

Post-Exercise Response of Ventricular Ejection Fraction after Total Repair of Congenital Heart Disease with Left to Right Shunt

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A radioisotope first pass study was done on patients over a period of 1 to 15 years (average 4.6 years) after repair for ventricular septal defect or atrial septal defect with a left to right shunt. The age of the patients ranged from 6 to 32 years (average 14.2 year) at the time of the study. The total work of exercise and the right and left ventricular ejection fraction (EF) were evaluated at rest and after exercise. The results were compared with the preoperative hemodynamic findings and with the age of patient at the time of the operation. 1) When the total work of exercise was divided with the maximal exercise capacity of the normal individual corresponding to the patients' height and body surface area (the percentage of total work), it were very low with the average of 40% of normal. There was no sexual difference, but the percentage of total work of exercise had significant correlation with the patients' age at the time of operation ($r = -0.52$, $p < 0.01$) and post-exercise left ventricular ejection fraction (LVEF) ($r = -0.39$, $p < 0.05$). 2) LVEF at rest had some correlation with the preoperative mean pulmonary arterial pressure ($r = -0.29$, $p = 0.05$), but showed no relationship with Qp/Qs or Rp/Rs ratios. The right ventricular ejection fraction (RVEF) at rest had no relations with the preoperative hemodynamic findings with maximal workload. 3) The post-exercise RVEF showed linear correlation with the preoperative Rp/Rs ratio ($r = -0.49$, $p < 0.005$), and mean pulmonary arterial pressure ($r = -0.37$, $p < 0.05$). The post-exercise LVEF had no significant correlation with any preoperative hemodynamic factors. 4) When greater than 5% increase in ventricular EF after exercise is considered normal, the group with the normal right and left ventricular responses ($n = 11$) showed normal preoperative Rp/Rs ratio (7.6 ± 4.1). In the group with normal left, but abnormal right ventricular response ($n = 9$) and the group with abnormal biventricular response ($n = 11$), both demonstrated incremental increase in Rp/Rs ratio (20.1 ± 11.3 , 26.3 ± 19.8 respectively). Normal right, but abnormal left ventricular reaction ($n = 2$) was noted in patients with residual aortic valvular insufficiency and residual ventricular septal defect. In conclusion, post-operative ventricular response was much more sensitive and informative than that of ventricular function at rest and to detect subclinical cardiac dysfunction. Post-exercise RVEF was closely correlated with preoperative pulmonary vascular hemodynamics, while post-exercise LVEF seemed to be a major determinant of working capacity after repair.

Key Words: Exercise test, congenital heart disease, radionuclide study, repair of CHD

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The radionuclide technique is widely applied in the evaluation of acquired cardiac diseases such as coronary arterial diseases or cardiomyopathies, but it is rarely used in the evaluation of congenital heart diseases (CHD) except in the identification and measurement of the left-to-right shunt (Treves *et al.* 1980). Although the exercise stress test is infrequently used in the evaluation of CHD, it can detect abnormality prior to corrective surgery as well as in postoperatively asymptomatic children (Hallidie-Smith *et al.* 1977; Wessel *et al.* 1980). This test can assess the response of cardiovascular and pulmonary systems in addition to the electrocardiographic (ECG) changes such as arrhythmia or ischemia following the maximal work load. Even though many reports have been documented on the measurement of the maximal work load and oxygen consumption rate, or hemodynamic alteration by cardiac catheterization during the exercise test, the concomitant application of the exercise test with the radionuclide test has been rarely reported in CHD (Reduto *et al.* 1980; Benson *et al.* 1982).

The purpose of this study was twofold: 1) to measure the ventricular EF at rest and after exercise in patients who had surgical repairs due to ventricular septal defect (VSD) or atrial septal defect (ASD); and 2) to compare the ventricular response with preoperative hemodynamics and with the age of the patients at the time of operation, by applying combined radionuclide technique and exercise stress test.

MATERIALS AND METHODS

A group of thirty three children consisting of 21 males and 12 females were included in this study. All of them had CHD with left-to-right shunt and had received corrective surgical repair. Only children over 6 years were tested since an exercise stress test requires cooperation from the patient. The age of patients at test ranged from 6 to 32 years (mean = 14.2 years), whereas their age ranged from 4 months to 22 years (average = 9.7 years) at the

time of operation. The time interval from the surgery to the test was 1 to 15 years (average = 4.6 years).

A rest study was conducted first. Ten mCi of Tc-99m-diethylene triamine pentaacetic acid (DTPA) were injected by bolus via antecubital vein. The right ventricular (RV) and LVEF were calculated by the first pass method. About 1 hour later when the radiopharmaceuticals were excreted by the renal calyceal system, the exercise study was performed. For the exercise stress test, the Collins cycle ergometer (Warren E. Collins Inc., Braintree, MA, USA) was employed, and the pedalling speed was maintained between 60 to 70 rotations per minute (RPM). The work load schedule was planned according to the method used by James *et al.* (1980) on the basis of the body surface area (Table 1). The percentage of the predicted maximal heart rate (% pred max HR) was obtained using the equation, the maximum heart rate of the patient during exercise divided by predicted maximum heart rate = $210 (0.65 \times \text{age of the patient in years})$ (Froelicher and Marcondes, 1989). Although the patients were pushed to do exercise until reaching 85% of the predicted maximum heart rate, many patients (n=25) stopped exercise before reaching 85% due to exhaustion. The first pass study was done just after cessation of exercise to avoid motion blurring during data acquisition. Twenty mCi of Tc-99m-pertechnetate were injected by the same method. There were no complaints of chest pain or depression of the ST segment on the ECG during the exercise test. One of the patients had frequent premature ventricular contractions (PVC), but the incidence of PVC was

Table 1. Work load schedule

BSA	<1m ² (Kg-m/min)	1~1.2m ² (Kg-m/min)	>1.2m ² (Kg-m/min)
level 1	200	200	200
level 2	300	400	500
level 3	500	600	800
Increments	100	100	200

BSA: Body Surface Area

Table 2. RVEF and LVEF in each group

Group	RVEF(%)			LVEF(%)		
	Rest	Post-ex	Increment	Rest	Post-ex	Increment
G I (n=11)	43.6±5.4	54.4±3.5	10.0±3.4	58.3±5.3	65.5±16.6	10.0±3.2
G II (n=9)	47.3±7.6	46.6±7.4	-0.8±6.3	53.0±6.6	66.9±3.9	10.8±3.7
G III (n=11)	46.8±6.4	43.4±7.1	-1.7±9.7	58.9±6.4	56.8±6.4	1.7±7.2
G IV (n=2)	43.0±5.6	52.0±4.2	6.5±0.7	57.0±3.6	56.0±8.5	-2.5±5.0
Statistical Significance		GI-II GI-III	GI-II GI-III	GI-II GII-III	GII-III	GI-III GI-IV GII-III GII-IV

The number means the mean ± standard deviation.

Statistical significance: p value < 0.05 by ANOVA and multiple comparison test between each group

paradoxically decreased by exercise. Blood pressure and heart rate were measured at rest and during exercise. The total workload of an individual patient was calculated by accumulating each stage of the workload multiplied by the exercise time. The percentage of total work (% total work) was calculated by the absolute value of total work divided by the average value of total work in age and body surface area (BSA) matching normal individual, accordingly to the data obtained by James *et al.* (1980).

Small field of view mobile Anger camera (Siemen LEM+) with Computer Design and Application Inc. (CDA) microdelta computer system (Siemens, Erlangen, Germany) were used for the gamma-camera. In order to separate the radioactivity by RV from the right atrium, the gamma-camera head was aimed at the patients with a 30 degree right anterior oblique angulation with a 10 degree cranio-caudal tilt. When the post-exercise ventricular EF was greater than +5% after subtracting the ventricular EF at rest, it was considered to be normal. The normal value of RV and LVEFs at rest were ventricular EF exceeding

52% and 42%, respectively, according to the normal criteria of our laboratory.

According to the rest and post-exercise RV and LVEF, the patients in the study were divided into 4 groups. Group I, which had 11 children, included those who exhibited the normal response, exhibiting normal range of rest EF and more than 5% increase in both ventricular EF after exercise. In group II, 9 patients with abnormal rest and post-exercise RV function, inspite of the normal rest and post-exercise the left ventricular (LV) function were included. Group III consisted of 11 patients with abnormal rest and post-exercise RV and LV function. Group IV consisted of 2 patients with a normal RV function and abnormal LV function, the exact reverse condition of group II (Table 2).

For the preoperative cardiac catheterization, a light cocktail (0.5 mg/kg of Phenalgan, 1 mg/kg of thorazine, and 1 mg/kg of Demerol) was administered 30 minutes prior to the test. Ketamine was administered intravenously (1~2 mg/kg) or intramuscularly (5~8 mg/kg) as the anesthetic agent. In most cases, self-respiration of room air was maintained. Pressure

Table 3. The relation between rest RVEF and LVEF and preoperative hemodynamics and age at operation

	Rest RVEF		Rest LVEF	
	r	p	r	p
Mean PA Pr	-0.25	=0.08	-0.29	=0.05
Qp/Qs ratio	-0.01	ns	0.12	ns
Rp/Rs ratio	-0.15	ns	-0.18	ns
Age at op.	0.05	ns	-0.11	ns
%total work	0.10	ns	0.14	ns

RVEF: right ventricular ejection fraction, LVEF: left ventricular ejection fraction, r: linear correlation coefficient, p: p-value, mean pA pr: mean pulmonary arterial pressure, Qp/Qs ratio: pulmonic/systemic flow ratio, Rp/Rs ratio: pulmonic/systemic vascular resistance ration, % total work: exercise total work/normal value \times 100, ns: nonsignificant

and blood oxygen saturation of the left and right heart were measured. The systemic blood flow and pulmonary blood flow were calculated using the Ficks principle, using the predictive value of the oxygen consumption rate. The hemodynamic findings were expressed as pulmonary to systemic blood flow ratio (Qp/Qs) and a pulmonary to systemic resistance ratio (Rp/Rs).

RESULTS

Negative correlations were seen between the percentage of total work and the age of patients during testing ($r=-0.46$, $p<0.01$) and between the percentage of total work and the age of patients at operation ($r=-0.52$, $p<0.01$). The statistically significant correlation was present between the percentage of total work and the heart rate at rest ($r=0.57$, $p<0.001$). The average of the percentage of total work was at 40% of workload capacity in normal person with corresponding height and BSA. There was no difference of the percentage of total work between the sexes (male= 34 ± 17 and female= $47\pm31\%$, $p>0.05$). No correlation was noted between the percentage of total work and the percentage of predicted maximum heart rate ($r=-0.13$, $p>0.05$).

RVEF at rest was less than 42% in 5 patients, and 2 of the 5 had less than 5% post-

exercise increment of EF. Rest LVEF was less than 52% in 5 patients and 2 of the 5 had less than 5% post-exercise increment EF. Post exercise increment of RVEF was less than normal in a total of 20 patients and less than normal in LVEF in a total of 12 patients

Table 3 to 5 summarized the linear correlation between LVEF and RVEF at rest and after exercise and with preoperative hemodynamics, the percentage of total work, the percentage of predicted maximum heart rate and the age of the patients at operation. LV and RV EF at rest showed no statistical correlation with various parameters except the preoperative mean pulmonary arterial pressure in which only a weak correlation was seen (with LVEF, $r=-0.29$, $p=0.05$ and with RVEF, $r=-0.25$, $p=0.08$) (Table 3). Post-exercise LV and RV EF showed a much higher correlation with the preoperative hemodynamics than the correlation with rest ventricular EFs. Post-exercise RVEF exhibited a more significant correlation with preoperative hemodynamics than post-exercise LVEF. Rp/Rs ratio ($r=-0.49$, $p<0.005$) showed the highest correlation with a post-exercise RVEF, followed by the mean pulmonary arterial pressure ($r=-0.37$, $p<0.05$) (Table 4)(Fig. 1). Post-exercise LVEF showed no correlation with Qp/Qs ratio whereas it showed a weak correlation with the mean pulmonary arterial pressure ($r=-0.33$, $p=0.08$) and Rp/Rs ratios ($r=-0.26$, $p=0.10$). However,

Table 4. The relation between rest RVEF and LVEF and preoperative hemodynamics and exercise status

	Post-Ex RVEF		Post-Ex LVEF	
	r	p	r	p
Mean PA Pr	-0.37	<0.05	-0.33	=0.08
Qp/Qs ratio	0.16	ns	0.02	ns
Rp/Rs ratio	-0.49	<0.005	-0.26	=0.10
Age at op.	0.14	ns	0.19	ns
% total work	0.20	ns	-0.39	<0.05
% pred max HR	-0.08	ns	0.08	ns

Post-Ex: post-exercise, % pred max HR: percentage of predicted maximum heart rate
Others: refer table 2

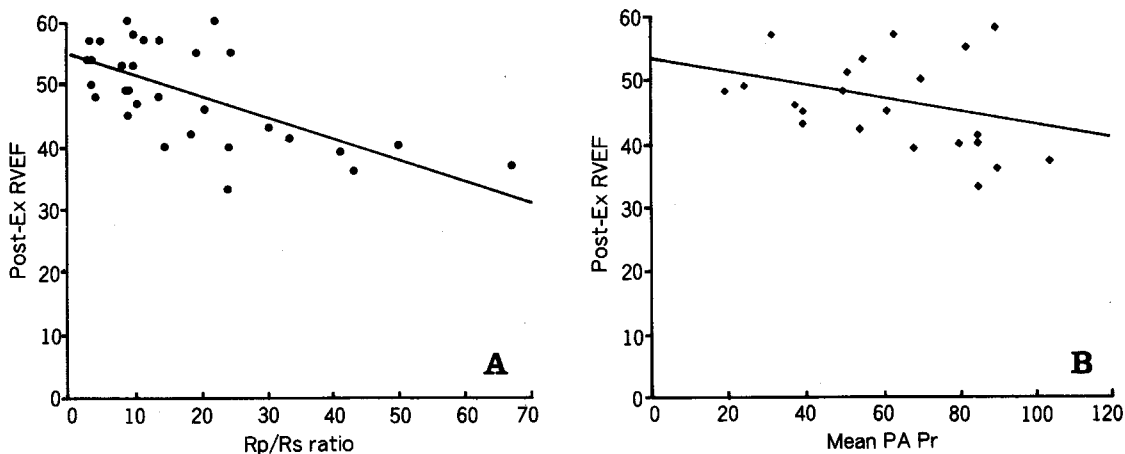


Fig. 1. The linear correlation between (A) post-exercise RVEF and preoperative Rp/Rs ratio, and between (B) Post-exercise RVEF and preoperative mean pulmonary arterial pressure. In (A), The correlation coefficient is -0.49 ($p < 0.005$), and in (B), the correlation coefficient is -0.37 ($p = 0.08$).

the age at the time of operation did not show a correlation with either RVEF or LVEF (Table 4).

Postexercise increments of RVEF and LVEF showed a good correlation with the preoperative Rp/Rs ratios (with RV: $r = -0.45$, $p < 0.005$ and with LV: $r = -0.47$, $p < 0.005$). A correlation was seen between the post-exercise increment of RVEF and preoperative Qp/Qs ratio ($r = 0.30$, $p < 0.05$) and between the post-exercise increment of LVEF and the preoperative mean pulmonary arterial pressure ($r =$

-0.39 , $p < 0.01$) (Table 5). The exercise stress test revealed that the preoperative Rp/Rs ratio and the mean pulmonary arterial pressure correlated with a biventricular response, but more closely with a RV response, and the Qp/Qs ratio showed a relationship only with the RV response.

The post-exercise LVEF had a negative correlation with the percentage of total work, and the post-exercise RVEF had no correlation with the percentage of total work (Table 4)(Fig. 2). The maximal workload was difficult

to obtain on a cycle ergometer since the patients could stop the exercise at will, unlike the treadmill test.

Table 6 listed data including age, the percentage total work, blood pressure during exercise, heart rate and the percentage of predicted maximum heart rate of each group. Our results indicated that the age of group I was older than the other groups. The percentage of total work and the percentage of predicted maximum heart rate were increased in

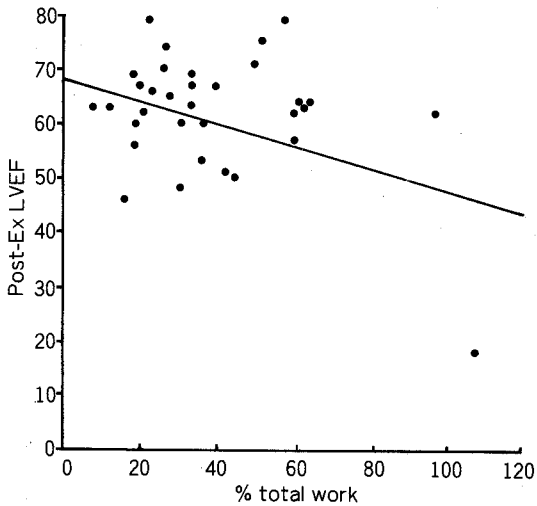


Fig. 2. The linear correlation between post-exercise LVEF and % total work. The linear correlation coefficient is -0.34 ($p < 0.05$).

the order of group I to IV, but no statistical significance was observed except between group I and IV. The relationship between the age at the time of operation and preoperative hemodynamic findings are compared in Table 7 and Fig. 3. The age of operation was older in group I than group II and IV, and it was probably due to the fact that an increase in pulmonary vascular resistance was small enough to delay the corrective surgery. In comparing preoperative hemodynamic findings, the Qp/Qs ratio in group I (3.8 ± 1.8) was significantly higher than group II (1.7 ± 0.8), and the Rp/Rs ratio in group I (7.6 ± 4.1) indicated a significantly lower than group III (26.3 ± 19.8). Therefore, preoperative hemodynamic findings of group I indicated a characteristically large left-to-right shunt volume with normal pulmonary vascular resistance whereas a moderate amount of shunt volume with moderate increase of pulmonary vascular resistance in group II and moderate shunt with relatively high resistance in group III were suggested. Preoperative hemodynamic findings in group IV were not remarkable.

In group IV, there were 2 cases of VSD, but each had either residual left-to-right shunt or residual aortic valvular insufficiency after surgical repair. Only in group IV, the rest heart rate was higher, and the systolic blood pressure during exercise reached only 130 mmHg. The cardiac defect corrected by surgery in group I included 4 cases of ASD (1 case with

Table 5. The relation between post-exercise increment of RVEF and LVEF and preoperative hemodynamic and exercise status

	Δ RVEF		Δ LVEF	
	r	p	r	p
Mean PA Pr	-0.28	=0.06	-0.39	<0.01
Qp/Qs ratio	0.30	<0.05	0.01	ns
Rp/Rs ratio	-0.45	<0.005	-0.47	<0.005
Age at op.	0.09	ns	0.26	=0.07
% total work	0.07	ns	-0.04	ns
% pred max HR	0.14	ns	-0.20	ns

Δ RVEF: Post-exercise RVEF - rest RVEF, Δ LVEF: post-exercise LVEF - rest LVEF, Other: refer tabel 3

Table 6. Exercise status in each group

	Age (yrs)	Total work (%)	Rest SP (mmHg)	Post-ex SP (mmHg)	Rest HR	% pred max HR
G I (n=11)	17.7±5.7	37±27	113±6	158±26.4	84±11	79±12
G II (n=9)	10.3±7.2	39±21	111±10	152±17	89±13	81± 9
G III (n=11)	13.5±8.3	37±23	118±13	154±23	90±19	83±10
G IV (n=2)	8.0±0.0	51±10	105± 7	130±14	102±13	91± 9
Statistical Significance		GI-II GI-III GI-IV	—	—	—	GI-IV GI-IV

The number means the mean±a standard deviation

SP: systolic blood pressure, HR: heart rate, Pred max HR: predicted maximum heart rate,
Statistical significance: refer table 2

Table 7. Age at operation and preoperative hemodynamics in each group

	Age at Operation (yrs)	Mean PA Pr. (mmHg)	Qp/Qs ratio.	RP/Rs ratio.
G I (n=11)	12.2±5.7	18±17	3.1±1.8	7.6± 4.1
G II (n=9)	7.3±3.7	31±22	1.71±0.8	20.1±17
G III (n=11)	8.3±5.7	39±23	2.5±1.3	26.3±19.8
G IV (n=2)	3.9±0.1	31±44	2.5±0.3	16.5±11.1
Statistical Significance		GI-IV GI-II	GI-III	GI-II GI-III

abb: refer table 2 & 3

pulmonary stenosis and 1 case with mitral valve insufficiency) and 8 cases of VSD (2 cases with RV infundibular stenosis), showing a higher incidence of ASD compared to other groups. Physical examination findings during test included 1 case of cardiac murmur consistent with tricuspid valvular insufficiency and 2 cases of mild systolic murmur. In addition,

although there was 1 case of frequent PVC and incomplete right bundle branch block on the ECG, the remaining cases had a normal ECG. In group II, the preoperative diagnosis included 1 case of ASD, 8 cases of VSD (combined with RV infundibular stenosis in 2 cases, aortic valve insufficiency in 2 cases and patent ductus arteriosus (PDA) in 1 case and

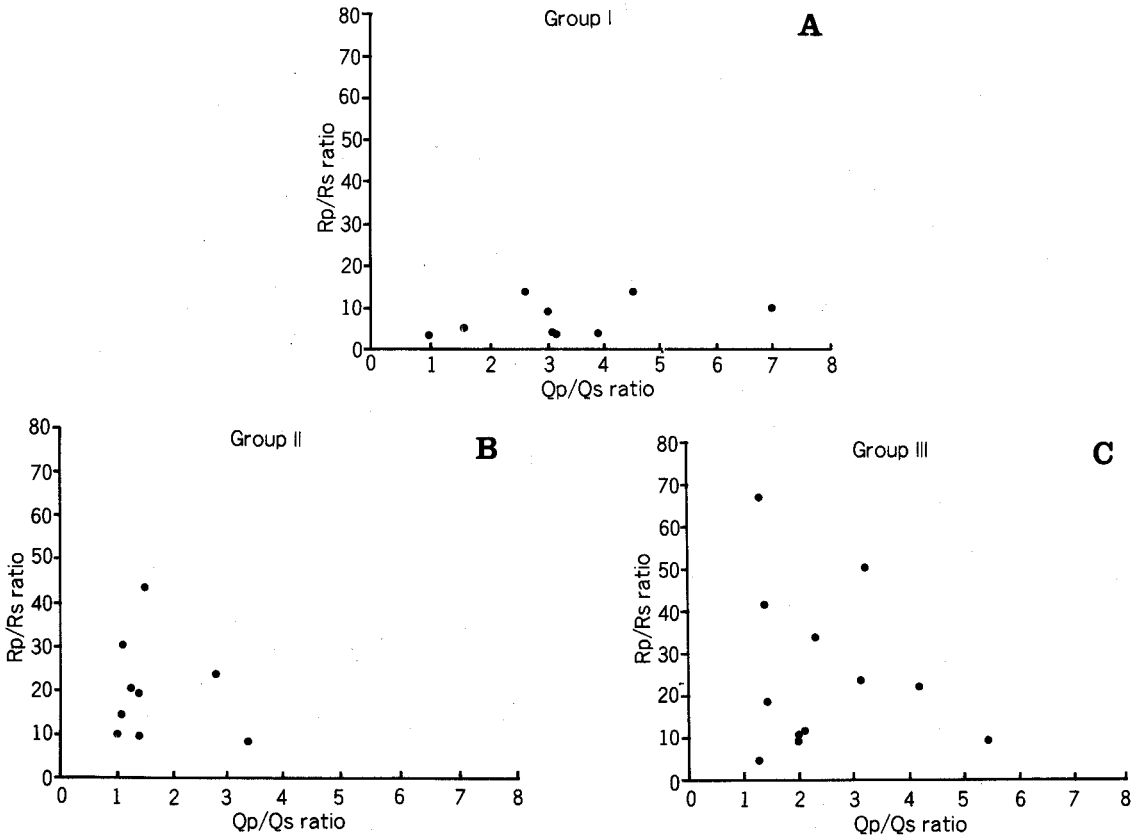


Fig. 3. The scattergram of cases according to the preoperative Rb/Rs ratio and Qp/Qs ratio in (A) Group I, (B) Group II and (C) Group III. The mean values of each group were shown in Table 7. The preoperative Qp/Qs ratio in group I (3.8 ± 1.8) was significantly higher than group II (1.7 ± 0.8), and the Rb/Rs ratio in group I (7.6 ± 4.1) indicated a significantly lower than group III (26.3 ± 19.8).

1 case had combination of ASD and VSD. Other clinical findings included 1 case of cardiac murmur compatible with residual PDA; 1 case of the first degree atrio-ventricular (AV) block and 3 cases of the incomplete right bundle branch block. In group III, 3 cases of ASD (1 case combined with RV infundibular stenosis), 5 cases of VSD (2 cases combined with RV infundibular stenosis) and 1 case of combined ASD and VSD were included. There was 1 case of residual postoperative pulmonary arterial hypertension measured by cardiac catheterization.

DISCUSSION

Any residual cardiovascular abnormalities can affect the quality of life of patients and their long-term prognosis. The involved factors of the longterm prognosis are like these. ① Only palliative-purpose treatment was given such as Fontan operation, ② residual disease such as incomplete closure of VSD or incomplete removal of valvular or outflow obstruction were remained unintentionally, ③ uncorrectable disease such as pulmonary vascular disease, ventricular hypoplasia or dys-

function was combined, ④ postoperative complications such as ventricular dysfunction were induced unintentionally, and ⑤ complication not related to operative technique such as complication of artificial valvular replacement occurred. In order to identify any hidden abnormal hemodynamic findings in a postoperative state, an exercise test was used as qualitative test to monitor progress and as a reference for advising patients on exercise, occupation and other activities. An exercise test measuring the total workload, oxygen consumption and ventilatory function alone or combined with cardiac catheterization are commonly applied to measure hemodynamic findings at rest and after exercise (Duffie and Adams, 1963; Graham, 1974; Vogel *et al.* 1974).

RVEF is difficult to obtain because of the particular geometry of RV by cardiac catheterization, although this can provide precise hemodynamic data. Moreover, the exercise stress test is cumbersome when conjoined with catheterization. There are two methods using the radionuclides technique to assess cardiac function, the first pass method and the equilibrium technique, and two methods are possible to be used in conjunction with the exercise test (Parrish *et al.* 1982). The authors used the first pass method as it can easily measure RV and LV EF simultaneously although it is known that the equilibrium method is as effective as the first pass test (Parrish *et al.* 1982). The exercise test provided an accurate assessment of the individual's physical functional ability and an evaluation of cardiopulmonary reserves. Our result revealed that only 9 patients (27%) showed abnormal rest RV and/or LV EF, but post-exercise ventricular response was abnormal in 19 patients (58%). Both rest EF and post-exercise response were normal in only 11 patients (33%). Thus, the exercise stress test can detect subclinical cardiovascular dysfunction because all patients in this study belonged to the NYHA functional class I except one who had residual pulmonary hypertension, belonging to class II.

The application of the combined method to assess congenital heart disease is not used fre-

quently. Parrish *et al.* (1982) studied the post-exercise response in CHD and observed the normal response of the left heart and abnormal response of the right heart in patients with pulmonary stenosis and mitral valve stenosis as well as the abnormal response of both the left and right heart in patients with transposition of great vessels (TGV) using equilibrium method. Reduto *et al.* (1980) conducted a study of post-exercise response of RV using radionuclides during the exercise stress test in sixteen asymptomatic patients, whose residual RV hypertrophy was proven by Tl-201 scan. Benson *et al.* (1982) conducted an exercise stress study using radionuclides in patients with TGV, in whom the Mustard operation was performed, and where RV functioned as the systemic ventricle. Some of these patients had no limitations in their daily life except abnormal response of RV, which is indicative of a poor long-term prognosis. The result of the above study suggested that this combined study can discriminate subclinical cardiac dysfunction of each separate ventricle.

The workload schedules were selected in order to achieve cardiopulmonary exhaustion at a mild to moderate exercise level rather than by providing a workload which the subjects could not accomplish because of inadequate muscle strength due to lack of supply of oxygen. According to the report done by Duffie and Adams (1963), children with a CHD with a left to right shunt, only 30 percentile or less of the working capacity of normal children was carried out in 52% of the patients before repair. The working capacity showed no correlation with Qp/Qs ratio, but a good correlation with the pulmonary artery pressure. After repair, the working capacity was not always improved, and the subnormal capacity was related, in part, with preoperative pulmonary arterial hypertension or post-operative AV block, but the suboptimal working capacity was encountered in some of adequate or uncomplicated anatomic repair, and the cause was not able to be explained in them (Duffie and Adams, 1963).

There was no significant residual disease except a few cases of residual left-to-right shunt and aortic valvular insufficiency and

minor ECG changes in our patients, after correction of congenital defects; furthermore, exercise induced no limitation of daily life. Even though the intended selection criteria of subjects were those with simple VSD or ASD, the number of patients in this study did have the presence of other combined preoperative cardiac anomaly, postoperative residual cardiac lesion or inappropriate timing of operation. In these patients, the average of the percentage of total work was below 50 percent of appropriate age. It appeared in this study that the capacity of exercise decreased in patients whose initial age at the operation was older. Low cardiac output response to exercise was reported in those with repaired VSD, and its degree of low cardiac output was related with the age at operation (Maron *et al.* 1973). As the operation was delayed, either residual organic disease in the cardiovascular system or a lack of motivation due to psychological factors could be proffered as a possible explanation. In this study, the post-exercise LVEF showed close correlation with the percentage of total work and was considered to be a major limiting factor of exercise capacity. On the other hand, the RV performance did not appear to have an apparent relationship to the exercise capacity. Futaki *et al.* (1986) reported the maximum oxygen consumption was correlated with rest LVEF ($r=0.53$, $p<0.01$) in the exercise stress test in those who had a repaired CHD; therefore, they concluded that the exercise capacity related significantly to LVEF at rest. On the other hand, the working capacity was correlated with the heart rate at rest but not with LVEF at rest in this study.

According to the report of Hallidie *et al.* (1977) on hemodynamic changes by cardiac catheterization observed during exercise tests a few years after repair of VSD combined with pulmonary arterial hypertension, 5 of 27 patients had an abnormal ventilatory response and 6 of 27 had a mild decrease in cardiac output. When the residual pulmonary arterial hypertension was mild at rest, the end diastolic pressure (EDP) of LV was normal at rest, and this pressure remained normal during the exercise test with an increase of the stroke

volume of LV. Meanwhile, if the residual pulmonary hypertension was significantly high, EDP of LV was elevated during exercise. This resulted in subnormal increases of the post-exercise stroke volume of LV, and they suggested impairment of LV function in these patients as a cause of post-exercise left ventricular failure. Graham (1974) found that in the similar group whose end-diastolic volume was decreased, LVEF was also decreased. Post-exercise LV failure was suggested to be due to preoperative volume overload of LV. This phenomenon became obvious when the LV volume overload decreased after corrective surgery (Graham, 1974).

The result of preoperative hemodynamics correlated with response to exercise after repair of VSD is controversial. Lucker *et al.* (1969) reported the significant correlation between the preoperative pulmonary arterial pressure and post-exercise decrease of cardiac index. Maron *et al.* (1973) denied this relationship except for the linear correlation of the post-exercise subnormal increase of cardiac output with the patients' age at the operation, while the age at operation was also correlated with exercise induced pulmonary arterial hypertension after repair. Maron *et al.* (1973) suggested that the cause of post-exercise increase of pulmonary arterial pressure may, at least in part, be due to impaired LV performance because the pulmonary capillary wedge pressure (PCWP) increased in some patients. It may also be attributed to the persistent pathologic changes or the abnormal vascular reactivity of pulmonary arterioles, since PCWP also remained normal in some patients. In this study, post-exercise RVEF showed a strong negative correlation with the preoperative Rp/Rs ratio, and a weak negative correlation with the mean pulmonary arterial pressure. Consequently, among LVEF and RVEF and post-exercise response, post-exercise RV response showed the strongest correlation with preoperative hemodynamic findings. Thus, the residual pulmonary vascular obstruction seemed to play the most important role in the post-exercise response of RV.

The natural history of pulmonary vascular

disease after the repair of cardiac defect varies, and it can disappear or persist and even progress in some cases after surgery. Pulmonary vascular disease is rare before 1 year of age, and an increase in the pulmonary vascular resistance following the operation in infants does not necessarily mean poor long-term prognosis (Wagenvoort and Wagenvoort, 1974). In patients older than 1 year of age, hypoxic condition was intentionally provoked during cardiac catheterization few year after repair of VSD, and the hemodynamic response was compared with lung biopsy findings obtained at the time of cardiac repair (Choe, 1986). The patients with a decreased concentration of the pulmonary arterioles in lung biopsy specimen tended to exhibit persistent pulmonary arterial hypertension even after the operation. In cases of preoperative pulmonary arterial hypertension due to the medial hyperplasia of pulmonary arterioles, the pulmonary hypertension was resolved in a follow up study. Moreover, the pulmonary arterial response to hypoxia appeared normal in them (Choe, 1986). Since both the medial hyperplasia of pulmonary arterioles and the decrease in the concentration of pulmonary arterioles were able to raise pulmonary arterial resistance, the preoperative increase of pulmonary vascular resistance was not always a reliable predictor for postoperative reversibility or irreversibility of pulmonary vascular obstruction. The evaluation of the pulmonary vascular change by histologic examination is practically and ethically impossible. This radioisotope study combined with exercise stress may be able to detect the post-operative regression or progression of the pulmonary vascular obstruction in individual patients using a noninvasive method.

In this study, post-exercise LVEF showed no statistically significant correlation with a preoperative hemodynamics. The Qp/Qs ratio is an indicator of volume overload of LV in cases of VSD or PDA and of RV in cases of ASD. Eight patients only had ASD, which did not show preoperative LV volume overload, but 4 of them showed the normal biventricular function (group I). However, the other 3 belonged to group III. Consequently, post-exer-

cise LV failure did not seem to be solely due to the preoperative LV volume overload. RV dysfunction can induce LV dysfunction since the RV and LV function as pumps in series, or an alteration of the shape of the interventricular septum can induce LV dysfunction (Slutsky et al. 1980) or the abnormal pulmonary vascular reactivity might limit cardiac output and then impaired LV function (Hallidie-Smith et al. 1977). Besides the residual pulmonary vascular disease and the decreased function of ventricles due to preoperative volume or pressure overload of the ventricles, the fibrotic change of pericardium and the surgical wound scar of the ventricular myocardium could be a reason for the further decrease of the ventricular function. Two patients in group IV each had either a residual left-to-right shunt or a residual aortic valvular insufficiency after surgical repair. It was presumed that the reason for the abnormal EF confined only to LV was postexercise LV failure because of residual cardiac disease.

In this study there was no relationship among LVEF and RVEF and the age of the patients at operation. Even though the optimal time for the corrective surgery of VSD is generally recommended before 2 years of age, a relatively large number of patients who survived to adulthood had been operated later on than this age criteria. There were only 2 patients in this study who were operated under 2 years of age. Subsequently, it was not possible to compare the test results of age at operation under or over 2 years of age.

In summary, the post-exercise ventricular response is much more sensitive and informative than at rest. Post-exercise LVEF had a close relation with the limitation of the working capacity but post-exercise RVEF had a correlation with the preoperative pulmonary vascular resistance in this study. In patients with the normal response of RV and LV, the pulmonary vascular resistance was normal regardless of any degree of preexisting left to right shunt prior to corrective surgery. In patients with abnormal response of RV or bilateral ventricles, the preoperative hemodynamic findings showed the closer relationship with the pulmonary vascular resistance and the

pulmonary arterial pressure. The abnormal response in both ventricles was more typical in cases of a large amount of left to right shunt combined with markedly increased pulmonary vascular resistance. Therefore, preoperative increase in the pulmonary vascular resistance and in shunt volume tended to show the functional disturbance after surgery. The abnormal post-exercise response confined to LV was due to the residual cardiac defect after repair. It is of great interest how the above findings can affect the patient's daily life in long-term follow-up and can assist in appropriate prescription of exercise.

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