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# 心エコー図による右室パフォーマンスの定量的検討：第II報　剣状突起下心エコー図法による右室径の信頼性の検討

# Quantitative evaluation of the right ventricular performance with echocardiography: II. A study of reliability of right ventricular dimension by subxiphoid echocardiography

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**Summary**

Right ventricular dimensions (RVDsx) were measured from subxiphoid echocardiograms in 140 patients. In 55 of these, right ventricular (RV) biplane cineangiograms were obtained during diagnostic cardiac catheterization.

Reliability of RVDsx was ascertained by comparison with the results obtained from RV cineangiograms.

RV fractional shortening as well as RV ejection fraction calculated from echocardiograms were demonstrated as useful indexes for evaluating the pump function of the RV.

For 38 normal subjects, excellent exponential fit was obtained with end-diastolic RVDsx (RVDsx-Dd) as a function of body surface area (BSA): RVDsx-Dd (cm)=4.3 (BSA in $m^2)^{0.70}$ ($r=0.98$, $p<0.001$).

RVDsx was in normal range in patients with ventricular septal defect (VSD) or patent ductus arteriosus (PDA) uncomplicated with pulmonary hypertension (PH), but was significantly larger than normal in patients with VSD or PDA complicated with PH (128±10%, $p<0.001$). RVDsx in patients with atrial septal defect was significantly larger than normal (126±11%, $p<0.001$), but was within normal range in patients with pulmonary stenosis. RVDsx was significantly smaller than normal in patients with tetralogy of Fallot (94±11%, $p<0.01$).

Simultaneous and continuous measurement of the subxiphoid echocardiogram and RV pressure was analyzed. It is thought that this method provides a new approach to study RV pressure-dimension relations.

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**Key words**
Right ventricular performance | Subxiphoid echocardiography | Right ventricular dimension
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Echocardiography has been used for the diagnosis of many cardiac disorders. It is also a useful technique for obtaining quantitative measurement of the size of cardiac chambers and vessels, which are used to assess the severity of cardiac lesions.

Left ventricular (LV) dimension measured from echocardiography has been utilized to estimate LV volume[1] and function[2,3].

However, right ventricular (RV) dimension has not been frequently used for estimating the RV volume[4]. It is because, in the routine echocardiographic examination, measurement of RV dimension is difficult and is often influenced by the position of the patient, the direction of the ultrasonic beam and the rotation of the heart[4~6].

Recently, we have reported that RV dimension measured from subxiphoid echocardiography (RVDsx) was a reliable and useful index to evaluate the RV volume[7].

In this study, we aimed to ascertain the reliability and the clinical applicability of RVDsx in comparison with the results obtained from angiocardiography.

## Materials and Methods

The subjects studied were 140 patients (70 females and 70 males) with congenital heart disease with the age ranging from one month to 15 years (**Table 1**).

**Table 1. Materials**

| | |
|---|---|
| Normal | 38 |
| VSD & PDA s̄ PH | 27 |
| VSD & PDA c̄ PH | 21 |
| ASD | 23 |
| PS | 4 |
| T/F | 27 |
| | 140 |

VSD=ventricular septal defect; PDA=patent ductus arteriosus; PH=pulmonary hypertension; ASD=atrial septal defect; PS=pulmonary stenosis; T/F=tetralogy of Fallot.

All echocardiograms were obtained with a Smith-Kline Ekoline 20-A ultrasonoscope interfaced with an Electronics for Medicine VR-12 optical recorder and a nonfocused 6 mm transducer with a frequency rate of 3.5 or 5 MHz.

Subxiphoid echocardiograms were obtained in the previously described manner[7]. The patient was examined in the supine position and the transducer was placed in the area just below the subxiphodal process and was tilted superiorly toward the throat.

**Fig. 1** shows a representative subxiphoid echocardiogram. RVDsx was defined as the distance from the endocardial surface of the anterior RV wall to the anterior aortic wall in the transducer plane where the tricuspid and the aortic valves could be recorded simultaneously. End-diastolic dimension (RVDsx-Dd) was measured at the peak of the R wave on the electrocardiogram and end-systolic dimension (RVDsx-Ds) was measured at the peak anterior motion of the anterior aortic wall.

In 55 patients, biplane RV cineangiograms were obtained during routine diagnostic cardiac catheterizations within 24 hours from the recording of echocardiograms. RV volumes were calculated from cineangiograms according to the method of Graham et al[8] based on a Simpson's rule. The RV body and outflow tract were separated by drawing a line from the most superior aspect of the tricuspid valve straight across the outflow tract parallel to the pulmonary valve annulus. The volume of the RV body was calculated using an area-length method[8] from the lateral view of the RV cineangiogram.

RV pressure was measured with a Millar instruments catheter-tip micromanometer and was recorded simultaneously with subxiphoid echocardiogram.

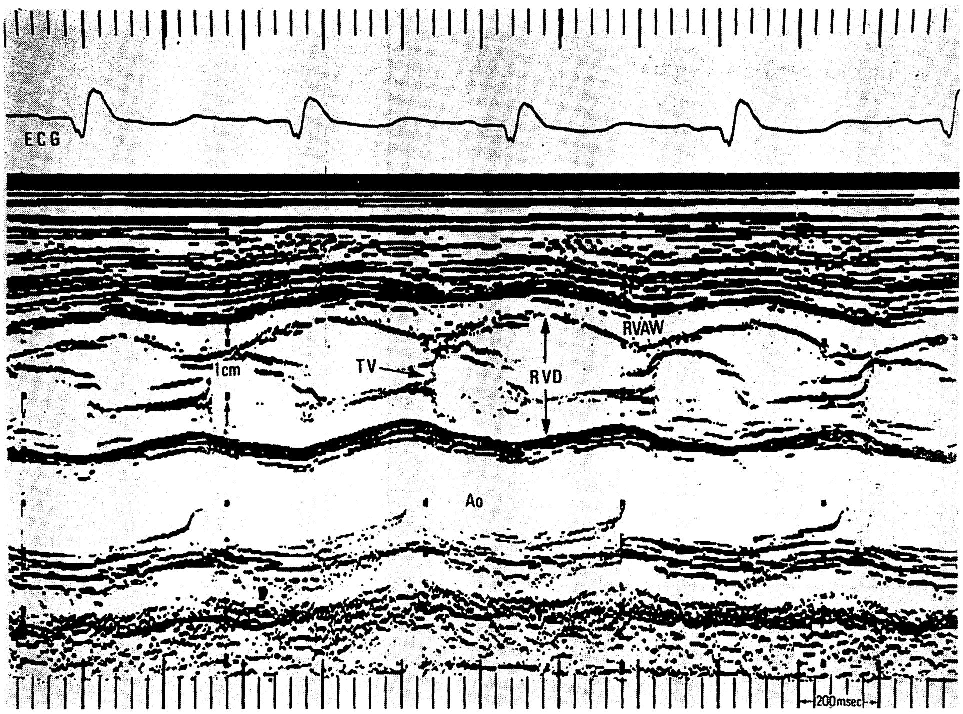


**Fig. 1. Subxiphoid echocardiogram.**
RVAW=right ventricular anterior wall; TV=tricuspid valve; Ao=aorta; RVD=right ventricular dimension; ECG=electrocardiogram.

## Results

RV end-diastolic volume plotted as a function of RVDsx-Dd is shown in **Fig. 2**. The cubic regression equation relating these two variables is shown with the correlation coefficient of 0.94. End-systolic volume-dimension relationship and a cubic regression equation are shown in **Fig. 3** ($r=0.89$). These two statistical analyses demonstrated the close relationship between RV volume and RVDsx.

The distance between the most superior aspect of the tricuspid valve and the most inferior point of the anterior RV wall (Lsx) was measured from the lateral view of the RV cineangiogram, and was compared with RVDsx (**Fig. 4**). In both end-diastole and end-systole, there were statistically good relationships between Lsx and RVDsx ($r=0.84$, $r=0.82$ resp.), and the linear regression equations in both were very similar.

The largest length of the RV body (Li) was measured from the lateral view of the RV cineangiogram. Li plotted as a function of RVDsx is shown in **Fig. 5**. The significant correlation was found between both measurements in both end-diastole and end-systole ($r=0.85$ in both).

The volume of the RV body (Vi) were compared with RVDsx (**Fig. 6**). The correlation relating these two variables was significant in both end-diastole and end-systole ($r=0.86$, $r=0.85$ resp.).

RV fractional shortening ($\triangle$D-ECHO) and ejection fraction (EF-ECHO) were calculated from the subxiphoid echocardiogram. The formula for these calculations are:

$\triangle$D-ECHO$=(Dd-Ds)\times 100/Dd$

EF-ECHO$=(Dd^3-Ds^3)\times 100/Dd^3$

where Dd=RVDsx-Dd in cm, Ds=RVDsx-

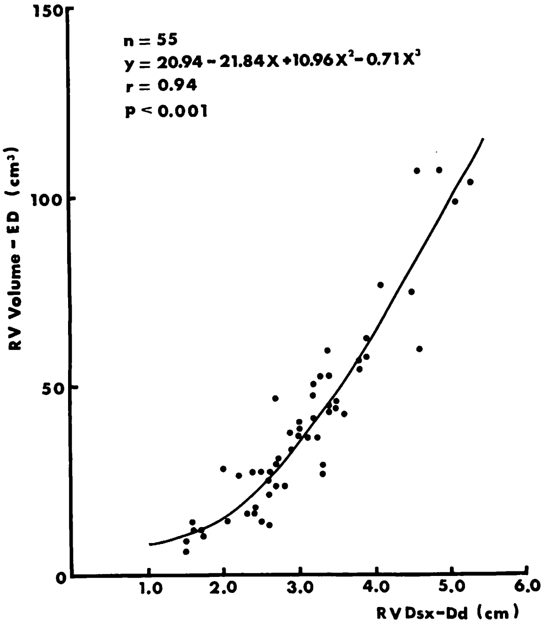


**Fig. 2. End-diastolic right ventricular volume** (RV volume-ED) **as a function of end-diastolic right ventricular dimension** (RVDsx-Dd).

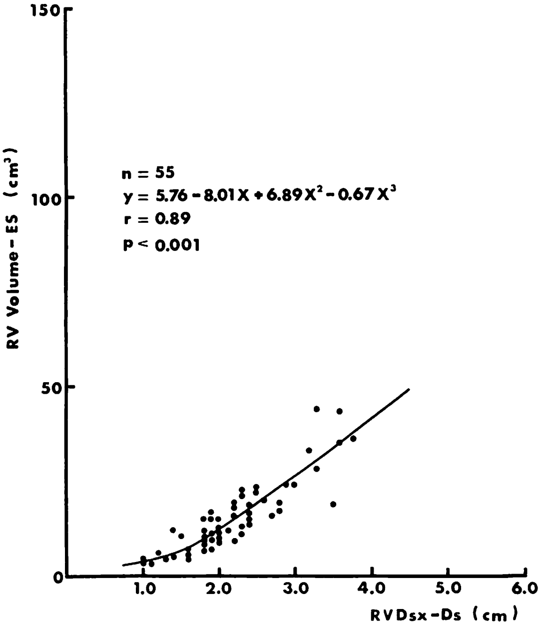


**Fig. 3. End-systolic right ventricular volume** (RV volume-ES) **as a function of end-systolic right ventricular dimension** (RVDsx-Ds).

Ds in cm.

RV ejection fraction was also calculated from cineangiogram (EF-ACG) using the equation:

EF-ACG = (EDV-ESV) × 100/EDV

where EDV = RV end-diastolic volume in $cm^3$, EVS = RV end-systolic volume in $cm^3$.

EF-ACG was compared with both △D-ECHO and EF-ECHO (**Fig. 7**), and statistically significant correlations were found in both comparisons.

RVDsx-Dd as a function of body surface area (BSA) is shown graphically for the normal subjects in **Fig. 8**. This relationship was fit best by the exponential curve shown with

$\text{RVDsx-Dd (cm)} = 4.3\ (\text{BSA in } m^2)^{0.70}$

$(r = 0.98,\ p < 0.001)$.

Using this regression equation, normal values were calculated for each BSA values. RVDsx were expressed as a percentage of predicted normal values for the patients with ventricular septal defect (VSD), patent ductus arteriosus (PDA), atrial septal defect (ASD), pulmonary stenosis (PS) and tetralogy of Fallot (T/F), and were compared with that of the patients with the normal right heart (**Fig. 9**). Shaded area indicates the normal values averaging 100±7%.

The mean value for the patients with VSD or PDA uncomplicated with pulmonary hypertension (PH) was not significantly different from normal. However, in patients with VSD or PDA complicated with PH, RVDsx averaged 128±10% of normal, and this value was significantly different from normal ($p < 0.001$). The mean value for the patients with ASD was also significantly ($p < 0.001$) different from normal, averaging 126±11%. RVDsx was in normal range in three of four patients with PS, and the mean value was not significantly different from normal. On the other hand, the mean value for the patients with T/F was slightly decreased from normal (94±11%) and this difference was significant ($p < 0.001$).

Sequential change in RV volume and RVDsx are illustrated in a patient with ASD in **Fig. 10.**

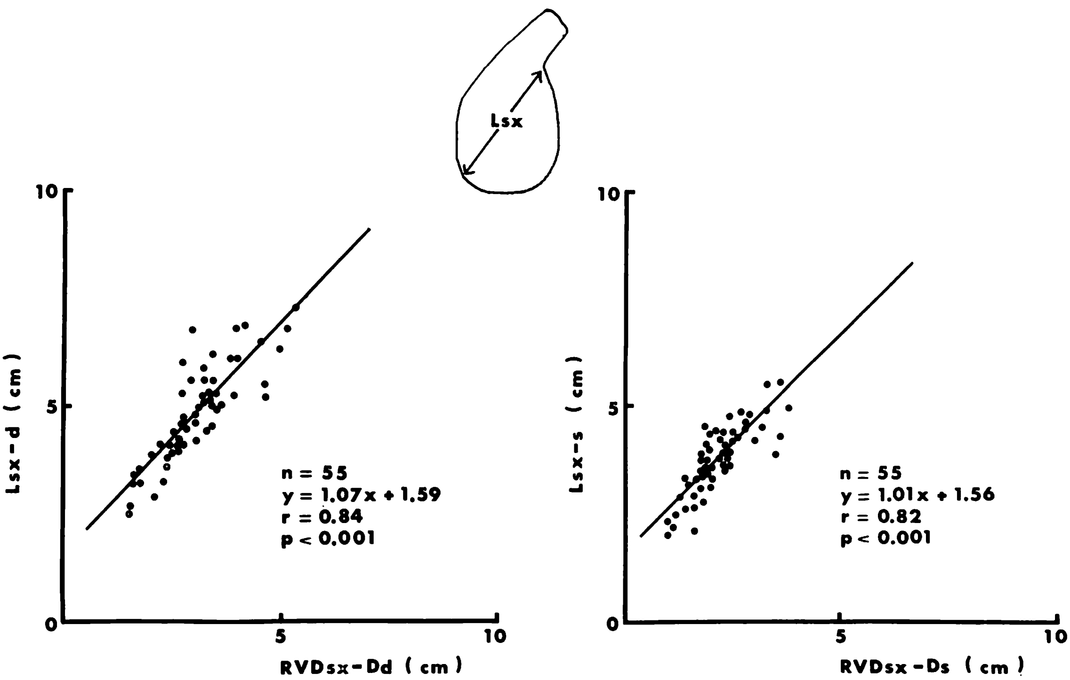


**Fig. 4. Correlation between Lsx and RVDsx in end-diastole** (left panel) **and in end-systole** (right panel).

Lsx = the distance between the most superior aspect of the tricuspid valve and the most inferior aspect of the right ventricular anterior wall; RVDsx = right ventricular dimension.

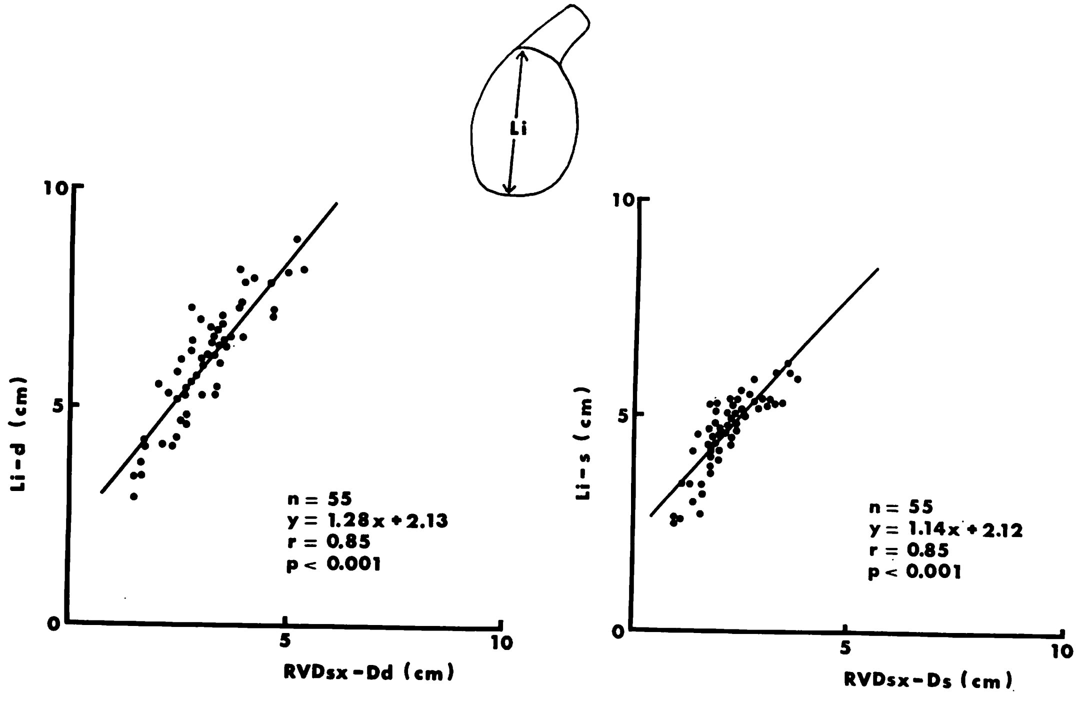


**Fig. 5. Correlation between Li and RVDsx in end-diastole** (left panel) **and in end-systole** (right panel).

Li=the largest length of the right ventricular body; RVDsx=right ventricular dimension.

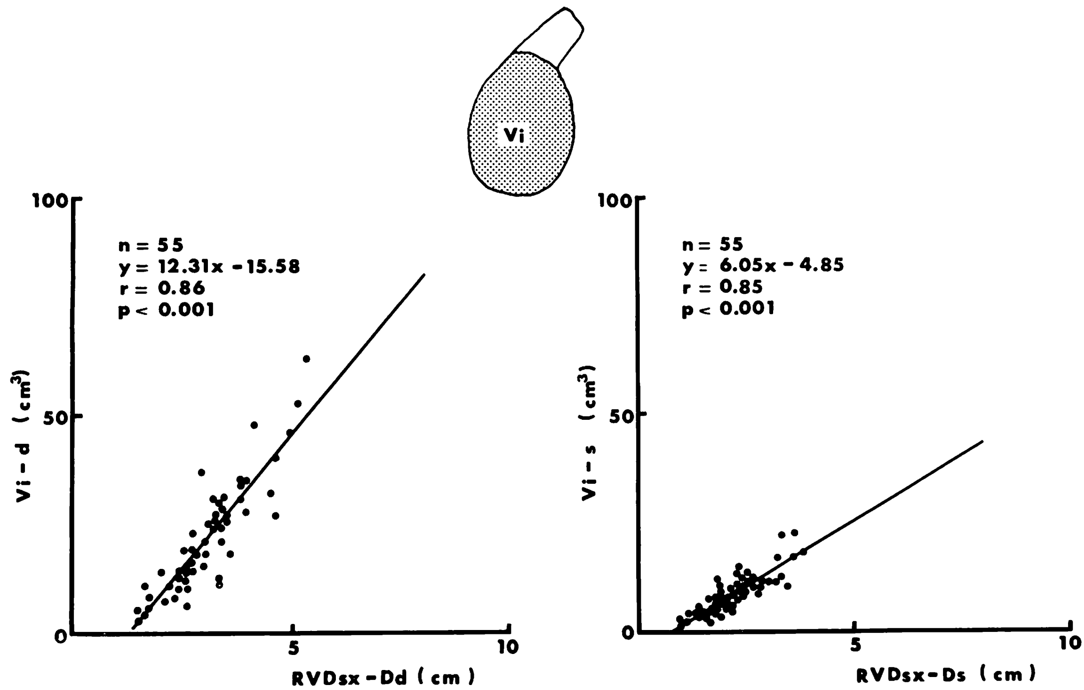


**Fig. 6. Correlation between Vi and RVDsx in end-diastole** (left panel) **and end-systole** (right panel).

Vi = the volume of the right ventricular body; RVDsx = right ventricular dimension.

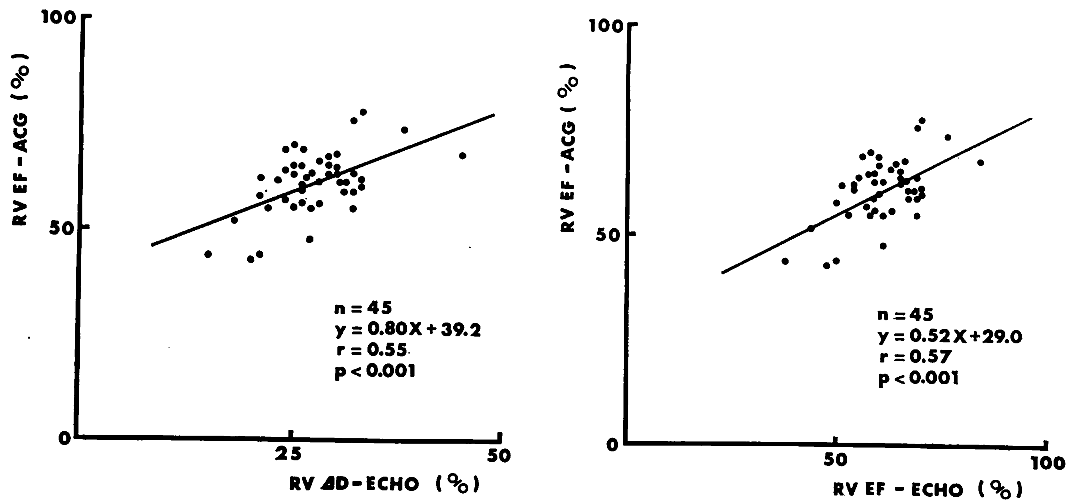


**Fig. 7. Correlation between RV EF-ACG and RV △D-ECHO** (left panel) **and correlation between RV EF-ACG and RV EF-ECHO** (right panel).

RV EF-ACG = right ventricular ejection fraction determined by angiocardiography; RV △D-ECHO = right ventricular fractional shortening determined by echocardiography; RV EF-ECHO = right ventricular ejection fraction determined by echocardiography.

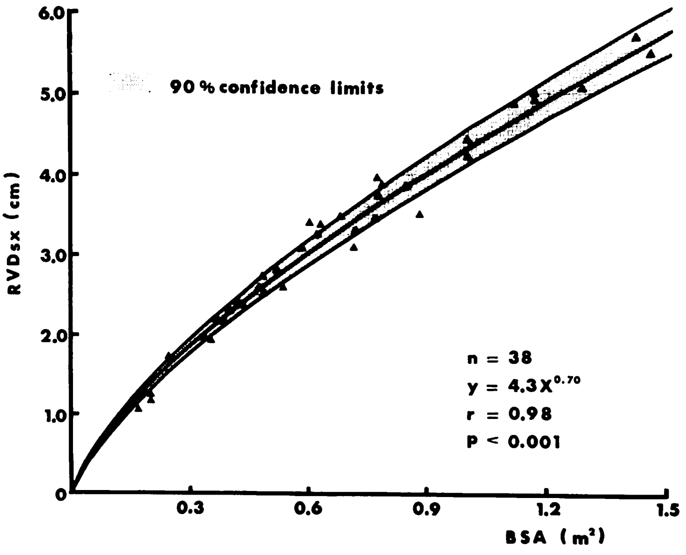


**Fig. 8. End-diastolic right ventricular dimension** (RVDsx) **as a function of body surface area** (BSA) **for children with the normal right hearts.**

90% confidence limits are indicated by shaded area.

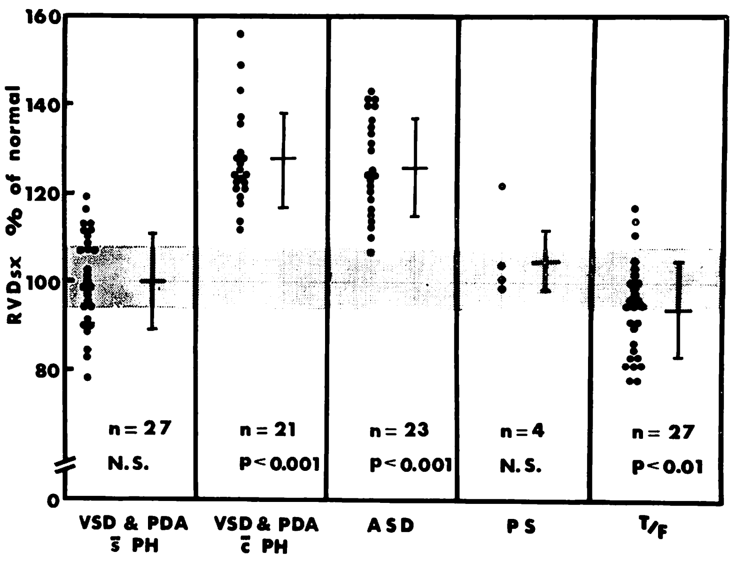


**Fig. 9. Right ventricular dimensions expressed as a percentage of predicted normal values** (RVDsx % of normal) **for the patients with congenital heart disease.**

Normal values are indicated by shaded area.

VSD=ventricular septal defect; PDA=patent ductus arteriosus; PH=pulmonary hypertension; ASD=atrial septal defect; PS=pulmonary stenosis; T/F=tetralogy of Fallot.

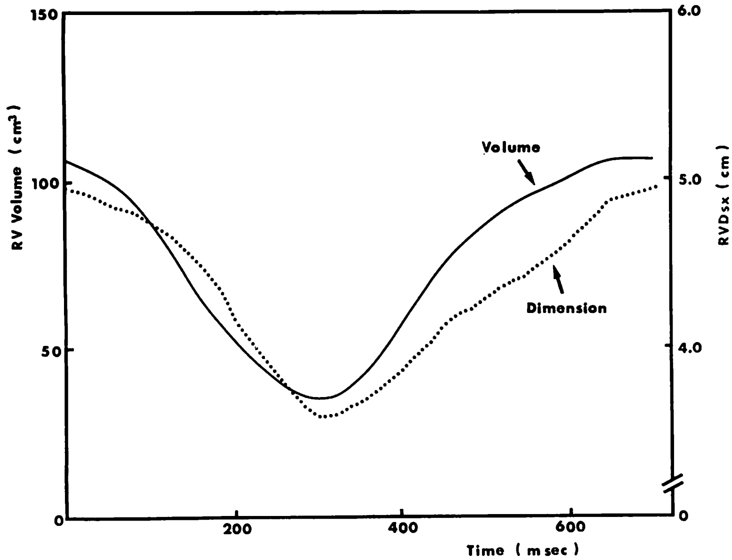


**Fig. 10. Sequential changes in right ventricular** (RV) **volume and right ventricular dimension** (RVDsx) **in a patient with atrial septal defect.**

These two curves were very similar throughout the cardiac cycle.

Simultaneous recording of the subxiphoid echocardiogram, RV pressure and electrocardiogram is shown in **Fig. 11**. Measurements of RVDsx and RV pressure were obtained every 10 msec utilizing an X-Y digitizer and programmed calculator (NOVA 01).

**Fig. 12** shows pressure-dimension plots of representative cardiac cycles from patients without hemodynamic evidence of heart disease (normal), ASD, PS and VSD. In a patient with ASD, increased end-diastolic dimension and large change of dimension during the cardiac cycle were apparent. On the other hand, abnormally increased RV pressure was demonstrated in a patient with PS. In these two cardiac states, the areas of the pressure-dimension curves were larger than those of normal or VSD.

## Discussion

Echocardiography has been shown to be a useful technique for evaluating LV dimension and function[1~4,9,14].

However, echocardiography has been less frequently applied for the determination of RV dimension, not only because it is technically difficult to clearly outline the anterior border of the RV, but also because RV dimension is easily influenced by the position of the patient or the rotation of the heart[4~6,10]. In previous reports, RV dimension measured from routine echocardiogram was compared with RV volume or RV cavity size measured from angiocardiogram, and the conclusion was that the estimation of the RV size or volume with an usual approach was unsatisfactory[4,7].

We have reported that the RV cavity could be easily detected with subxiphoid echocardiography, and the RV dimension measured from the subxiphoid echocardiogram (RVDsx) had an excellent correlation with RV volume[7].

In the present study, RVDsx was compared with the results obtained from RV cineangiograms, and the excellent correlation coefficients were found. These facts demonstrated that RVDsx was a reliable and useful index to estimate RV volume and cavity size.

RV fractional shortening (△D-ECHO) and ejection fraction (EF-ECHO) determined by

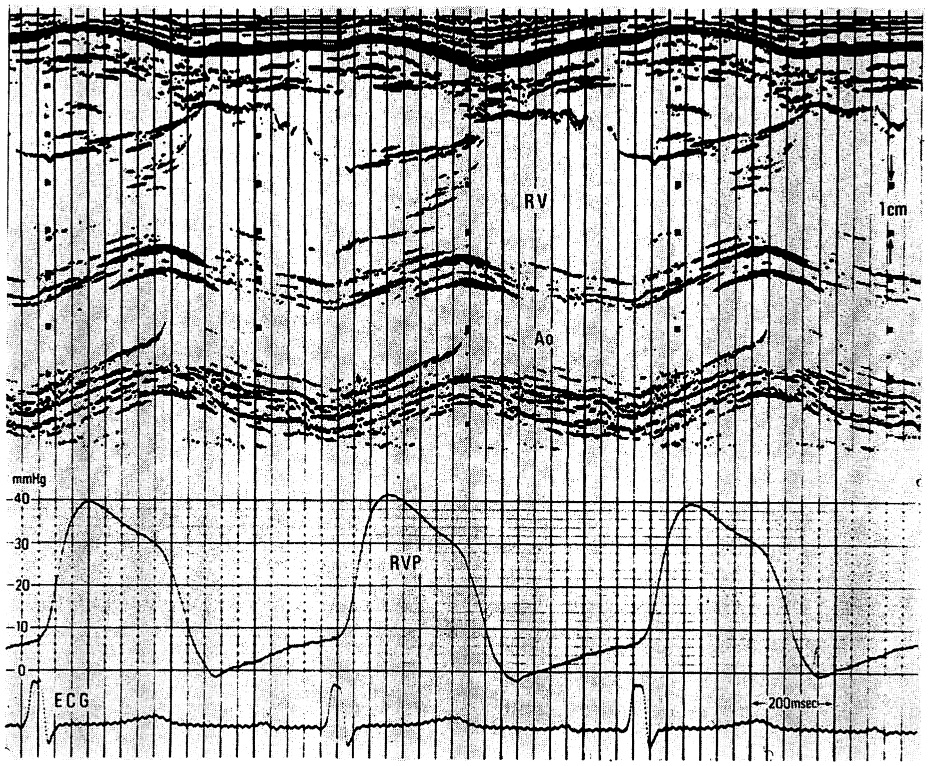


**Fig. 11. Simultaneous recording of the subxiphoid echocardiogram, right ventricular pressure** (RVP) **and electrocardiogram** (ECG).
RV = right ventricle; Ao = aorta.

subxiphoid echocardiography showed statistically significant relationships with angiocardiographically determined ejection fraction (EF-ACG). Thus, △D-ECHO and EF-ECHO seemed to be useful indexes for the pump function of the RV.

Regression analysis between RVDsx and BSA for the normal subjects revealed the exponential equation: RVDsx-Dd(cm) = 4.3 (BSA in $m^2)^{0.70}$.

RVDsx was larger than normal in patients with ASD but was within normal range in patients with PS or LV volume overload. In patients with LV volume overload complicated with PH, RVDsx was larger than normal. Because most of these patients have larger shunt than the patients without PH, it is suggested that the degree of dilatation of RVDsx is proportional to the degree of left-to-right shunt. The previous report validated this assumption[11]. In addition, the dilated RV in these patients may be based on the reduced RV compliance with increased afterload, but this speculation requires further investigation.

In contrast, RVDsx was smaller than normal in patients with T/F. This will be well explained by the fact that in T/F patients pulmonary blood flow affects RV size[12].

Consideration of the LV pressure-volume relation has long been recognized to be of importance in the evaluation of LV performance[13]. However, the relationship between RV pressure and RV volume does not seem to have been reported so far. The major problems encountered in the angiographic RV volume studies are the inability to repeat them frequently and

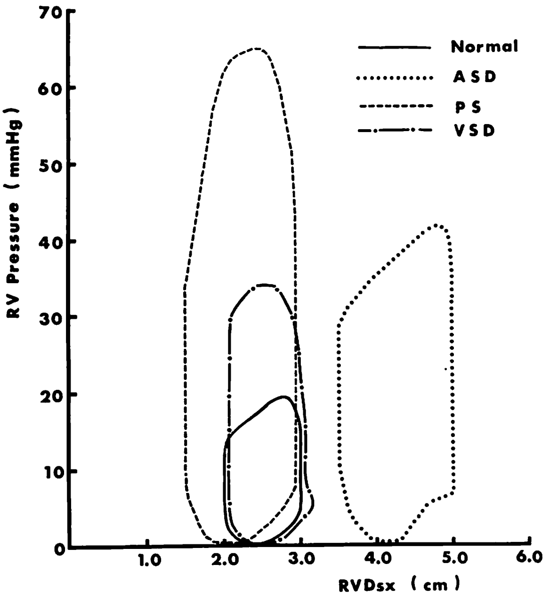


**Fig. 12. Right ventricular pressure-dimension plots of representative cardiac cycles from patients** with the normal right heart (normal), atrial septal defect (ASD), pulmonary stenosis (PS) and ventricular septal defect (VSD).

RV pressure=right ventricular pressure; RVDsx=right ventricular dimension.

the time consuming analysis required. The use of subxiphoid echocardiography obviates some of these problems and makes it possible to study RV pressure-dimension relations easily.

The pressure-dimension plots demonstrated the characteristic shapes for the various states of congenital heart disease.

Analysis of pressure-dimension relationship will permit to obtain some useful indexes for RV stroke work or diastolic compliance.

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