-1)	20.00 ± 3.96	24.78 ± 1.84	26.21 ± 2.63	19.46 ± 3.47	21.53 ± 4.73	22.69 ± 3.81	24.630	P < 0.001*	0.361	2.580	0.085	0.679	10.985	P < 0.001*	0.305
PP (mmHg)	36.28 ± 5.71	34.92 ± 8.03	31.57 ± 7.16	33.46 ± 9.79	30.53 ± 6.67	28.15 ± 7.31	2.797	0.100	0.330	52.984	P < 0.001*	0.315	0.003	0.996	0.001
FMD (%)	2.78 ± 5.69	3.41 ± 5.50	1.39 ± 7.62	10.44 ± 6.01	5.22 ± 9.87	2.79 ± 6.63	2.887	0.095	0.053	11.511	P < 0.001*	0.099	2.397	0.101	0.091
CIMT (mm)	0.45 ± 0.05	0.44 ± 0.05	0.44 ± 0.06	0.45 ± 0.04	0.46 ± 0.05	0.46 ± 0.05	5.316		0.057	2.643	0.081	0.009	3.369	0.42	0.123

Abbreviations: AT, aerobic training; RT, resistance training; Pre, measured before each training; Mid, measured in the middle of each training; Post, measured after each training; VO2 max, maximum rate of oxygen consumption; PP, pulse pressure; FMD, flow-mediated dilation; CIMT, carotid intima-media thickness.

*Significantly different from Pre-Tr (P < 0.05)

activity or elevated parasympathetic tone (21). However, Yoon et al. (2010) marked that resistance training at the intensity of 60% 1RM did not significantly change the bPP of healthy males aged 20 - 29 years (22). In another study, Sharman et al. (2005) evaluated the effect of aerobic exercise on the hemodynamics of large arteries. They found a significant increase in peripheral PP and aortic stiffness (23). Diverse influences of aerobic exercise and resistance training on PP can be attributed to differences in exercise modalities, age, and nutrition as well as to individual, hereditary, and racial differences.

The findings of the present study revealed no significant change in the FMD of aerobic and resistance training groups. In a review article, Son et al. (2017) assessed the impact of various sport interventions on FMD index among overweight and obese adults. They stated that sport interventions, such as aerobic exercise, resistance training, and a combination of both exercises, exerted significant physiological effects on endothelial function and FMD index (24). Some studies have reported that the increase in the FMD index and improvement in endothelial function during exercise are not localized and adaptations are systemic. Therefore, lower-limb muscle training, regardless of the lower extremities, can enhance endothelial function throughout the body. The exercises involving the large muscle groups are associated with hemodynamic changes in the blood pressure and cardiac output and result in systemic changes in the arterial function due to shear stress (25). Siasos et al. claimed in 2016 that exercise could result in the enhancement of blood flow and shear stress led to increased nitric oxide production. Following the rise in nitric oxide, a series of intracellular biochemical processes, such as enzymatic (upregulation of superoxide dismutase and nitric oxide synthase) and molecular (adhesion molecules and endothelial growth factor receptors) changes, occurred that could improve FMD (26).

Andrew et al. systematically reviewed 43 studies on the effect of intense aerobic exercise on arterial stiffness in 2016. They suggested that exercise elevated the intramuscular shear stress as well as the amplitude and frequency of continuous blood flow. This elevation resulted in the production and release of the endothelium-dependent regulators of vascular tone (nitric oxide, prostaglandins, and natriuretic peptide) from the endothelium. The final result of this process was a decrease in vascular smooth muscle tone (27).

Regarding the influence of resistance training on endothelial function, Randy et al. (2006) marked that four months of resistance training did not reduce the FMD of the brachial artery in young healthy males. The elasticity properties of the arterial wall are affected by both structural (elastin and collagen) and functional (vasoconstrictor tone) components. Therefore, it is unlikely that three-four months of resistance training would produce significant structural changes in the arterial wall (28).

The results of the current research demonstrated that eight weeks of aerobic and resistance exercises caused no significant changes in the cIMT of the participants. Meanwhile, Park et al. (2017) indicated that 24 weeks of aerobic exercise and resistance training (40 - 80 min sessions five days a week) improved the cIMT of overweight and obese older females. In addition, they found an increase in the systolic diameter of the carotid artery and the rate of blood flow in these individuals (29). Feairheller et al. (2014) also mentioned that performing aerobic exercises for six months could lead to a 6.4% reduction in the cIMTs of inactive African American adults (30). Nonetheless, a prior study by Horner's group revealed that a three-month intervention caused no significant changes in cIMT following either resistance or aerobic exercise alone (e.g., no caloric restriction) (31). Different results regarding the effect of exercise on cIMT can be attributed to various training methods and time periods. The key mechanisms involved in the impact of exercise on cIMT depend on local (shear stress patterns) and systemic (arterial pressure) hemodynamic factors as well as on non-hemodynamic factors, such as vascular tone, sympathetic nerve activity, and oxidative stress. Given that diverse exercise methods have distinct effects on shear stress patterns and hemodynamics, further research is required to determine the most efficient exercise guidelines to maximize the effectiveness of exercise in the arterial wall thickness.

In conclusion, eight-week aerobic and resistance training schedules resulted in the enhancement of VO2 max without any significant decrease in weight. However, no improvement was observed in arterial health indices. In addition, the results revealed no significant difference between the two groups regarding improvement in the indices, except for VO2 max. Overall, it could be concluded that regular and long-term practice of each of these exercises as an effective non-pharmacological approach, along with proper nutrition, might prevent cardiovascular diseases in inactive obese women. Nevertheless, further studies are required to be performed on the effective structural and functional factors and arterial blood markers of the mentioned individuals to achieve more definitive results.

5.1. Ethical Approval

This research was approved by the Ethics Committee on Biological Research of Ferdowsi University of Mashhad, Mashhad, Iran (IR.MUM.FUM.REC.1396.15).

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Authors' Contribution

Study concept and design: Z.R.M., R.A.H., and M.A.S. Analysis and interpretation of data: Z.R.M., R.A.H., M.A.S., S.N., and R.G. Drafting of the manuscript: Z.R.M., R.A.H., and M.A.S. Critical revision of the manuscript for important intellectual content: Z.R.M., R.A.H., A.R.L., M.A.S., S.N., and R.G. Statistical analysis: Z.R.M., R.A.H., and M.A.S.

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