Left Ventricular Function and Cardiovascular Responses during Moderate Exercise; Investigation of the Exercise M-mode Echocardiography

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Abstract. Using exercise echocardiography (M-mode method) with a supine-position leg ergometer, we examined cardiovascular responses and the contractile wall movement and pumping function of the left ventricle in healthy male subjects. Under a moderate exercise load equivalent to the optimum exercise intensity, it is necessary to fully understand changes in PRP and systolic blood pressure to accurately estimate myocardial oxygen demand. Decreases in the telediastolic and telesystolic volumes of the left ventricle, especially a marked decrease in the telesystolic volume, led to differences between the two volumes, resulting in an increased EF. There was a high correlation between changes in PRP and EF during exercise. Although exercise echocardiography requires complex measurement techniques, it is very useful in physiotherapy for risk control in cardiac rehabilitation.

Key words: Exercise echocardiography, Ejection fraction (EF), Healthy male subjects.

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INTRODUCTION

The contractile function of the left ventricle strongly correlates with the prognosis of ischemic heart disease, and is thus very useful as an index in the evaluation of the severity of the disease and the effects of therapy¹⁾. Ischemic heart disease is diagnosed using tomographic echocardiography, cardiac pool scintigraphy, and left ventricular imaging. Among these methods, tomographic echocardiography, unlike the other methods, is a convenient and non-invasive physical examination that enables the simultaneous evaluation of the car-

diac pumping function and systolic wall movement without the infliction of pain on patients. In recent years, exercise echocardiography²⁻⁵⁾ has been clinically used and has been suggested as a useful means for evaluating risk control in cardiac rehabilitation.

This study was performed as part of basic studies to examine the application of exercise echocardiography in physiotherapy. In this study, we examined the clinical usefulness of exercise echocardiography by using a supine-position leg ergometer as an exercise machine to compare the left ventricular ejection fraction (EF), indicative of cardiac pumping function, with the product of the

heartrate and systolic blood pressure (PRP), which is highly correlative with myocardial oxygen demand.

METHODS

The subjects of this study were five healthy males aged 21–34 (average 27.8 ± 5.1). The exercise machine was a leg ergometer (Aerobike 710, Combi Co., Ltd.) set for pedaling in the supine position. To prevent body movement of the subjects, the scapular and pelvic bands were fixed with belts. The exercise load was increased stepwise. The initial load was 30 W, and was increased at increments of 30 W every three min. The exercise was stopped at 70% of the age-estimated maximum heart rate (estimative equation for young men $Y=201.7-0.583X$; $X=\text{age}$). Heart rate (HR) was calculated from R-R intervals of ten beats before and after measurement, using an elec-

trocardiograph (Cardiofax V ECAP 512, Nihon Kohden Corporation). Systolic blood pressure (SBP) was determined by auscultation of the radial artery. In tomographic echocardiography, the M-mode of the longitudinal section of the left ventricle was recorded (SSH-140A, TOSHIBA) from rest to the end of the exercise. Using the same apparatus, the telesystolic diameter of the left ventricle (Ds), telediastolic diameter of the left ventricle (Dd), and the left-ventricular ejection time (ET) were determined. Figure 1 shows the M mode of the longitudinal section of the left ventricle, Dd, and Ds. The determinations of HR and SBP and echocardiography were carried out at rest (after three minutes of rest) and every three minutes after the start of exercise (3, 6, 9, and 12 min after the start of exercise). Using data obtained in this way, the values of PRP ($\text{HR} \times \text{SBP}$), EF ($\{1 - \text{Ds}^3\} / \text{Dd}^3 \times 100$), Vcf ($\{\text{Dd} - \text{Ds}\} / \text{Dd} \times \text{ET}$), and $\text{EF} \times \text{Vcf}$ were calculated.

Fig. 1. Echocardiograph.

Left graph is a M mode of the longitudinal section of the left ventricle, Dd and Ds. Right graph is a tomographic echocardiograph of the left ventricle.

All data were analyzed using Stat View software (J-4.5, Abacus). Changes in each parameter due to the gradually increased exercise load were analyzed at each loading stage using two-way ANOVA. The comparison of various parameters between rest and exercise was performed using the correlation analysis (in particular, partial correlation analysis).

RESULTS

All of the subjects attained 70% of the age-estimated maximum heart rate at the end of 120 W exercise load and completed the test. Figure 2 shows the parameters of cardiovascular responses (HR, %HR, SBP, and PRP) during leg-ergometric exercise. Figures 3 and 4 show the parameters of left ventricular systolic wall movement (Dd, Ds, and EF), and those of cardiac pumping function (ET, Vcf, and $ET \times Vcf$), respectively. There were determined using leg-ergometric exercise echocardiography. At rest, the HR value was 69.80 ± 8.78 beats/min, %HR $37.4 \pm 4.6\%$, SBP

123.6 ± 15.6 mmHg, PRP 8626.0 ± 1475.5 beats·mmHg/min, Dd 59.6 ± 6.6 mm, Ds 36.3 ± 5.0 mm, EF $77.5 \pm 3.0\%$, ET 0.36 ± 0.04 sec, Vcf 1.01 ± 0.09 sirc/sec, and $ET \times Vcf$ 84.53 ± 7.52 sirc.

The ANOVA revealed that all parameters excluding Dd changed significantly throughout the study ($p < 0.002$). With increasing exercise loads, the HR, %HR, SBP, EF, Vcf, and $ET \times Vcf$ values tended to increase, while the Dd, Ds, and ET values tended to decrease.

The relationships between the decrease in the various parameters with increasing exercise loads were analyzed using correlation analysis and partial correlation analysis, excluding double correlation. These results are shown in Table 1. The parameters were divided into two groups: cardiovascular responses, and left ventricular systolic wall movement and cardiac pumping function. The parameters were compared in each group. In the former group (cardiovascular responses), there were significant partial correlations between PRP and SBP and between HR and SBP, and PRP

Fig. 2. Effect of exercise stress (leg ergometer) on general cardiovascular response indices; Heart rate (HR), %Heart rate (%HR), Systolic blood pressure (SBP), Pressure rate products (PRP). Values ($\bar{x} \pm s$) are means $\pm$ standard deviation; the statistical significance is * ($p < 0.01$) with ANOVA.

Fig. 3. Echocardiographic left ventricular wall-kinesis and pumping-function parameters during exercise stress (leg ergometer); End-systolic diameter of Left ventricle (Ds), End-diastolic diameter of Left ventricle (Dd), Ejection fraction (EF). Values ($\bullet$) are means $\pm$ standard deviation; the statistical significance is * ($p<0.01$) with ANOVA.

Fig. 4. Echocardiographic left ventricular wall-kinesis and pumping-function parameters during exercise stress (leg ergometer); velocity of circumferential fiber shortening (Vcf), $EF \times Vc$. Values ($\bullet$) are means $\pm$ standard deviation; the statistical significance is * ($p<0.01$) with ANOVA.

Table 1. Partial correlation coefficients and coefficients between parameters at rest and during exercise

A: Partial correlation coefficients	Cardiovascular responses					Left ventricle wall movement and cardiac pumping functions				
	HR	%HR	SBP	PRP	Ds	Dd	EF	ET	Vcf	EF×Vcf
(cardiovascular responses group)	Heart rate (HR)	1.00								
	%Heart rate (%HR)	0.92**	1.00							
	Systolic blood pressure (SBP)	-0.53*	0.17	1.00						
	Pressure rate products (PRP)	0.10	0.22	0.9**	1.00					
	End-systolic diameter of Left ventricle (Ds)	0.67**	-0.28	0.32	-0.20	1.00				
(Left ventricle wall movement and cardiac pumping function group)	End-diastolic diameter of Left ventricle (Dd)	-0.38	0.31	-0.28	0.15	0.99**	1.00			
	Ejection fraction (EF)	0.19	0.05	0.51*	-0.54*	-0.76**	0.72**	1.00		
	Ejection time (ET)	-0.13	0.05	-0.21	0.20	-0.20	0.17	-0.09	1.00	
	Velocity of circumferential fiber shortening (Vcf)	-0.27	0.34	0.10	-0.16	0.20	-0.50*	-0.31	-0.78**	1.00
	EF × Vcf	0.32	-0.42	-0.51*	0.23	-0.90**	0.12	0.34	0.66**	0.98**

Significant's partial correlation coefficients (*p<0.05, **p<0.01, n=25)

B: Correlation coefficients	Cardiovascular responses					Left ventricle wall movement and cardiac pumping functions				
	HR	%HR	SBP	PRP	Ds	Dd	EF	ET	Vcf	EF×Vcf
(cardiovascular responses group)	Heart rate (HR)	1.00								
	%Heart rate (%HR)	0.99**	1.00							
	Systolic blood pressure (SBP)	0.80**	0.98**	1.00						
	Pressure rate products (PRP)	0.96**	0.97**	0.93**	1.00					
	End-systolic diameter of Left ventricle (Ds)	-0.48*	-0.45*	-0.28	-0.42*	1.00				
(Left ventricle wall movement and cardiac pumping function group)	End-diastolic diameter of Left ventricle (Dd)	-0.50*	-0.24	0.07	-0.02	0.83**	1.00			
	Ejection fraction (EF)	0.78**	0.76**	0.56**	0.72**	-0.84**	-0.41*	1.00		
	Ejection time (ET)	-0.66**	-0.65**	-0.54**	-0.61**	0.13	-0.10	-0.36	1.00	
	Velocity of circumferential fiber shortening (Vcf)	0.82**	0.80**	0.62**	0.76**	-0.66**	-0.28	0.84**	-0.78**	1.00
	EF × Vcf	0.82**	0.80**	0.61**	0.76**	-0.73**	-0.33	0.89**	-0.69**	0.99**

Significant's partial correlation coefficients (*p<0.05, **p<0.01, n=25)

tended to increase as a result of its dependence on SBP ($r=0.93$). In the latter group (left ventricular systolic wall movement and cardiac pumping function), there were significant partial correlations between Dd and Ds, EF and Ds, EF and Dd, and Ds and $EF \times Vcf$. Both Ds and Dd decreased ($r=0.83$), though the degree of decrease was higher for Ds ($r=0.84$) than for Dd ($r=0.41$). As the difference between Ds and Dd increased, the EF increased. In comparing the parameters of the two groups, significant partial correlations between HR and Ds, EF and SBP, EF and PRP, and SBP and $EF \times Vcf$ were identified. In addition, EF increased as a result of its dependence on SBP ($r=0.56$), rather than on PRP ($r=0.72$), which is thought to be indicative of myocardial oxygen demand.

DISCUSSION

Myocardial oxygen demand is determined primarily by (1) myocardial contractility, (2) ventricular tension, and (3) heartrate⁶.

The present experiments showed that the PRP value, which is the product of the heartrate and systolic blood pressure, correlated highly with the left ventricular ejection fraction. These experiments also revealed that changes in PRP were induced by changes in systolic blood pressure rather than heartrate. This indicates that increased systolic blood pressure can predict a concurrent increase in myocardial oxygen demand. In other words, to estimate myocardial oxygen demand, it is important to understand changes in systolic blood pressure. In the experiments, echocardiography was performed by the M-mode method, and Ds, Dd, and EF, primarily, were analyzed. As the exercise load was increased, Ds and Dd reduced. The degree of the reduction was higher for Ds than for Dd, and the increased difference between Ds and Dd led to an increase in the EF value. That is, the moderate exercise load caused the telediastolic and telesystolic volumes of the left ventricle to decrease, while the telesystolic volume decreased even more markedly. Thus, there was found to be an increase in the ejection fraction, which is given by dividing the difference between the two volumes by the telediastolic volume. Sharma et al.³ obtained similar results using left ventricular imaging, and also reported that exercise load increased the telediastolic and telesystolic volumes of the left ventricle in cases of coronary artery disease, thus

decreasing the left ventricular ejection fraction.

In evaluating myocardial infarction using traditional exercise electrocardiography, the local wall movement cannot be estimated and evidence of new ischemia cannot be found using an electrocardiogram during exercise in cases of myocardial infarction with existing cardiographic abnormality. In contrast, exercise echocardiography allows the separate observation of the wall movements of uninfarcted and infarcted areas during exercise⁴. In the estimation of coronary arterial lesions, exercise echocardiography is slightly higher in sensitivity than exercise electrocardiography, and has been reported to be very helpful in examining patients with cardiographic abnormality even at rest, patients in whom cardiographic abnormality is induced by standing or hyperapnea, and patients with changes in non-specific ST-T waves due to cardiomegaly⁷. In these areas, exercise echocardiography is clinically useful and effective in controlling the risk of coronary artery diseases. With respect to precision, the results of echocardiography are at least 85% consistent with those of heart pool scintigraphy. It has been reported that there are no difficulties with echocardiography measurement techniques, which have long been considered the major disadvantage of echocardiography, and no problems with its reproducibility². There have also been many reports on the trial use of this method as a routine study⁵. Based on these reports and after comparing the results of this study with those of other studies, we judged exercise echocardiography to be a credible test method.

This method could also have useful clinical applications in physiotherapy for risk control in cardiac rehabilitation. We believe that in the future physiotherapy will require clinical data obtained from a combination of exercise echocardiography and exercise electrocardiography.

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