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Normal Values of Echocardiography in Pediatric Age Groups III. Left and Right Ventricular Systolic Time Intervals *

The Shimane Heart Study

(echocardiography/systolic time intervals)

MASAKAZU SAITO, TAKESHI SOEDA, KATSUTOSHI ABE, YUTAKA TOMITA, TOSHIKAZU NISHIO, and CHUZO MORI

Department of Pediatrics, Shimane Medical University, Izumo 693, Japan

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Systolic time intervals (STIs) were obtained from simultaneous recordings of electrocardiogram, phonocardiogram and echograms of aortic and pulmonary valves in normal school age children. Pre-ejection time, ejection time and the ratio of the former to the latter were analyzed on both sides of the heart. Analysis was performed on 171 cases on the left and 144 cases on the right side of the heart.

Because of the technical difficulty in detecting echograms of pulmonary valve closure, the onset of the second heart sound was employed in place as the end of right ventricular ejection time. This might bring about errors in the values of right ventricular ejection time, and, therefore, the ratio of right pre-ejection period. The error ratios of both of these indices were estimated to be about ten per cent. Ejection time was closely correlated with the cardiac cycle, suggesting that it is affected by the heart rate. The other indices appeared to be independent of the heart rate. There was virtually no difference attributable to age or sex.

Mean and standard deviation of each index was (m±SD) : LPEP : 0.07±0.01 sec, RPEP : 0.06±0.01 sec, LVET : 0.27±0.02 sec, RVET : 0.28±0.03 sec, LPEP/LVET : 0.25±0.04, RPEP/RVET : 0.23±0.04. The upper limits of the latter two were 0.35 and 0.30, respectively.

We performed echocardiography on school age children and investigated the cardiac function in normal subjects. In this report, the systolic time intervals (STIs) on both sides of the heart are discussed with regard to their

Abbreviations
STIs : systolic time intervals
LSTIs : left ventricular systolic time intervals
RSTIs : right ventricular systolic time intervals
LPEP : left pre-ejection period
RPEP : right pre-ejection period
LVET : left ventricular ejection time
RVET : right ventricular ejection time

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normal range or to the problems related to the indices of cardiac function.

MATERIALS AND METHODS

Japanese school age children ranging from five to ten years of age were studied. Echocardiography was performed as one of the mass screening examinations for heart disease. Children who are diagnosed as WPW syndrome, bundle branch block, or organic heart disease including postoperative states were excluded from the present study. Echograms inadequate for measurements were also omitted. A total of 207 children were examined, but 13 per cent concerning the left and 30 per cent related to the right side of the heart were excluded for the above reasons. Table I lists the cases grouped into six according to age and sex.

TABLE I. *Children*

		Left	Right
5– 6 yr	male	32	32
	female	28	23
6– 7 yr	male	24	24
	female	28	22
9–10 yr	male	37	20
	female	22	23
Total		171	144

Echocardiograms of pulmonary and aortic valves were recorded with simultaneous electro- and phonocardiograms, using an Aloka SSD-110S echo-polygraph, an ECO-125 recorder, and transducers with a 3.5 or 5 MHz ultrasonic beam. The paper speed for recording was 100 mm/sec.

The echograms were measured as illustrated on Figs. 1 and 2, and four time intervals, ie. LPEP, RPEP, LVET and RVET were obtained. LPEP is the interval from the onset of the QRS complex of the electrocardiogram up to the opening of the aortic valve on the echocardiogram. LVET is from the opening of aortic valve to the onset of the second heart sound on the phonocardiogram. RPEP is from the QRS complex to the opening of the pulmonary valve ; RVET is then up to the onset of the second heart sound.

Measurements were performed on at least three heart beats and the results were averaged considering the beat to beat alteration, mainly due to respiration.

The end of the ejection time is in itself the closure of the semilunar valve at the corresponding side of the heart. We regarded the second heart sound, instead of the echogram of the aortic or pulmonary valve closure, as the end of LVET or RVET, because it was difficult to detect the echo of the closure of these valves during ordinary examination. Since the closure of the aortic valve is at the same time as the beginning of the second heart sound, namely the sound of aortic valve closure itself, this way of measurement is proper,

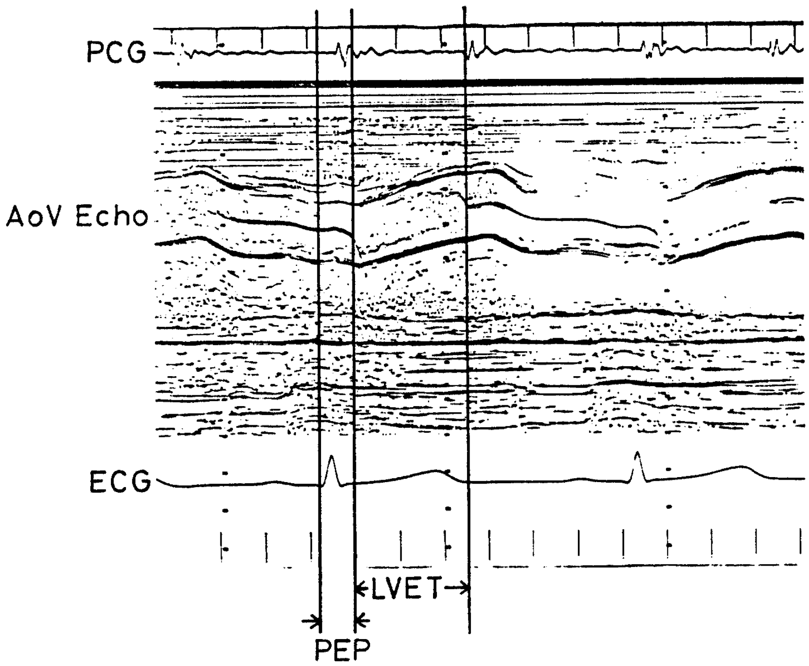

Fig. 1. Aortic valve echogram with simultaneous phono- and electrocardiogram. PEP is measured as the interval from the onset of the QRS complex of the electrocardiogram to the echogram of the aortic valve opening. LVET is the interval from the echogram of aortic valve opening to the onset of the second heart sound.

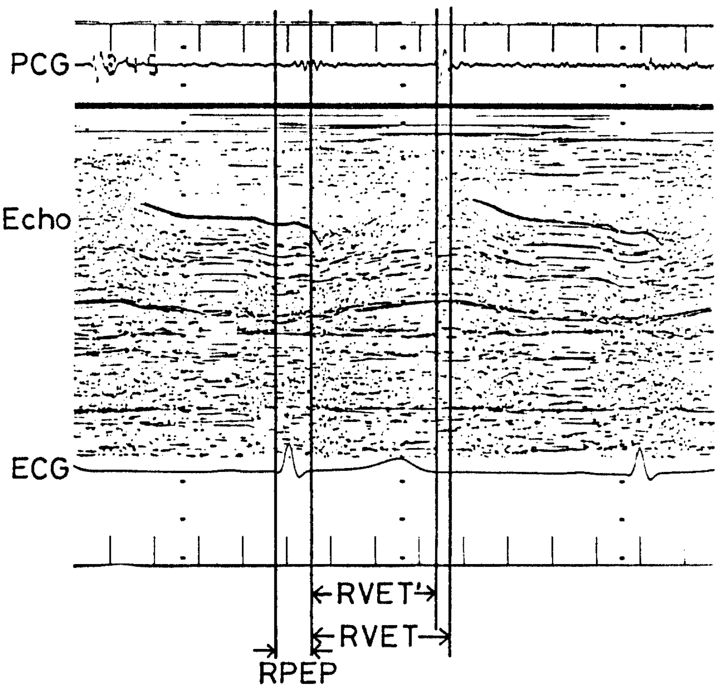

Fig. 2. Pulmonary valve echogram with simultaneous phono- and electrocardiogram. RPEP is measured as the interval from the onset of the QRS complex to the echogram of the pulmonary valve opening. True RVET is the interval from the opening to the closure of the pulmonary valve. Since the echogram of pulmonary valve closure is difficult to detect, the onset of the second heart sound is used. Thus, the RVET we measured is in fact RVET' on the figure, and is shorter than true RVET by about 0.04 second.

as for LVET. It is, however, not the case with RVET. The pulmonary valve closes later than the aortic valve, and the mean time from the second heart sound to the pulmonary valve closure is about 0.04 second (1). Thus, RVET may be underestimated by approximately 10 per cent using such measurements.

RESULTS

The beat to beat fluctuation in the measurement of the pre-ejection period was unrecognizable and that in the ejection time was within 0.02 seconds. The effect of respiration was thus negligible.

Figs. 3 and 4 show the relation of heart rate to the four STIs thereby obtained. They also show its relation to the ratios of pre-ejection period to the ejection time, ie. LPEP/LVET and RPEP/RVET. LVET and RVET are closely correlated with the R-R interval of the corresponding heart beat, on the simultaneous electrocardiograms. This means that such are affected

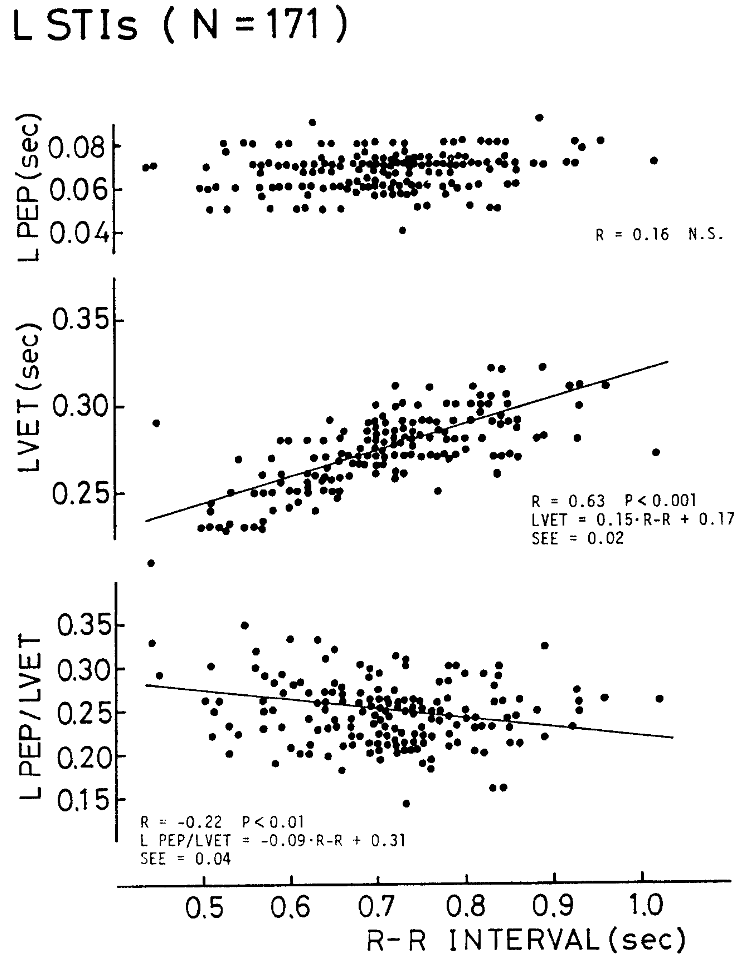

Fig. 3. Left ventricular systolic time intervals in relation to the cardiac cycle. LVET is closely correlated with the cardiac cycle, therefore with heart rate. LPEP/LVET is relatively unaffected by heart rate, and LPEP is virtually independent of it.

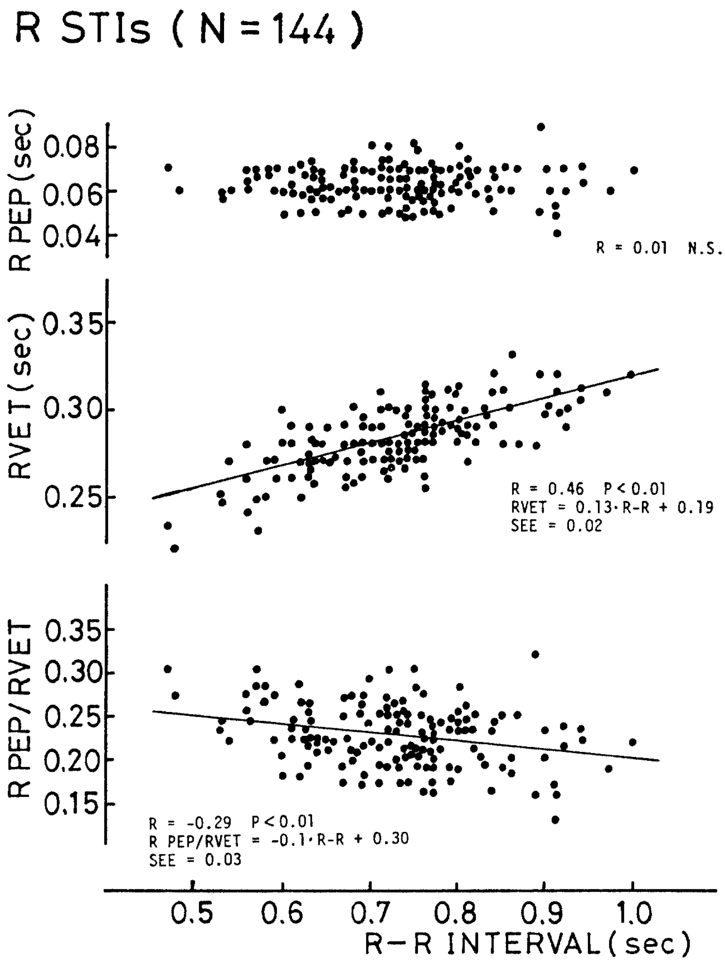

Fig. 4. Right ventricular systolic time intervals in relation to the cardiac cycle. RVET is closely correlated with the cardiac cycle, therefore with heart rate. RPEP/RVET is relatively unaffected by heart rate, and RVET is virtually independent of heart rate.

by heart rate at the time of the examination. LPEP and RPEP are virtually independent of heart rate; the ratios LPEP/LVET and RPEP/RVET are relatively unaffected by heart rate.

The mean and standard deviation of these indices in each group of age and sex are listed on Table II. The difference attributable to age or sex is not apparent. Among the six indices mentioned above, LPEP/LVET and RPEP/RVET are of considerable utility, and are well documented. LPEP/LVET exceed 0.35 in none, nor exceed RPEP/RVET 0.30 in most of our cases. The upper limits are, therefore, estimated to be 0.35 and 0.30 respectively, in the population we studied.

DISCUSSION

The STIs

The cardiac cycle is composed of several sequential events, namely, electrical

TABLE II. *Mean and Standard Deviation of the STIs*

Age (yr)	Sex	LPEP(sec) Mean	LPEP(sec) S. D.	LVET(sec) Mean	LVET(sec) S. D.	LPEP/LVET Mean	LPEP/LVET S. D.
5 – 6	male	0.07	0.01	0.27	0.02	0.24	0.04
	female	0.07	0.01	0.27	0.03	0.26	0.05
6 – 7	male	0.07	0.01	0.27	0.02	0.26	0.04
	female	0.06	0.01	0.26	0.02	0.24	0.04
9 –10	male	0.07	0.01	0.27	0.03	0.25	0.04
	female	0.07	0.01	0.27	0.02	0.26	0.04
in all		0.07	0.01	0.27	0.02	0.25	0.04

Age (yr)	Sex	RPEP(sec) Mean	RPEP(sec) S. D.	RVET(sec) Mean	RVET(sec) S. D.	RPEP/RVET Mean	RPEP/RVET S. D.
5 – 6	male	0.06	0.01	0.28	0.04	0.21	0.03
	female	0.06	0.01	0.29	0.02	0.22	0.04
6 – 7	male	0.06	0.01	0.28	0.03	0.23	0.04
	female	0.06	0.01.	0.27	0.02	0.24	0.03
9 –10	male	0.07	0.01	0.29	0.02	0.24	0.04
	female	0.06	0.01	0.28	0.02	0.23	0.04
in all		0.06	0.01	0.28	0.03	0.23	0.04

depolarization of ventricular muscle fibers, ventricular contraction with the closure of inlet (mitral and tricuspid) valves and the opening of outlet (aortic and pulmonary) valves, and ventricular dilatation with closure of the outlet and opening of the inlet valves. The STIs are the time intervals which occur at the systolic phase of these events. The mode of contraction at the left and right sides of the heart is more or less different ; the STIs are also different on each side of the heart, with respect to the value or significance.

Basic Measurements

Three basic measurements are established (2). At the left side of the heart, the time from the onset of electrical depolarization to the opening of aortic valve is PEP, which in this article is described as LPEP to distinguish from right pre-ejection period (RPEP). The interval from the opening to the closure of the aortic valve is LVET, and the sum of PEP and LVET is QS_2 time, that is, the interval from the onset of electrical depolarization to the closure of the aortic valve (3). Similarly, on the right side, RPEP is the interval from the onset of electrical depolarization to the opening of the pulmonary valve, RVET is that from the opening to the closure of the pulmonary valve, and the sum of RPEP and RVET is the QS_2 time of the right heart (4). In addition to these six basic meaurement, the ratio of LPEP to LPEP (LPEP/LVET in this article) and that of RPEP to RVET (RPEP/RVET) are well documented as indices of cardiac function (5, 6).

Acquisition of the STIs

The onset of electrical depolarization can be determined only by electrocardiography, as the onset of the QRS complex. Various methods are utilized to determine the opening and the closure of aortic and pulmonary valves. Phonocardiography, arterial pulse recording and ultrasound methods now feasible (2, 7-10). On the left side of the heart, carotid pulse recording yields considerably good results. The onset of the upstroke and the dicrotic notch represent the opening and the closure of the aortic valve. Phonocardiography also provides information on valve motion. The first heart sound means the closure of the mitral valve and the second sound, closure of the aortic valve.

In contrast, on the right side of the heart, an exact determination of the timing of the events is extremely difficult. At present, the only non-invasive method providing information on the timing of the opening or the closure of the pulmonary valve is ultrasound (9, 10). Echocardiography will provide information, however, detection of the closure of aortic or pulmonary valve is technically difficult, and actually impossible in certain cases. To improve the yield of data and to diminish the technical difficulty, we combined electro-, echo- and phonocardiography.

Significance of the STIs

The STIs are affected by a variety of factors, eg. heart rate, respiration, aberrancy of intraventricular conduction, and inotropic agents (2, 4). The most important is, however, the ventricular afterload and contractility. In general, LPEP increases and LVET decreases when systemic pressure is elevated or left ventricular performance is diminished ; as a result, the ratio LPEP/LVET increases. RPEP increases and RVET decreases when right ventricular afterload increases : the ratio RPEP/RVET increases as well. In our study, the effect of inotropic agents was excluded, because we were examining healthy children. Children with intraventricular conduction defects such as WPW syndrome or bundle branch block were not included in the evaluations. The effect of respiration is the change in pre- and afterload on both sides of the heart, as there is fluctuation with deep respiration. Actually, left ventricular dimension and perhaps right ventricular dimension as well are said to change with respiration (11). However, in our series of echocardiographic examinations, the STIs did not change to any great extent from beat to beat. It is difficult for small children to hold their breath at certain phases of respiration, therefore examination done during natural breathing states. In this way, we avoided excessive exertion during the examination.

LPEP, RPEP, LPEP/LVET and RPEP/RVET are relatively independent of heart rate while LVET and RVET increase with prolongation of the cardiac cycle. Our present findings support this idea.

Normal Ranges of the STIs

The range of the value of the STIs may differ with age and sex, however, there were no apparent differences in our groups of children. When there is no impairment of cardiac function, the upper limits of both LPEP/LVET and RPEP/RVET are said to be 0.30. Our results were in good agreement though the range of these indices was somewhat broader. The difference may in part be due to the difference in the methods of measurement. LPEP and RPEP fell into the range from 0.05 to 0.08 second. LVET and RVET, which altered with the heart rate showed values between 0.14 and 0.28 seconds.

Problems of the STIs

In addition to the utility as indices of cardiac function, the STIs can be obtained noninvasively and repeatedly, at the bedside clinic. The greatest problem to be overcome is determination of the exact timing of the events involved in the cardiac cycle. It is most difficult to detect the pulmonary valve closure (10). As stated previously, we regard the end of RVET as the second heart sound, which in fact is the end of LVET. In healthy subjects, the aortic valve closes some tens of milliseconds earlier, so the value we obtained as RVET was smaller than the true RVET by approximately ten per cent. The value of RPEP/RVET is thus greater by about 10%. The errors, however, may be rounded considering the feasibility of these indices, and, actually, do not lead to confusion in the use of STIs, in clinical practice.

REFERENCES

1) Keith, J. D. (1978) In : Heart Disease in Infancy and Childhood, 3rd Ed. (Keith, J. D., Rowe, R. D., and Vlad, P., eds.) pp. 23–24, Macmillan, New York
2) Weissler, A. M., Lewis, R. P., and Leighton, R. R. (1972) The systolic time intervals as a measure of left ventricular performance in man. *Prog. Cardiol.* **1**, 155–188
3) Gutgesell, H. P., Paquet, M., Duff, D. F., and McNamara, D. G. (1977) Evaluation of left ventricular size and function by echocardiography. Results in normal chidren. *Circulation* **56**, 457–462
4) Leighton, R. F., Weissler, A. M., Weinstein, P. B., and Wooley, C. F. (1971) Right and left ventricular systolic time intervals. Effects of heart rate, respiration and atrial pacing. *Am. J. Cardiol.* **27**, 66–72
5) Weissler, A. M., Harris, W. S., and Schoenfeld, C. D. (1969) Bedside technics for the evaluation of ventricular function in man. *Am. J. Cardiol.* **23**, 577–583
6) Hirschfeld, S., Meyer, R., Schwartz, D. C., Korfhagen, J., and Kaplan, S. (1975) The echocardiographic assessment of pulmonary artery pressure and pulmonary vascular resistance. *Circulation* **52**, 642–650
7) Burstein, L. (1967) Determination of pressure in the pulmonary artery by external graphic recordings. *Br. Heart J.* **29**, 396–404
8) Stefadouros, M. A. and Witham, A. C. (1975) Systolic time intervals by echocardiography. *Circulation* **51**, 114–117
9) Hirschfeld, S., Meyer, R., Schwartz, D. C., Korfhagen, J., and Kaplan, S. (1975) Measurement of right and left ventricular systolic time intervals by echcardiography. *Circulation* **51**, 304–309
10) Tsuda, S. (1978) Studies on right ventricular performance by non-invasive measurement of systolic and diastolic time intervals in patients with chronic right ventricular overloading. *Jpn. Circ. J.* **42**, 1373–1384 (in Japanese)
11) Brenner, J. I. and Waugh, R. A. (1978) Effect of phasic respiration on left ventricular dimension and performance in a normal population. An echocardiographic study. *Circulation* **57**, 122–127