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小児期心疾患の心エコー図による右室収縮期圧の評価

Echocardiographic estimation of right ventricular peak systolic pressure in children with heart disease

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Summary

Left ventricular wall stress can be simply expressed as the product of peak systolic pressure and relative wall thickness according to the Laplace law. Several recent investigators have reported the feasibility of estimation of peak left ventricular systolic pressure in children with aortic stenosis from the formula $P = c \times Ws/Ds$ (P=left ventricular peak systolic pressure; c=stress index; Ws=left ventricular end-systolic wall thickness; Ds=left ventricular end-systolic cavity dimension) using the value for c derived from normal subjects. In this study, we applied the method used in estimation of left ventricular pressure to the right ventricle and attempted to assess right ventricular peak systolic pressure by echocardiography.

Seventy-eight patients were studied and divided into 4 groups according to the functional state of the right ventricle (RV): Group I, normal RV (15 cases); group II, RV volume overload (15 cases); group III, RV pressure overload (32 cases); and group IV, RV failure (16 cases). Simultaneous recordings of RV pressures by a micromanometer and RV echocardiograms were obtained in all patients. The mean value for calculated stress index was 63 mmHg in group I, 88 mmHg in group II ($p<0.001$), 68 mmHg in group III ($p<0.05$) and 128 mmHg in group IV ($p<0.001$), respectively. From the value for group I, peak RV systolic pressure was estimated using the formula $P = 63 \times Ws/Ds$ in each patient. RV pressure estimated echocardiographically corresponded well with that measured by a micromanometer in group III ($Y = 1.01X - 4.78$, $r = 0.92$). In contrast, echocardiographic data were significantly underestimated compared to actual pressures in groups II and IV.

The method herein was found to be useful for estimating peak RV systolic pressure except in the cases of pure RV volume overload or the failing RV. It is concluded that these echocardiographic measurements provide a useful noninvasive means of assessing the severity of the heart disease with pulmonary stenosis or with pulmonary hypertension.

Key words

Echocardiography　RV pressure　RV wall stress　Micromanometer　Congenital heart disease　RV failure

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Since a variety of types of congenital heart disease are associated with hemodynamic alterations in the right heart, it is clinically useful to estimate right ventricular pressure by a noninvasive method. Recently, several investigators[1~5] have estimated left ventricular peak systolic pressure in children with aortic stenosis by echocardiography. This approach is based on the law of Laplace applied to the left ventricle, which implies that left ventricular wall stress is related to the ventricular pressure and to the relative wall thickness.

In this study we investigated the relationship of echocardiographically determined relative wall thickness and intraventricular pressure, and attempted to assess right ventricular pressure noninvasively.

Materials and Methods

Seventy-eight patients with congenital cardiac lesions were studied and the patient population was divided into four groups according to the functional state of the right ventricle. Group I consisted of 15 patients, 7 males and 8 females, ranging in age from 7 months to 11 years. All had normal hemodynamics of the right ventricle. Group II consisted of 15 patients, 9 males and 6 females, aged from 2 to 13 years, with right ventricular volume overload including 13 secundum atrial septal defect (ASD) patients and 2 ASD combined with pulmonary stenosis patients. The left to right shunt was greater than 35% of pulmonary blood flow in all patients. Group III consisted of 32 patients, 21 males and 11 females, ranging in age from 1 month to 12 years, with right ventricular pressure overload. All patients had elevated peak right ventricular pressure more than 40 mmHg measured by a micromanometer. The patients with right ventricular failure were excluded from this group. Group IV consisted of 16 patients, 9 males and 7 females, ranging in age from 2 days to 7 years, with the failing right ventricle. All had depressed right ventricular ejection fraction less than 0.50 determined by biplane cineangiograms[6].

The classification of cardiac defects in each group was presented in **Table 1**.

Data Acquisition: After the routine diagnostic cardiac catheterization was completed, simul-

Table 1. Materials

	I	II	III	IV
	Normal RV	RV volume load	RV pressure load	Failing RV
NHD	2			
ASD		13		
ASD+PS		2		
VSD	7		7	7
PDA	4		4	1
VSD+PDA			2	1
PS			4	2
TF			10	
TGA			2	2
Co A				3
Misc	2		3	
	15	15	32	16

RV=right ventricle; NHD=no heart disease; ASD=atrial septal defect; PS=pulmonary stenosis; VSD=ventricular septal defect; PDA=patent ductus arteriosus; TF=tetralogy of Fallot; TGA=transposition of the great arteries; CoA=coarctation of the aorta; Misc=miscellaneous.

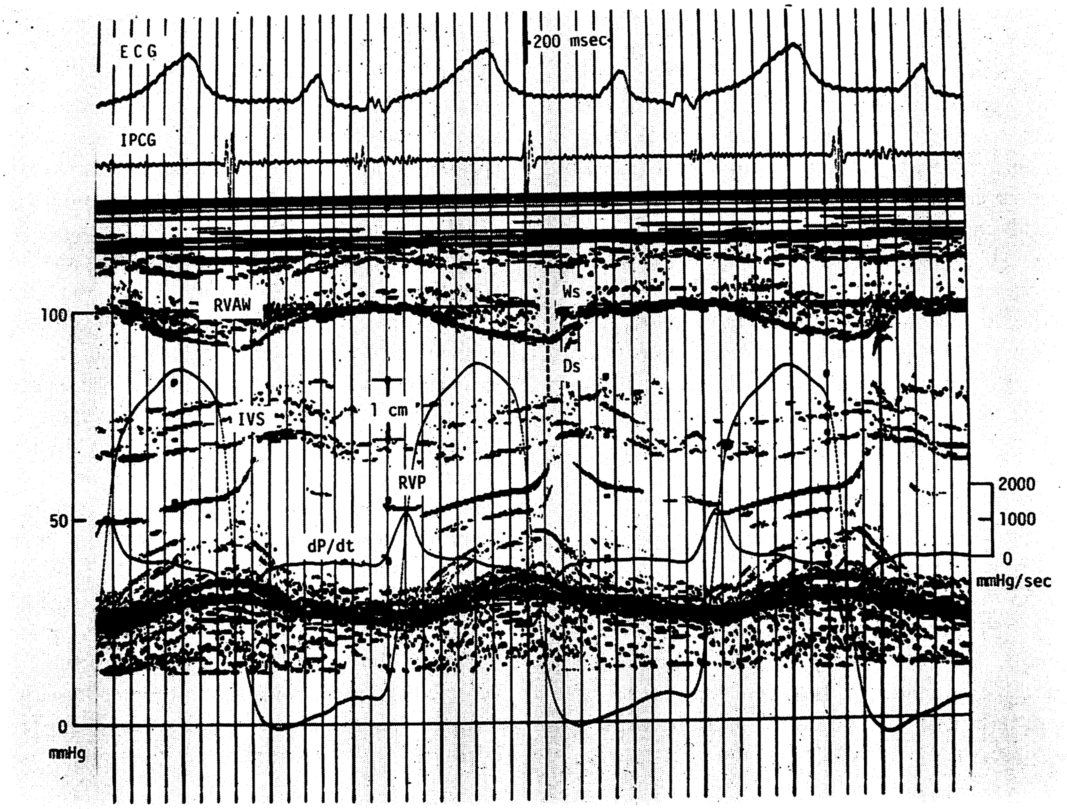

Fig. 1. Simultaneous recording of right ventricular echocardiogram and right ventricular pressure.

ECG = electrocardiogram; IPCG = internal phonocardiogram; Ws = systolic wall thickness of the right ventricle; Ds = end-systolic cavity dimension of the right ventricle; RVAW = right ventricular anterior wall; IVS = interventricular septum; RVP = right ventricular pressure; dP/dt = the first derivative of right ventricular pressure.

taneous recordings of right ventricular pressure and echocardiogram were taken in all patients (**Fig. 1**). All pressure recordings were obtained with a Millar micromanometer and the details of the methods have been previously described[7].

Echocardiograms were obtained with the use of an Ekoline 20A ultrasonoscope with patients in a supine position. A 3.5 MHz or 5 MHz nonfocused transducer was placed parasternally in the third or fourth intercostal space and directed inferiorly and laterally until the mitral valve apparatus was located. All tracings were recorded on an Electronics for Medicine VR-12 optical recorder at a paper speed of 100 mm/sec.

Measurements of end-systolic wall thickness (Ws) and end-systolic cavity dimension (Ds) were obtained from right ventricular echocardiograms. Right ventricular systolic wall thickness was measured from the epicardium to endocardium at the point of maximum posterior movement of the right ventricular anterior wall. At the same point, right ventricular systolic cavity dimension was measured as the distance between the endocardium of the right ventricular anterior wall and the inner surface of the endocardium of the interventricular septum. Echocardiographic and pressure measurements were made from five successive cardiac cycles and averaged.

In patients with normal right ventricle, peak systolic right ventricular pressure (P) was related to relative systolic wall thickness (Ws/Ds) by echocardiograms. The ratio (c) which is termed stress index[2] was calculated separately for each patient using the formula

$$c = P \times Ds/Ws$$

and a mean value for c in the group of patients with the normal right ventricle was then derived. With the use of this value, right ventricular peak systolic pressure was estimated in each patient of other groups according to the formula

$$P = c \times Ws/Ds.$$

Results

Values for stress index (c) in the 15 patients with normal right ventricle (group I) ranged from 53 to 71 mmHg (mean $\pm$ SD; 63 ± 7 mmHg) (**Fig. 2**). There was a slight significant difference ($p<0.05$) of the mean value for c ($p<0.05$) demonstrated between the groups of the normal right ventricle and of right ventricular pressure overload (range 54～88 mmHg, mean$\pm$SD; 68 ± 9 mmHg). In the 15 patients with right ventricular volume overload (group II), the mean value for c (range 72～117 mmHg, mean$\pm$SD; 88 ± 13 mmHg) was significantly higher than that obtained in the control group ($p<0.001$). There was a wide scatter of values for c ranging from 69 to 198 mmHg in the group of the patients with right ventricular failure (group IV), and the mean value was markedly elevated compared to the controls ($p<0.001$).

The relationship between right ventricular peak systolic pressure and relative wall thickness in each group is shown in **Fig. 3**. Except the group of the patients with right ventricular failure, correlation coefficients of both the measurements were excellent. In addition, a close relation of each linear regression equation was demonstrated between groups of the normal right ventricle ($Y=0.016X-0.0007$) and right ventricular pressure overload ($Y=0.016X-0.08$).

Fig. 4 shows the comparison of actual right ventricular peak systolic pressure measured directly by means of a micromanometer and estimated right ventricular peak systolic pressure

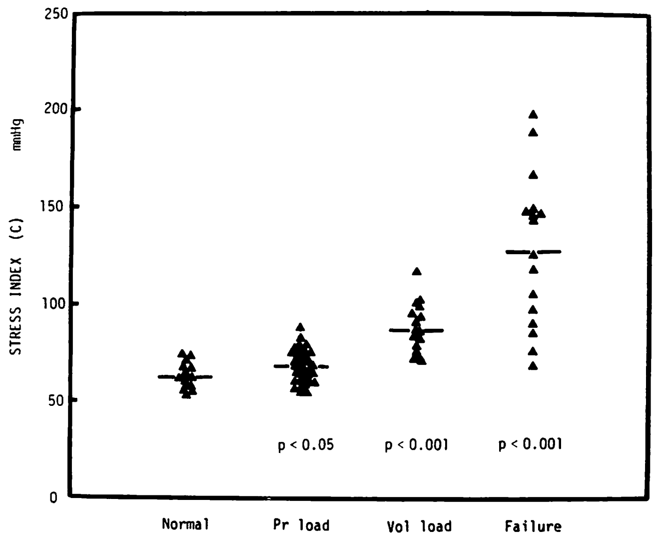

Fig. 2. Values for stress index in each group.
Pr load=right ventricular pressure overload; Vol load=right ventricular volume overload.

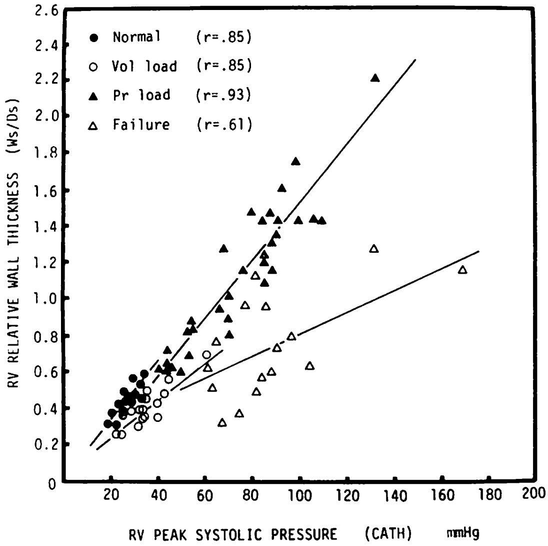

Fig. 3. Correlation between right ventricular peak systolic pressure and right ventricular relative wall thickness in each group.

RV=right ventricle; Vol load=right ventricular volume overload; Pr load=right ventricular pressure overload.

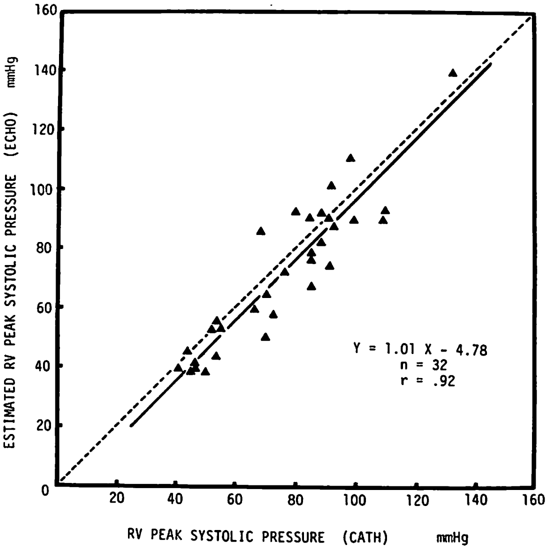

Fig. 4. Comparison of right ventricular peak systolic pressure measured with a micromanometer and right ventricular pressure estimated echocardiographically in 32 children with right ventricular pressure overload.

Dashed line is line of identity; solid line is regression line.

by echocardiography in the patients with right ventricular pressure overload. There was a strong linear correlation (r=0.92) demonstrated between peak right ventricular pressure estimated by echocardiography and that measured directly. In contrast, actual peak right ventricular pressure and echocardiographically determined right ventricular anterior wall thickness were less significantly correlated (r=0.69) in the patients with right ventricular pressure overload (**Fig. 5**).

In comparison of directly measured peak right ventricular pressure and echocardiographically estimated pressure using values for c derived from the patients of the normal right ventricle, the latter was underestimated in both groups of the patients with right ventricular volume overload and with failing right ventricle (**Fig. 6**).

Discussion

Several recent investigators[2~5] have estimated left ventricular pressure in children with aortic stenosis by using left ventricular diameter and wall thickness at end-systole determined by echocardiography. This methodology[1] is based on the facts that wall stress is proportional to intraventricular pressure and cavity radius, and inversely proportional to wall thickness, and that in the presence of good ventricular function left ventricular wall stress remains relatively constant[8] and within the normal limits over a broad range of peak systolic pressures. Thus it follows that with the use of the ratio (c) of peak systolic pressure (P) to echocardiographically determined relative wall thickness (Ws/Ds) derived from the normal subjects, peak systolic intraventricular pressure can be calculated from the formula $P = c \times Ws/Ds$ in the cases of left ventricular pressure overload.

In this study, we attempted to apply the above mentioned methodology to the right ventricle and examined the validity and feasi-

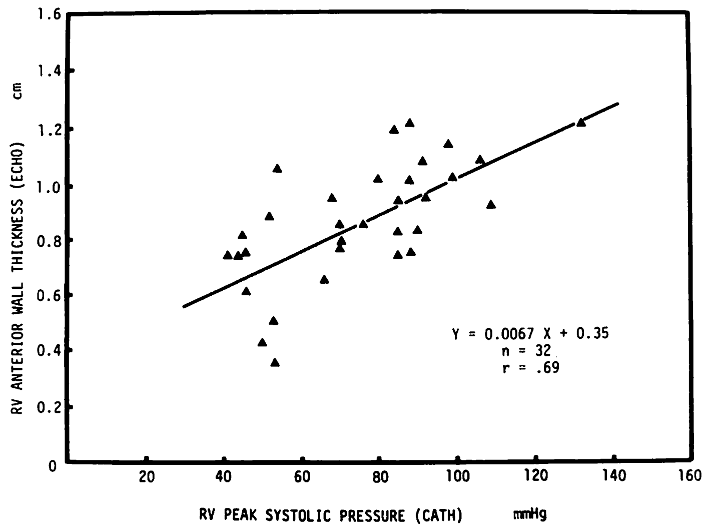

Fig. 5. Correlation between right ventricular peak systolic pressure and right ventricular anterior wall thickness in the patients with right ventricular pressure overload.
RV=right ventricle.

bility of estimation of right ventricular systolic pressure by echocardiography. Models applicable to compute accurately right ventricular wall stress in man remains unknown. However, the method herein requires no actual determination of right ventricular stress but it is concerned with the fundamental relations of intraventricular pressure and relative wall thickness in each group of heart disease.

The results of this investigation demonstrated that a slight difference of mean value for stress index was found between normal subjects and patients with right ventricular pressure overload, whereas the index was elevated moderately in right ventricular volume overload and markedly in the failing right ventricle when compared to normal control. It means that the right ventricular relative wall thickness is increased in proportion to right ventricular load until systolic wall stress returns to normal in the absence of poor ventricular function or pure right ventricular volume overload. Then, it was confirmed that there was an excellent linear relationship between actual right ventricular systolic pressure and estimated pressure using the value for stress index derived from the normal subjects in the group of pressure overload without ventricular failure.

Elevated value for stress index has been demonstrated in the group with poor right ventricular function or pure right ventricular volume overload. In cases of right ventricular failure, cavity dilatation may occur even in the absence of volume overload, and under this circumstance, relative wall thickness may be reduced in both volume and pressure overloads with resultant of elevated right ventricular stress. The method thus proved to be invalid for estimating right ventricular systolic pressure by echocardiography in the presence of right ventricular failure.

Another consideration for higher values for stress index found in right ventricular volume overload without failure is required. Calculation of wall stress was conveniently performed in this study using transverse distance instead of curvature diameter of the right ventricular anterior wall. It is considered that the right

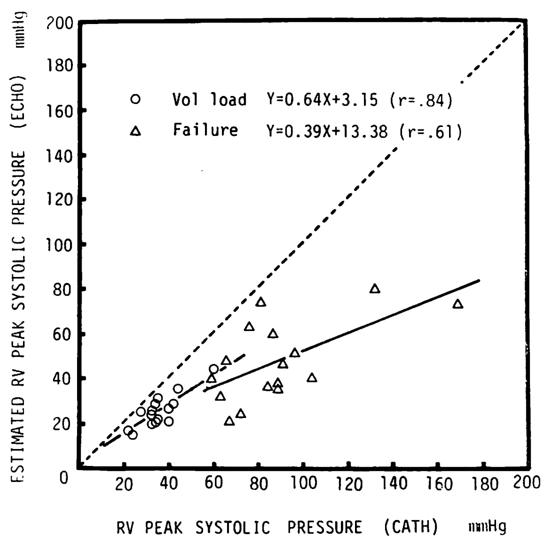

Fig. 6. Comparison of right ventricular peak systolic pressure measured directly and that estimated by echocardiography in the patients with right ventricular volume overload or with right ventricular failure.

RV=right ventricle; Vol load=right ventricular volume overload.

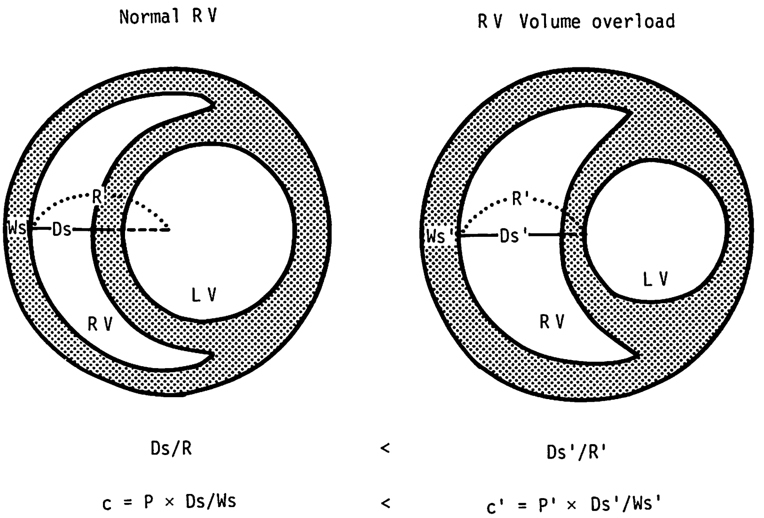

Fig. 7. Diagrammatic representation of the cross-sectional aspect of the heart with normal right ventricle and with right ventricular volume overload.

Since calculation of stress index is performed from transverse dimension instead of curvature diameter, the index is increased in right ventricular volume overload compared to control.

RV=right ventricle; LV=left ventricle; Ws=systolic right ventricular wall thickness; Ds=end-systolic right ventricular cavity dimension; R=curvature diameter of the right ventricular anterior wall.

ventricle alters its geometry with dilatation of the chamber[9], and the ratio of transverse distance (Ds′) to curvature diameter (R′) becomes larger in the dilated ventricle as shown in **Fig. 7**. Therefore, even with good ventricular function the values for stress index calculated herein are increased in the patients with right ventricular volume overload.

There are some problems in the present study. The first is in the echocardiographic measurement of right ventricular wall thickness. Fortunately, pediatric patients often reveal clear echocardiographic recordings of the right ventricular wall, and in particular, it is easy to determine end-systolic wall thickness in pressure overload of the right ventricle. Also, it is important to obtain echocardiograms available for reliable measurements because the right ventricular cavity dimension changes significantly by the position of the ultrasonic transducer and the direction of the echo beam.

The second is the problem of the simultaneous recordings of echocardiogram and pressure. Since both relative wall thickness and intraventricular pressure are influenced by heart rate and other conditions at the examination, it is desirable for reliable evaluation to obtain recordings of pressure and echocardiogram simultaneously. In addition, we performed pressure measurement by means of a micromanometer for accurate assessment of ventricular pressure. It is well known[10] that the pressure tracings obtained by fluid-filled catheter system induce significant distortion especially in small children. None of the previous investigations[1~5] dealing with echocardiographic estimation of ventricular pressure had either the simultaneous recording of pressure and echocardiogram or the measurement by a micromanometer, so their results can not be expected to be accurate and reliable.

The present study confirmed that peak right ventricular systolic pressure can be estimated echocardiographically in children with right ventricular pressure overload with good ventricular function. Echocardiography offers a noninvasive method for evaluation of the severity of the heart disease with pulmonary stenosis or with pulmonary hypertension. Furthermore, this approach is thought to provide a clue for the study about right ventricular wall stress in terms of intraventricular pressure, relative wall thickness and right ventricular geometry.

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