

## Ventricular Arrhythmias in Children: The Validity of Exercise Stress Tests for Their Diagnosis and Management

YOSHIHO RYUJIN, M.D., YOSHIO ARAKAKI, M.D., OSAHIRO TAKAHASHI, M.D.  
AND TETSURO KAMIYA, M.D.

One hundred ninety-six children ranging in age from 4 years to 15 years with premature ventricular contraction (PVC) on a resting electrocardiogram (ECG) underwent exercise tests and 29 of them were found to have significant ventricular arrhythmias. They included 8 patients with 2 PVC's in row, 8 patients with 3-4 PVC's in row, and 13 patients with more than 5 PVC's in row (ventricular tachycardia: VT). These 29 patients were evaluated with exercise tests by two-step exercise ECG (TSE) and by treadmill (TM), and with 24 hour continuous ECG monitoring (Holter monitoring). 141 ECG's, 77 TSE's, 77 TM's and 46 Holter monitorings were obtained in total, and the incidence of the each study revealing findings compatible with the final diagnosis was 3%, 15%, 51% and 26%, respectively. For detection of 2 PVC's in row, the sensitivity of TSE and TM was not different, but for picking up 3-4 PVC's in row and VT, TM was significantly superior to TSE. Among the VT patients, there were a few cases in whom neither TM nor Holter monitoring alone was sufficient to confirm the diagnosis. Children with symptoms suggestive of ventricular arrhythmias should be carefully evaluated with a combination of exercise tests and Holter monitoring.

**R**ECENTLY, arrhythmias in children have been much more frequently detected by mass screening of school children than previously. Among the many types of arrhythmias, premature ventricular contraction (PVC) is the most common arrhythmia found in children. However, other types of ventricular arrhythmias, such as short runs of PVC or ventricular tachycardia (VT), are obviously much less frequently found than in adults. However, the exact incidence of such arrhythmias in children remains unknown, because they may not necessarily be recognized, due to the fact that VT in children is short in duration, and that it may be associated with

either no or only minimal symptoms. Children exercise much more than adults in general, but their exercises are sporadic with sudden strenuous activities rather than sustained activities. Therefore, even VT may not produce any subjective symptoms during exercise. Besides, the majority of ventricular arrhythmias in children is associated with no underlying organic heart disease, so the patients have very little chance for detailed cardiac examinations. These could be the other reasons for the low incidence of short runs of PVC's or VT in children. Because of the factors mentioned above, relatively little information about the clinical significance of the ventricular arrhythmias in children, particularly regarding their long term prognosis and the management has been available up to now! This report deals with the validity of exercise stress testing and 24-hour continuous electrocardio-

---

### Key Words:

Ventricular tachycardia  
Premature ventricular contraction  
Treadmill  
Two-step exercise electrocardiogram

---

*Department of Pediatrics, National Cardiovascular Center, Osaka, Japan*

Mailing address: Yoshiho Ryuji, M.D., Department of Pediatrics, National Cardiovascular Center,  
5 Fujishirodai, Suita 565, Japan

TABLE I LIST OF PATIENTS WITH SIGNIFICANT VENTRICULAR ARRHYTHMIAS

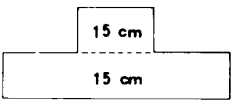
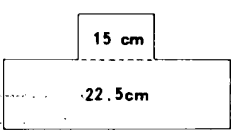
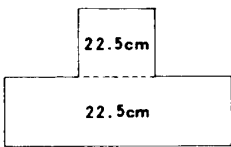
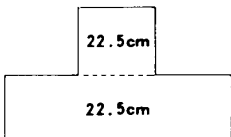
Case	Age	Sex	HR/min	Symptom	Complication	Treatment
<b>2PVC's</b>						
No.1	5y	M	150	—	—	—
2	5y	M	150	—	—	—
3	7y	M	120	—	IRBBB	—
4	8y	F	152	—	—	—
5	10y	M	136	—	—	—
6	11y	F	230	—	—	—
7	12y	F	102	—	—	—
8	13y	M	115	—	—	—
<b>3-4PVC's</b>						
No.1	6y	M	212	—	—	—
2	8y	M	214	—	—	—
3	9y	M	115	—	—	—
4	12y	M	89	—	—	—
5	13y	M	115	—	—	—
6	13y	F	167	—	—	—
7	13y	F	176	Nausea, palor	Epilepsy, sinus bradycardia	—
8	14y	M	214	—	—	—
<b>VT</b>						
No.1	4y	M	167	—	—	—
2	4y	F	150	—	—	—
3	6y	F	185	—	—	$\beta$ -blocker
4	6y	F	188	Palpitation	Left ventricular false tendon	$\beta$ -blocker
5	6y	F	115	—	—	—
6	8y	M	160	—	—	$\beta$ -blocker
7	12y	M	300	Palpitation	—	$\beta$ -blocker
8	12y	F	180	Syncope	—	$\beta$ -blocker, disopyramide, chlordiazepoxide
9	12y	F	115	—	—	—
10	13y	F	136	Syncope	Periodic paralysis	$\beta$ -blocker, disopyramide, phenytoin
11	15y	M	90	—	—	—
12	15y	M	163	—	—	$\beta$ -blocker
13	15y	M	176	—	—	$\beta$ -blocker

graphic monitoring (Holter monitoring) to detect serious ventricular arrhythmias in children and with their prognosis.

#### MATERIAL AND METHOD

From 1979 to 1982, 196 children who had PVC on a resting electrocardiogram (ECG) with no evidence of underlying organic heart disease based on physical examination, chest X-ray and

echocardiography, were seen in the pediatric outpatient clinic of the National Cardiovascular Center. They included 22 patients aged 4–5 years, 68 aged 6–9 years, 49 aged 10–12 years and 57 aged 13–15 years; and 110 boys and 86 girls. The associated ECG abnormalities included WPW syndrome in 9 cases, AV dissociation in 1 case, first degree AV block in 1 case, complete right bundle branch block (RBBB) in 1 case, and incomplete RBBB in 4 cases. Patients with

Age	height of steps	Speed (steps/min)
4y~5y		120
6y~8y		120
9y~11y		120
12y~15y		120

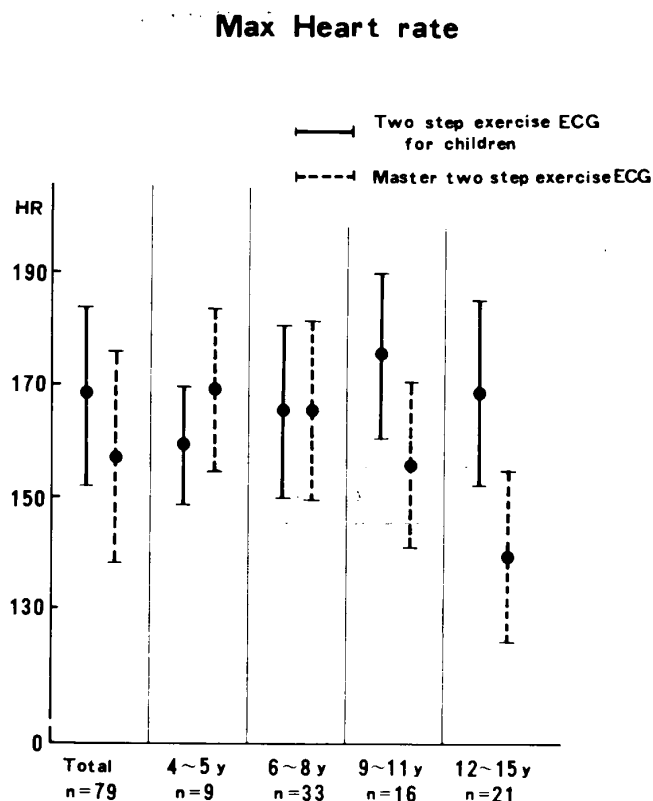


Fig.1. Two-step exercise ECG.

minor structural abnormalities including 2 cases with mitral valve prolapse and 2 cases with false tendon of the left ventricle were included in the study. These patients underwent an exercise test with treadmill, and 29 patients were noted to develop multiple PVC's with exercise, including 8 patients with 2 PVC's in row, 8 patients with 3-4 PVC's in row, and 13 patients with more than 5 PVC's in row (VT). These 29 patients were evaluated in detail (Table I).

Exercises stress testing was done using two-step exercise ECG (TSE) and treadmill (TM). TSE was primarily a modification of Master's test, using steps with different heights according to the age of patients. Exercise was continued for 3 minutes, and an ECG was recorded for 8 minutes after completion of the exercise. The steps were designed in such that more than 70% of the examinees reached a maximum heart rate of over 150 BPM in the each age group. TSE had been found to be more appropriate than the standard Master's two-step test due to its simplicity and the degree of the heart rate increase (Fig. 1).

TM was done using a modification of Bruce's protocol (Fig. 2). One stage was for 3 minutes. The goal of the duration of the exercise was 12 minutes from Stage 3 to Stage 5, 7 and 9, follow-

		Program				
STAGE		1	3	5	7	9
km/h	Pre	2.5 - 4.5	5.5	5.5	7.5	
3 min each Grade %		10	10	14	22	22

NCVC

Fig.2. Protocol for treadmill test.

ing warming up for about 30 seconds with Stage 1. An ECG was recorded for 8 minutes after completion of the exercise. Holter monitoring was done using Model 405 by Del Mar Avionics, and PVC's were manually counted using an eliminator.

## RESULTS

A total of 141 ECG's 77 TSE's, 77 TM's and 46 Holter monitorings was obtained on the 29 patients. The mean number of the examinations for one patient was 4.7 for ECG, 2.7 for TSE and TM and 1.6 for Holter monitoring. The test was considered to be positive when the finding agreed with the final diagnosis. 4 ECG's (3%), 12 TSE's (15%), 39 TM's (51%) and 12 Holter monitorings

TABLE II INVESTIGATION OF CHILDREN WITH PVC SHORT RUN AND VT

	Total number of examination	Number of examination per patient	Positive result
ECG	141	4.7 ( $\pm$ 3.4)	3%
Two step exercise ECG	77	2.7 ( $\pm$ 2.0)	15%
Treadmill test	77	2.7 ( $\pm$ 2.2)	51%
Holter monitoring	46	1.6 ( $\pm$ 1.3)	26%

(Follow up duration:  $2.8 \pm 0.9$  years)

TABLE III INVESTIGATION OF CHILDREN WITH VT

	Total number of examination	2PVC's	3-4PVC's	VT	Total (n = 13)
ECG	51	3 (6%)	1 (2%)	2 (40%)	6 (12%)
Tow step exercise ECG	25	5 (20%)	1 (4%)	5 (20%)	11 (44%)
Treadmill test	22	1 (5%)	2 (9%)	11 (50%)	14 (64%)
Holter monitoring	17	4 (24%)	3 (18%)	6 (35%)	13 (76%)

TABLE IV FINDINGS OF EXERCISE TESTS AND HOLTER MONITORINGS IN PATIENTS WITH VT

	ECG			Two step exercise ECG			Treadmill test			Holter monitoring		
	2PVC's	3-4PVC's	VT	2PVC's	3-4PVC's	VT	2PVC's	3-4PVC's	VT	2PVC's	3-4PVC's	VT
No. 1	—	—	—	—	—	+	—	—	+	—	—	+
No. 2	—	—	—	—	—	+	—	—	+	—	—	+
No. 3	+	—	—	—	—	—	+	+	+	+	+	—
No. 4	—	—	—	+	—	—	—	—	+	*	*	*
No. 5	+	—	+	+	—	—	—	—	—	+	—	—
No. 6	—	+	+	+	+	+	+	+	+	+	+	+
No. 7	—	—	—	—	—	—	—	—	—	—	+	+
No. 8	+	—	—	—	—	—	+	+	—	+	+	+
No. 9	—	—	—	—	—	—	—	—	+	—	—	+
No.10	—	—	—	—	—	—	+	+	+	+	+	+
No.11	—	—	—	+	+	+	—	—	—	—	—	—
No.12	—	—	—	+	+	+	+	+	+	—	+	—
No.13	—	—	—	*	*	*	—	+	—	+	+	+
	23%	8%	15%	42%	25%	42%	38%	46%	62%	50%	58%	67%

(\* = not performed)

(26%) were positive, and TM had the highest overall sensitivity (Table II).

**2 PVC's in row:** 2 PVC's in row (couplets) were seen in 2 out of 27 ECG's (7%), 5 of 15 TSE's (33%), 6 of 14 TM's (43%) and 2 of 6 Holter monitorings (33%). In terms of number of patients, couplets were picked up in 1 patient of 8 by ECG (8%), 4 patients of 7 by TSE (43%), 6 of 8 by TM (75%) and 1 of 3 patients by Holter monitoring (33%). 2 patients had a positive TSE but a negative TM test.

**3-4 PVC's in row:** As far as the patients with 3-4 PVC's in row were concerned, 1 couplet was noted in 39 ECG's. By TSE, 7 couplets and one episode of 3-4 PVC's were noted in 25 examinations. TM was positive in 5 with couplets (28%) and in 8 with 3-4 PVC's in row (27%) out of 11 examinations. In terms of number of patients, none of the patients had a positive ECG, and one of the 8 patients had a positive TSE (7%). Six of 8 patients had a positive TM (75%) and 3 of 6 patients had a positive Holter monitoring (50%). One patient had negative TSE and TM but a positive Holter monitoring.

**VT:** The results of the patients with VT are summarized in Table III. ECG was positive only in 2 examinations (4%) out of 51, and including 2-4 PVC's in row, only 6 ECG's (12%) were positive. TSE was positive in 5 examinations (20%) of 25; TM was positive in 11 examinations (50%) out of 22; and Holter monitorings picked up VT in 6 examinations (35%) out of 17. However, including 2-4 PVC's in row, 5 TSE's (42%) of 12, 8 TM's (62%) of 13, and 8 Holter monitorings (67%) of 12 were positive. Thus, when 2-4 PVC's were included, Holter monitoring was found to be most sensitive among the tests performed. Two patients had a positive TM and a negative holter monitoring, and 3 had the opposite. One patient had negative TM and Holter monitoring, but a standard ECG showed VT (Table IV).

Analyzing the incidence of positive results of the exercise tests, TSE and TM showed no statistical significance in terms of picking up couplets, but for detection of 3-4 PVC's in row and VT, TM was found to have statistically significant superiority to TSE ( $p < 0.025$  and  $p < 0.05$ , respectively).

**Long term follow-up:** Twenty patients had adequate follow-ups and the duration of the follow-up was 2.8 years on the average. To date there has been only one fatal case (No.8 of the VT patients). This patient was the only one who

did not have PVC's on a resting ECG. She had and a history of syncopal episodes and had been treated as a case of seizure disorder. She developed VT on TSE and this was confirmed by a TM test. With a heart rate of more than 120 BPM, she developed bidirectional VT, and when it persisted for 30 to 60 seconds, she developed chest discomfort followed by syncope. Her dysrhythmia was resistant to most antiarrhythmic agents. She was allowed to participate in activities only in the class room, but she died suddenly on a stairway of the school. No autopsy was available.

## DISCUSSION

In recent years, many school children have been found to have cardiac arrhythmias, particularly ventricular arrhythmias, by school physical examinations and by cardiac screening. Their management and the selection of children who require management have become a significant problems. Exercise testing has been used frequently for the evaluation of those children. Although the methodology of exercise stress tests has not been well established in children yet, the number of exercise tests in many institutions has been increasing. While they are performed primarily in patients with ischemic heart disease in adults, in children, the conditions in which exercise tests are indicated encompass a wide variety including pre- and postoperative patients of congenital heart disease in addition to arrhythmia patients. Parameters available with exercise are usually only ECG, heart rate and blood pressure, therefore the exact hemodynamic changes with exercise are rather difficult to evaluate. Exercise tests have been done only in selected patients with congenital heart disease in terms of their pre- and postoperative assessment.

The treadmill test has been chosen in many institutions as the method of exercise, since it has been considered to be more physiological and similar to the regular physical activities of children than the other method. Each institution has employed its own exercise protocol, usually modifications of Bruce's protocol<sup>2,3</sup>. However, according to those protocols, the stress is minimal during the early part of the tests, primarily due to the patients with potentially serious illness. Our protocol is also a modification of Bruce's protocol, but we started the exercise with Stage 3 following approximately 30 second

warming up with Stage 1, and increased the load to Stage 5, 7 and 9 every 3 minutes. This protocol was based on the characteristics of the regular physical activities of children. The exercise capacity of children is expected to be higher than in adults in general, and they usually start strenuous activities suddenly without warming up, and also stop them suddenly. Therefore, a rather rapid increase of the exercise load was thought to simulate better their daily activities. Using the original Bruce protocol, children tend to get tired physically and psychologically due to the slow increase of exercise load, and many do not reach the maximum level of exercise. With our protocol, they can tolerate much higher load of exercise, and the test can be done very safely as long as it is performed symptom-limited, although a very sudden change of the hemodynamics is expected during exercise. Actually all of our patients achieved a heart rate of more than 170 BPM. The treadmill test was obviously the best way to assess the children with ventricular arrhythmias, but it is time-consuming and requires expensive facilities. A two-step exercise ECG could perhaps be used as an alternative in some cases.

According to the results of our study, the incidence of serious ventricular arrhythmias was 14.8% of the 196 patients with PVC's on a resting ECG without an underlying heart disease. The incidence of sudden death in children is generally low, but children with a potential risk of sudden death should be screened and some measure of prevention of sudden death should be exercised in them. According to previous reports, there has been very few sudden deaths in ventricular arrhythmia patients with no underlying heart disease. Jacobsen has reported one case of sudden death among 2 patients with multifocal PVC short runs with no underlying heart disease.<sup>4</sup> Pedersen experienced no fatal case, although only 2 of the 4 patients with such arrhythmias received treatment.<sup>5</sup> Hernandez has also reported no mortality in the 7 patients who were observed for 7 months to 3 years.<sup>6</sup> Exercise testing was not done in many of those patients, and their long term prognosis remains unclear at this point. Another important point is that there may be many more patients with ventricular arrhythmias who are not aware of having them.<sup>7-9</sup>

In view of the fact that in one of our 13 patients with VT, it was documented only by the

exercise test, and that this particular patient subsequently died suddenly despite medical treatment by various antiarrhythmic agents, the current means of screening and management are obviously insufficient for the prevention of sudden death. As far as exercise testing as a method for the follow-up of patients whose diagnosis of ventricular arrhythmias has been confirmed is concerned, for patients with single PVC's and couplets, a two-step exercise ECG every 6 to 12 months, and for patients with short runs of PVC and with VT, treadmill testing every 6 months appears to be appropriate. We are currently determining the regular activity level of children with ventricular arrhythmias based on the findings of those tests using the guideline of management of school children with heart disease described by the Japanese Pediatric Society!<sup>10</sup>

#### REFERENCES

1. WOLFF GS, MEHTA AV: Pediatric dysrhythmia conference - Miami, Florida, November 16, 1980. *Ped Cardiol* 4: 65, 1983
2. CUMMING GR, EVERRATT D, HASTMAN L: Bruce treadmill test in children: normal values in a clinic population. *Am J Cardiol* 41: 69, 1978
3. ROZANSKI JJ, DIMICH I, STEINFELD L, KUPERSMITH J: Maximal exercise stress testing in evaluation of arrhythmias in children: results and reproducibility. *Am J Cardiol* 43: 951, 1979
4. JACOBSEN JR, GARSON A, GILLETTE PC, McNAMARA DG: Premature ventricular contractions in normal children. *J Pediatr* 92: 36, 1978
5. PEDERSEN DH, ZIPES DP, FOSTER PR, TROUP PJ: Ventricular tachycardia and ventricular fibrillation in a young population. *Circulation* 60: 988, 1979
6. HERNANDEZ A, STREUSS A, KLEIGER RE, GOLDRING D: Idiopathic paroxysmal ventricular tachycardia in infants and children. *J Pediatr* 86: 182, 1975
7. ROCCHINI AP, CHUN PO, DICK M: Ventricular tachycardia in children. *Am J Cardiol* 47: 1091, 1981
8. BERGDAHL DM, STEVENSON JG, KAWABORI I, GUNTHEROTH WG: Prognosis in primary ventricular tachycardia in the pediatric patients. *Circulation* 62: 897, 1980
9. NIIMURA I, GOTO A, HARAGUCHI H: Premature ventricular contractions in children with no underlying heart disease. *Acta Paed Jap* 86: 1286, 1982 (in Japanese)
10. OHKUNI M: Guideline of management of children with arrhythmias. *Acta Paed Jap* 86: 1023, 1982 (in Japanese)