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The effects of long-term aerobic exercise on cardiac structure, stroke volume of the left ventricle, and cardiac output

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The purpose of this study is to investigate the effect of the long-term aerobic exercises on cardiac structure, left ventricular stroke volume, and cardiac output. To achieve the purpose of the study, a total of 22 volunteers—including 10 people who have continued regular exercises and 12 people as the control group—were selected as subjects. With regard to data processing, the IBM SPSS Statistics ver. 21.0 was used to calculate the mean and standard deviation, and the difference of the means between the groups was verified through an independent *t*-test. As a result, there were significant differences between groups in the left ventricular end-diastolic internal dimension, left ventricular end-systolic internal dimension, left ventricular end-diastolic septum thickness. There were significant differences between groups in left ventricular end-diastolic volume, left ventricular mass, and left ventricular mass index per body surface area. However, in cardiac function, only left ventricular stroke volume showed a significant difference between groups.

Keywords: Aerobic exercise, Cardiac structure, Stroke volume of the left ventricle, Cardiac output

INTRODUCTION

Looking at the cardiac functions of people who do long-term aerobic exercises, the resting heart rate is 40–60 times, which is close to bradyrhythmia. Also, stroke volume (SV) is large. In addition, the heart rate changes during respiration, but pulse is normal. The development of cardiac structure is called "athletic heart," which is remarkable but distinguishable from pathologic symptoms. It is said that such athletic hearts bring transfiguration in cardiac structure and function, if they are exposed to exercises for a long time, like the size of muscles or body forms change by types of exercises (Maron and Pelliccia, 2006; Paterick et al., 2014; Pluim et al., 2000). The exercise type of these phenomena can be divided into aerobic exercise, anaerobic exercise, and complex exercise of aerobic and anaerobic exercises.

If a person participates in an endurance exercise like marathon for a long time, the eccentric left ventricle hypertrophy, in which the thickness of ventricle is not large whereas the left ventricular wall is a relatively increased, will be produced (Vinereanu et al., 2002). Conversely, for resistive exercises like wrestling, weightlifting, and body building, the characteristics of the concentric left ventricle hypertrophy, in which the ventricular wall is not large whereas the thickness of ventricle is increased, will be generated. In addition, cyclists and rowing athletes who have the characteristics of both aerobic and anaerobic exercise systems have eccentric-concentric left ventricle hypertrophy (Baggish et al., 2010; Pluim et al., 2000). The biggest causes of such physiological reformation are heart rate and blood pressure due to exercises (Mihl et al., 2008). Endurance exercise, despite having individual difference, has a systolic blood pressure that is not more than 200 mmHg and maintains a cardiac output (CO) through adequate blood pressure reaction without causing a big burden to the heart muscle, thus increasing the vein return rate and showing an increase of the internal dimension with the increase of CO (Palatini

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et al., 1988). However, in resistive exercise, a momentary high increase of blood pressure and increase of heart rate are shown, but these phenomena repeat motions. Also, high blood pressure becomes the cause of myocardial hypertrophy as it increases the pressure of ventricular dimension (Kasikcioglu et al., 2004). In cyclists and rowing athletes who have the characteristics of both endurance and resistive exercises, systolic blood pressure increases to not less than 200 mmHg, and the heart rate of rowing athletes increases to almost the maximum (Mitchell et al., 1994). With these reactions as evidence, it can be seen that cyclists have two characteristics of eccentric left ventricle hypertrophy and concentric left ventricle hypertrophy (Pluim et al., 2000). However, these features of the heart structure are not clearly distinguished, but they can be different depending on how people are exposed to period, intensity, and frequency of exercises (Pluim et al., 2000). In addition, it was studied under the hypothesis that because heart transfiguration differs depending on they exercise types, they may affect the function of the heart, but it was reported that most of them displayed no difference from ordinary people (Pluim et al., 2000). Recently, aerobic exercises are often to enhance physical and mental health (Banz et al., 2003). Among them, swimming—wherein the risk of injury is lesser than ground exercises—is considered as a typical aerobic exercise. In particular, it is reported that swimming in a horizontal position—wherein blood is retained in the lower limbs—but streamlined form has a high vein return rate and decreases the risk of heart diseases (Ussher et al., 2003). Also, this exercise uses the four characteristics of water—buoyancy, water pressure, resistance, and water temperature—to maximize the exercise effect with excellent stability. Thus, the purpose of this study is to investigate how the structure and function of heart are changed because of regular exercise in the middle age, as well as the positive and negative effects of exercise.

MATERIALS AND METHODS

Subjects

Subjects were all healthy volunteers who had experiences in swimming exercises for 5 yr or more with a frequency of 4 times a week and a 1-hr exercise time (Table 1). People who have diseases that might affect the heart were excluded from this study. The general characteristics of subjects are described in Table 2.

Measurement item and method

Measurement item

In this study, body compositions (weight, body fat percentage, and body mass index [BMI]) and echocardiography (cardiac structure and function) were measured and analyzed.

Measurement method

Body compositions: For body compositions, weight, body fat percentage, and BMI were measured using the body composition analyzer of Bio-Space. Subjects were measured while in a simple clothing without metals and after a controlled food intake of 3 hr and a 30-min rest before the measurement.

Echocardiography: To measure cardiac structure and functions, the subjects rested for 10 min after arriving at the hospital. Then,

Table 2. General characteristics of subjects

Characteristic	Exercise (n=10)	Control (n=12)
Age (yr)	46.41±3.82	47.07±3.71
Weight (kg)	64.84±6.43	70.78±7.91
Height (cm)	168.72±6.78	170.38±5.87
Body mass index (kg/m^2)	24.45±1.76	24.56±2.45
Body fat percentage	20.96±6.83	23.55±5.09

Values are presented as mean±standard deviation.

Table 1. Exercise program

Exercise program	Intensity	Exercise	Frequency
Warm-up (10 min)	RPE, 7–9	Stretching	4 Times/wk
Main exercise (40 min)	60%–70% HRR (RPE, 11–13)	Long and free	
		Freestyle kick	
		Freestyle pull	
		Drill	
	70%–80% HRR (RPE, 13–15)	Interval swim	
		Freestyle combination	
		Sprint swim	
		Free backstroke	
Cooldown (10 min)	RPE, 7–9	Stretching	

RPE, rating of perceived exertion; HRR, heart rate reserve.

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using the Sequoir 256 ultrasound machine with a 5 MHz converter, left ventricular internal dimension-diastole (LVIDd), interventricular septal thickness at diastole (IVSd), left ventricular posterior wall dimensions (LVPWd), left ventricular end-diastolic volume (LVEDV), SV, left ventricular ejection fraction (LVEF), and CO were measured using the American Society Echocardiography (ASE) recommendation method conducted by a nurse specializing in echocardiography. Left ventricular mass (LVM) was calculated using the corrected ASE cube method. All measured items were divided by body surface area (BSA) to obtain the index.

Data processing

The mean and standard deviation of all measured items were calculated using IBM SPSS Statistics ver. 21.0 (IBM Co., Armonk, NY, USA), and they were analyzed using an independent sample *t*-test to test the difference of means between groups. The statistical significance level was set as $\alpha = 0.05$.

RESULTS

Comparison of cardiac structure between groups

When verifying the differences of LVIDd, LVIDs, and IVSd, significant differences were found ($P < 0.05$, $P < 0.05$, and $P < 0.01$, Table 3). In terms of the difference of LVPWd, there was no significant difference between the groups. However, when analyzing the differences of LVEDV, LVM, and LVM-Index, there was a significant difference between the groups ($P < 0.05$, $P < 0.01$, and $P < 0.05$, Table 3).

Table 3. Result of comparison of cardiac structures

Cardiac structure	Group	Mean ± SD	*t*-test	*P*-value
LVIDd	Swimming	4.95 ± 0.30	6.791	0.048*
	Control	4.29 ± 0.13		
LVIDs	Swimming	3.26 ± 0.31	6.662	0.037*
	Control	2.59 ± 0.13		
IVSd	Swimming	0.92 ± 0.09	4.338	0.009**
	Control	0.71 ± 0.10		
LVPWd	Swimming	0.92 ± 0.09	2.577	0.780
	Control	0.81 ± 0.10		
LVEDV	Swimming	118.82 ± 16.95	6.289	0.025*
	Control	85.82 ± 6.15		
LVM	Swimming	161.00 ± 12.45	4.608	0.007**
	Control	121.50 ± 24.53		
LVM-index	Swimming	84.27 ± 6.37	3.086	0.027*
	Control	68.35 ± 15.18		

*P< 0.05. **P< 0.01.
SD, standard deviation; LVIDd, left ventricular internal dimension-diastole; LVIDs, left ventricular internal dimension in systole; IVSd, interventricular septal thickness at diastole; LVPWd, left ventricular posterior wall dimensions; LVEDV, left ventricular end-diastolic volume; LVM, left ventricular mass; LVM-Index, left ventricular mass index difference.

Comparison of cardiac functions between groups

When investigating the differences of LVSV between the groups, significant difference was found ($P < 0.05$, Table 4). With regard to the difference of LVCO and LVEF, no significant difference was found.

DISCUSSION

This study was conducted to investigate the body composition, structure, and functions of the heart in people who regularly participate in swimming exercises.

The studies that prove that regular exercise have a lot of effects on the form and functions of heart have been known for a long time. If a person continuously exercises for a long time, the form and functions of heart will show changes. Moreover, it has been reported that these changes depend on types, intensity, and time of exercises (Pluim et al., 2000). Therefore, long-term aerobic exercises are characterized as having the ability to increase internal dimension of the left ventricle and make the septum or posterior wall of the ventricle thick or bring about a change in the eccentric left ventricle hypertrophy (Barbier et al., 2006). In the study by Sharma et al. (2000), it was reported that the structure and function of the heart change as a physiological phenomenon due to exercises, and regular exercises increase the thickness of the wall of the left ventricle. These adaptive features brought about by aerobic exercise are caused by a gradual increase in the internal dimension of the heart muscle with continuous maintenance of blood pressure and heart rate, as well as increased CO (Palatini et al., 1988).

Also, it has been reported that if the LVM is excessively high in athletes because of diseases such as hypertrophic cardiomyopathy,

Table 4. Result of comparison of cardiac functions

Cardiac function	Group	Mean ± SD	*t*-test	*P*-value
LVSV	Swimming	74.35 ± 9.98	5.126	0.040*
	Control	58.39 ± 3.81		
LVCO	Swimming	4.43 ± 0.42	0.983	0.054
	Control	4.21 ± 0.57		
LVEF	Swimming	65.40 ± 3.57	-2.228	0.470
	Control	69.18 ± 4.26		

*P< 0.05.
SD, standard deviation; LVSV, left ventricular stroke volume; LVCO, left ventricular cardiac output; LVEF, left ventricular ejection fraction.

fatal arrhythmia may occur and it may become the cause of sudden death in young athletes (Maron et al., 2009). However, hypertrophic cardiomyopathy is not likely to be acquired, and the hypertrophy shown in this study was not morbid in size. In addition, it was reported that the high LVM in the swimming group is thought to produce high volume pressure, and the left ventricular capacity was increased because mitochondria in the ventricular cell increased in quantity and volume because of the blood inflow time delay in the end-diastolic period and excessive ventricular volume load in isotonic exercise (Perini et al., 2002). According to Hoogsteen et al. (2004), in athletes who do endurance exercises and are trained hard, eccentric reformation change was shown, which is similar to the result of this study. It is then characterized that the internal dimension of the ventricle was increased because of such eccentric hypertrophy, and because of the large left ventricular volume, the SV was also high. In addition, a high SV in the aerobic exercise group was shown with a low heart rate as mentioned above. This compensation mechanism was also shown as the result that might maintain a consistent resting CO. In other words, high SV is maintained with low heart rate, while low SV is maintained with a high heart rate. Also, regular exercise makes the flow of the venous blood smooth, thus increasing the amount of blood returning to diastolic heart, which increases CO. Such phenomenon is reported to be one of the important heart adaptations for exercise (Maron, 1986). Therefore, aerobic exercise groups can conduct higher exercise capacity at an exercise situation because they show CO of up to 40 L higher than the nonexercise group (Pluim et al., 2000). The index representing the left ventricular systolic capacity is ejection fraction (EF) of the left ventricle. The left ventricular EF is evaluated using the ratio of the total blood amount that come into the left ventricle and the blood amount left after one stroke. According to Vinereanu et al. (2002), the left ventricular EF showed no significant difference in stability among endurance athletes, muscular athletes, and nonexercise groups. Pluim et al. (2000) proved that there is no difference of EF between athletes and normal people in the meta-analysis result, which was consistent with the result of this study. As this phenomenon is the ratio of the blood amount that have come into the left ventricle and the SV, it can be interpreted as a compensation mechanism in which the left ventricle does not contract a lot at the end of the systole as the internal dimension of the left ventricle increases in the aerobic exercise group.

In this study, when conducting a study to investigate the effects of long-term aerobic exercises on cardiac structures and functions, the following conclusions are obtained. There was a significant difference between groups with regard to the left ventricular internal dimension-diastole, left ventricular internal end-systolic dimension, and left ventricular septum thickness end-diastolic, which are the cardiac structure factors. Also, in LVEDV, LVM, and LVM index per BSA, a significant difference was found between groups. However, in cardiac function, only the left ventricular SV showed a significant difference between groups.

The result of this study showed a positive effect through exercise in cardiac structure, but it did not have much effect in cardiac function. Therefore, it is thought that it is necessary to have a follow-up study that will closely analyze the relationship between exercise and systolic and diastolic functions.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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