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Right ventricular volume determination by two-dimensional echocardiography

Akihiro SAITO
Ken UEDA
Hiroyuki NAKANO

Summary

Right ventricular (RV) volume was calculated by two-dimensional echocardiography (2DE) using a subxiphoidal approach in 31 patients with congenital heart disease.

Using 2DE, two views which were equivalent to the frontal and lateral views of RV angiocardiograms were obtained. Frontal view was defined as the plane which included the apex of RV, pulmonary and tricuspid valves. Lateral view was also defined as the frame which included the round shaped left ventricle, pulmonary and mitral valves. RV cavity was traced in both views, and subsequently, two area outlines were combined to calculate volumes by the biplane area-length (AL) and Simpson's rule (Simpson) methods. RV volumes were also determined by angiocardiography (ACG) using Simpson's rule method.

In some patients, considerable limitations were noted such as, loss of echoes from the RV free wall, unusual and excess echoes from the left ventricle in RV cavity. Tracing of RV cavity was sometimes difficult because of the thickened RV myocardium or difficult recognization of the pulmonary valve.

The correlation between RV volume by 2DE and that by ACG was good ($r=0.86$ by AL method, $r=0.85$ by Simpson) but not satisfactory for the clinical application.

We conclude that RV volume is estimated from 2DE, but further investigations are required for this technique to be an accurate and a reliable means in the clinical practice.

Key words

Right ventricular volume　Two-dimensional echocardiography　Congenital heart disease

Two-dimensional echocardiography has been widely utilized to provide a noninvasive diagnostic instrument of the spatial relationship of the cardiovascular systems. It has also served as a noninvasive means for the quantitative evaluation of the cardiac chambers and vessels.

Many investigators have reported the methods to estimate the left ventricular volume using two-dimensional echocardiography[1~3] since Shiller and colleagues[1] first reported the availability of this method. These studies proved the accuracy and reliability of the technique to calculate left ventricular volume, and were applied to the clinical practice.

静岡県立こども病院　循環器科
静岡市漆山 860 (〒420)

Division of Pediatric Cardiology, Shizuoka Children's Hospital, Urushiyama 860, Shizuoka 420

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On the other hand, there were only few reports[2,4,5] concerning the noninvasive estimation of right ventricular volume by two-dimensional echocardiography, and the methodology to calculate volume is still a controversial subject. There is a considerable interest in developing an accurate and simple method to calculate the volume of the right ventricle using two-dimensional echocardiography.

Thus, we designed this study to investigate the feasibility and accuracy of determining right ventricular volume from two-dimensional echocardiography in children with congenital heart disease.

Materials and methods

The children studied were 31 patients with congenital heart disease (18 males and 13 females) ranging in age from 6 months to 6 years. They consisted of 8 children with ventricular septal defect, 6 with atrial septal defect, 6 with pulmonary stenosis, 5 with tetralogy of Fallot, 2 with patent ductus arteriosus and 4 with other congenital heart disorders.

Two-dimensional echocardiographic recordings were obtained using a wide angle (90°) mechanical sector scan (Advanced Technology Laboratories, Mark III) with a 3 megahertz transducer.

In two-dimensional echocardiographic examination, two views of the right ventricle, frontal and lateral views, were obtained. The frontal view was recorded with the transducer placed in the subxiphoid area. The ultrasonic beam was directed to the head with the sector plane parallel to the frontal plane of the trunk. With some rotational adjustment, the pulmonary and tricuspid valves and the apex of the right ventricle were imaged simultaneously. The frontal view was defined as the frame incuding these three structures. The end-diastolic frame was chosen at the peak of the R wave of the simultaneously recorded electrocardiogram (**Fig. 1**).

The lateral view was obtained from the same position as the frontal view by rotating the transducer about 90° so that the sector plane was parallel to the sagittal plane of the trunk. In this view, the pulmonary valve, right ventricle and left ventricle, which appeared almost circular, were included (**Fig. 2**). The representative recordings of the frontal and lateral views

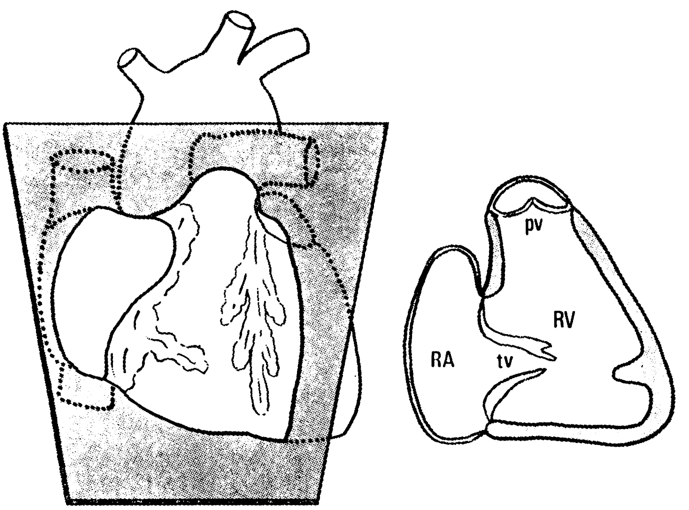

Fig. 1. Diagram of the cross-sectional plane of the frontal view.
pv=pulmonary valve; tv=tricuspid valve; RV=right ventricle; RA=right atrium.

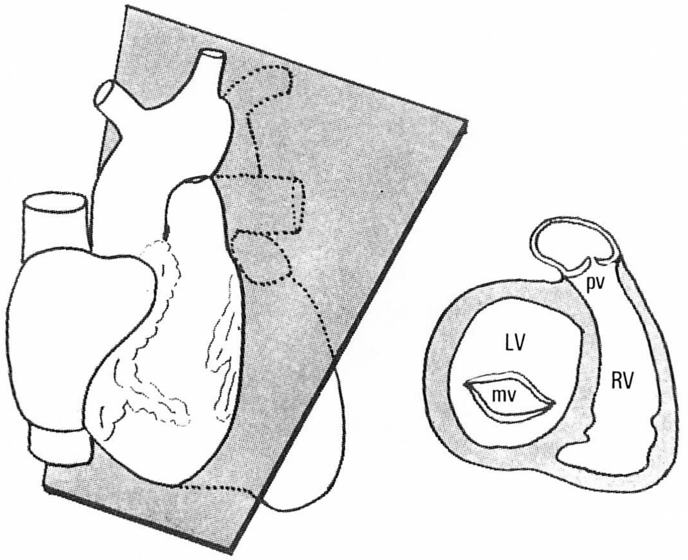

Fig. 2. Diagram of the cross-sectional plane of the lateral view.
pv=pulmonary valve; mv=mitral valve; RV=right ventricle; LV=left ventricle.

are shown in **Fig. 3**.

Then right ventricular cavity was outlined by tracing the endocardial surface of the right ventricle in the two-dimensional echocardiographic image. In this procedure, the apparatus of the tricuspid valves, that is, the tricuspid valves, chordae and papillary muscles, were neglected.

In this study, two mathematical models were used for quantifying right ventricular volume from the frontal and lateral outlines of right ventricular cavity. One model based on the assumption that the cross-sectional outline of the right ventricle was approximately circular or elliptical[6]. Thus, the right ventricle was divided into 10 slices from base to apex (**Fig. 4**). The volume of each slice was calculated as the product of the cross-sectional area and the hight. The cross-sectional area was calculated using a formula for the calculation of the area of the ellipse, and two axes of an ellipse were determined as the diameters of cross-scetion at the same level in two views. The hight of each segment was determined arbitrarily by dividing the apex-base length by the number of sections. The total volume of the right ventricle was given by summing up the volume of all segments utilizing the modification of the Simpson's rule[6].

Another model postulated that right ventricular cavity could be represented by an ellipsoid[7]. This method, modified area-length method, for the calculation of the right ventricular volume essentially consisted of dividing the product of the areas of the frontal and lateral views by the maximal apex-base length (**Fig. 4**).

All patients studied underwent both diagnostic cardiac catheterization and angiocardiography within 24 hours of the examination of two-dimensional echocardiography. Right ventricular volume was also calculated from the biplane right ventricular cineangiograms using Simpson's rule method according to Graham and his coworkers[6].

All measurements and calculations described above were performed using sonic pen connecting to the programed 16K minicomputer.

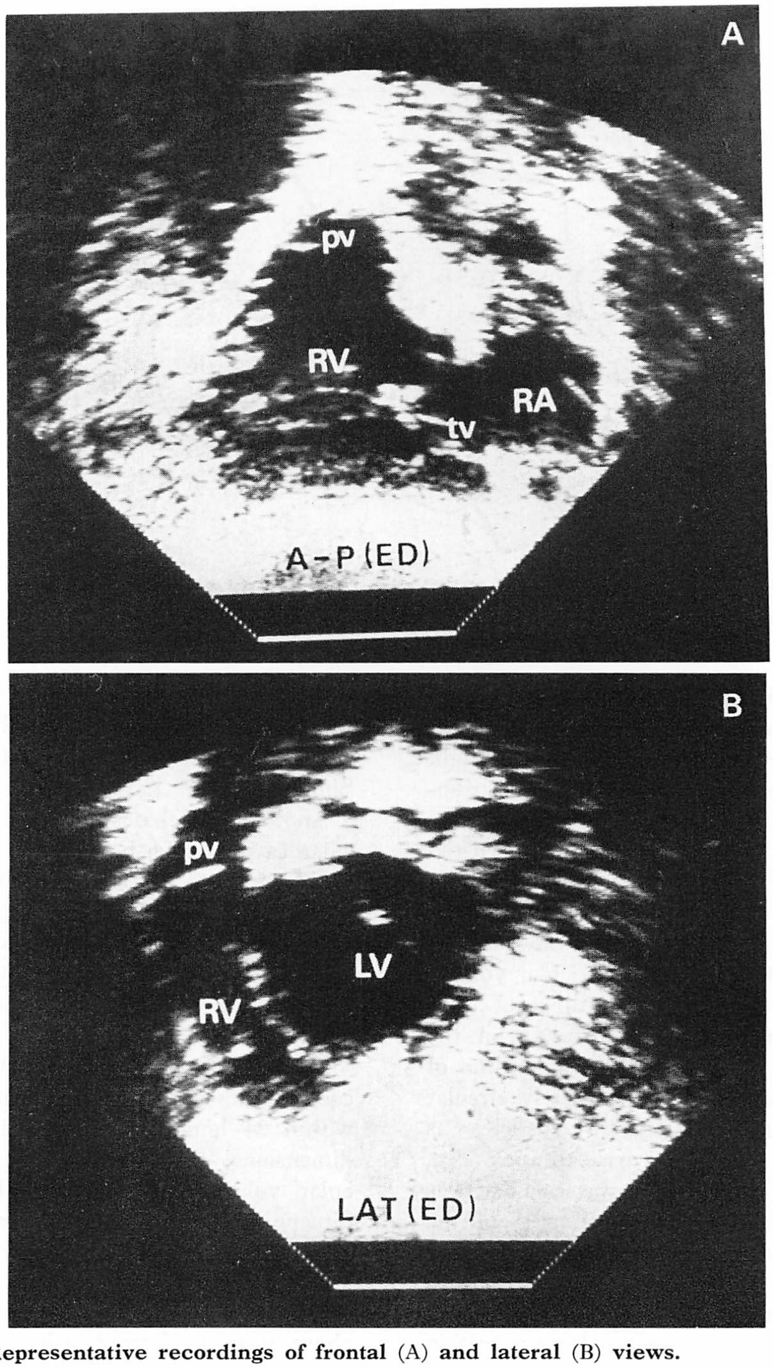

Fig. 3. Representative recordings of frontal (A) **and lateral** (B) **views.**
pv=pulmonary valve; tv=tricuspid valve; RV=right ventricle; RA=right atrium; LV=left ventricle.

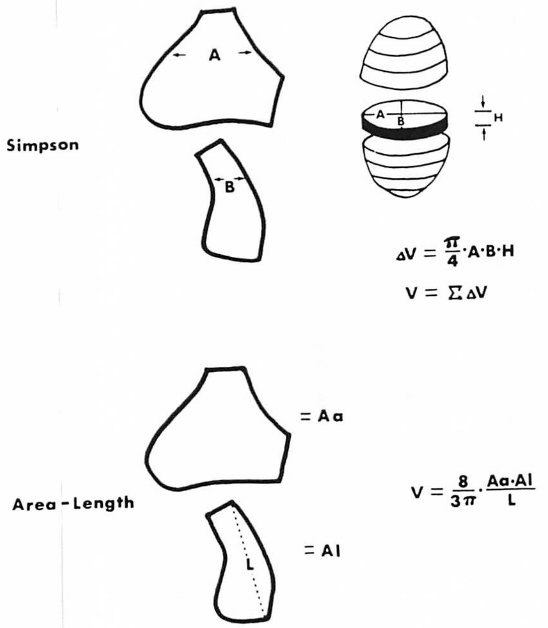

Fig. 4. Diagram of mathematical models, Simpson's rule and area-length methods, for the calculation of right ventricular volume.

Results

In some cases, there are some difficulties in obtaining the clear echocardiograms, tracing the cross-sectional area distinctly and positioning the sector plane correctly.

Fig. 5 is an echogram of such a case, one year and two months old, with ventricular septal defect and pulmonary hypertension. In the frontal view, the myocardium of the right ventricle is so thick that the apex of the right ventricle is filled with it. This is often observed in those with right ventricular pressure overload, and make it difficult to correctly outline the endocardial surface of the right ventricle. Moreover, in the lateral view, there exists a loss of echoes from the interventricular septum. Such a loss of echoes is not rare in those with large ventricular septal defect, therefore careful attention must be paid to the tracing.

In **Fig. 6**, two-dimensional echocardiograms of a patient with ventricular septal defect, aged two years and two months, is shown. In the frontal view, uncommon echoes are observed in the left half of right ventricular cavity. Because of these echoes, it is very awkward to trace right ventricular cavity. The origin of these

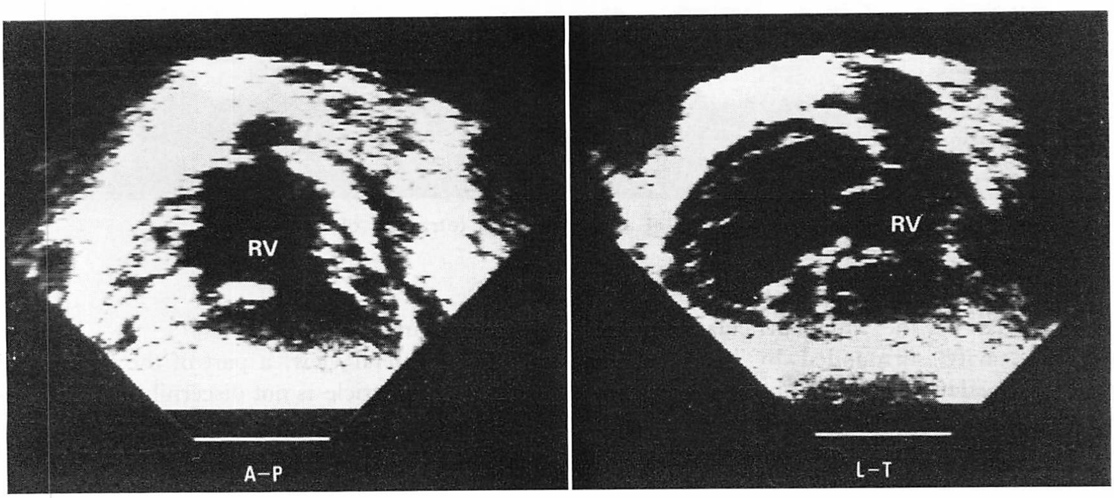

Fig. 5. Frontal and lateral views of a patient with ventricular septal defect and pulmonary hypertension (1 y 2 m).
RV=right ventricle.

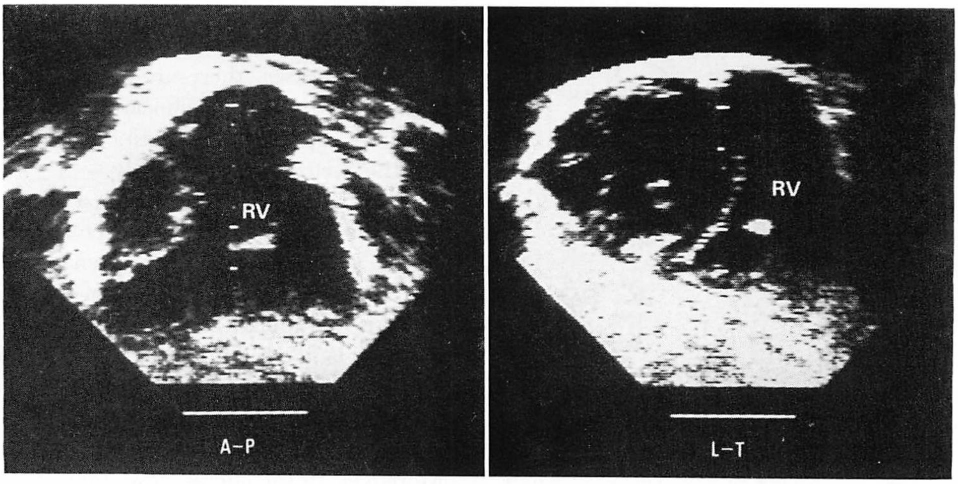

Fig. 6. Frontal and lateral views of a patient with ventricular septal defect (2 y 2 m). RV=right ventricle.

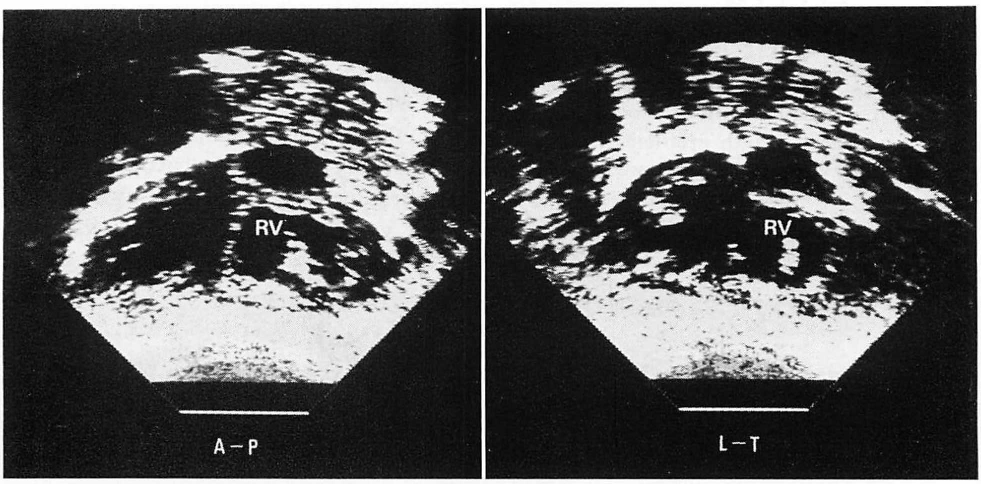

Fig. 7. Frontal and lateral views of a patient with tetralogy of Fallot (1 y). RV=right ventricle.

echoes must be the interventricular septum, and the cavity surrounded by these echoes must be the left ventricle. These unnecessary echoes are occasionally noticed in those with left ventricular volume overload whose hearts are counterclockwise rotated. To avoid to record these troublesome echoes, one must gradually rotate the transducer counterclockwise until the structures from the left ventricle become unrecognizable.

In the lateral view, a part of the free wall of the right ventricle is not discernible. This phenomenon is not rare in any patients who underwent two-dimensional echocardiography, and in limited children, clear continuous echoes from the free wall cannot be obtained with much effort. To obtain an ideal echocardiogram of the lateral view, it is essential to push and angu-

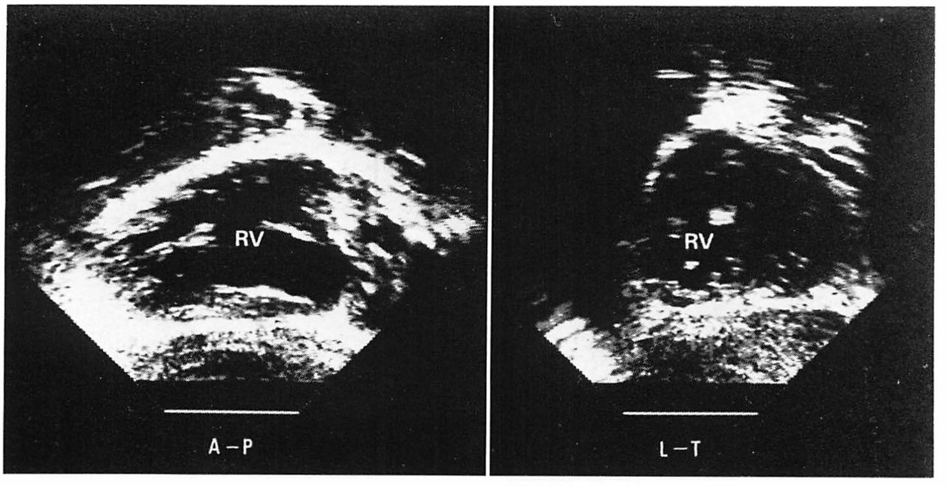

Fig. 8. Frontal and lateral views of a patient with tetralogy of Fallot (1 y 5 m).
RV=right ventricle.

late the transducer until the free wall is recognizable.

Both frontal and lateral views of a patient with tetralogy of Fallot aged one year are given in **Fig. 7**. Also in this case, the echoes from the left ventricle occupy right ventricular cavity in the frontal view. As mentioned above, this phenomenon is generally noticed in those with left ventricular volume overload, it may be recorded in those with relatively small right ventricular cavity as this case.

Because of the thickened myocardium and crista supraventricularis, right ventricular cavity is divided into two parts, the inflow and outflow portion. This is observed in both views, and it is almost impossible to outline right ventricular cavity.

In **Fig. 8**, two-dimensional views of a patient with tetralogy of Fallot aged one year and 5 months are shown. There exists no unnecessary echoes in right ventricular cavity which are demonstrated in the forementioned case. This will be explained by the fact that in this case no counterclockwise rotation of the heart is occured because of small left ventricular cavity.

However, to outline right ventricular cavity is still troublesome and inaccurate because of the thickened myocardium and the obscure echoes from the pulmonary valve.

The comparison between right ventricular volume determined by two-dimensional echocardiography using area-length method and that by angiocardiography is illustrated in **Fig. 9**. Although the plots of individual data are considerably scattering, the correlation coefficient is good ($r=0.86$) and the relation between these two measurements is statistically significant ($p<0.001$). In general, right ventricular volume is apt to be overestimated when calculated using area-length method.

Fig. 10 illustrates the correlation between the right ventricular volume by two-dimensional echocardiography using Simpson's rule and that by angiocardiography. The correlation coefficient is also good ($r=0.85$) and statistically significant ($p<0.001$). The plots of the data are less scattering than the graph demonstrated in **Fig. 9**. In contrast to the calculation using area-length method, the volume tends to be underestimated when calculated using Simpson's rule.

Discussion

M-mode echocardiography has been applied for the estimation of the size of cardiac chambers and vessels. Numerous studies have demonstrated that M-mode echocardiographic

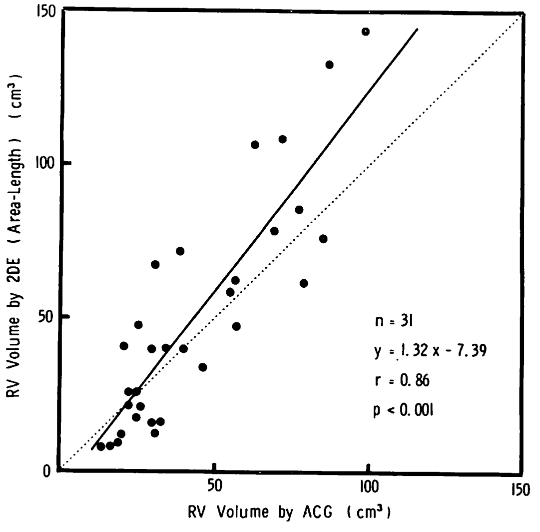

Fig. 9. Correlation between right ventricular volumes determined by two-dimensional echocardiography using area-length method and by angiocardiography.

RV = right ventricle; 2DE = two-dimensional echocardiography; ACG = angiocardiography.

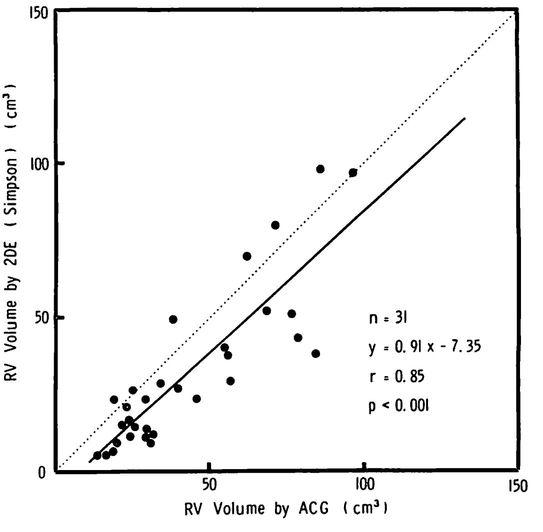

Fig. 10. Correlation between right ventricular volumes determined by two-dimensional echocardiography using Simpson's rule method and by angiocardiography.

RV = right ventricle; 2DE = two-dimensional echocardiography; ACG = angiocardiography.

measurements have a good linear relationship with the corresponding angiographic volumes, and that therefore this technique is useful in the noninvasive assessment of the cardiac size and function of patients with cardiac disorders in the clinical practice.

Despite this clinical usefulness, M-mode echocardiography has many limitations. The most fundamental limitation is that this method never measure actual cardiac volume. In this point, two-dimensional echocardiography has an advantage over M-mode echocardiography.

Two-dimensional echocardiography can vizualize many cross-sectional views which cannot be obtained by any other techniques currently available. Moreover, this technique can image any cross-sectional views equivalent to the angiocardiographic views. The examination is easy to perform, noninvasive and repeatable. Thus, there is an increasing interest in calculating cardiac volume using this method, and already there are many articles[1~3] concerning the estimation of left ventricular volume.

We have been making some effort to evaluate the size of right-sided cardiac chambers noninvasively in patients with congenital heart disease[8]. In regard to right ventricular volume, an excellent correlation was revealed with right ventricular dimension measured by M-mode echocardiography using a subxiphoid approach. However, this dimension is at best only an index of the volume and, as stated before, is not the actual volume. This is why we attempted to calculate right ventricular volume using two-dimensional echocardigraphy.

First, we chose a subxiphoid approach for the examination because this approach is excellent for imaging the right ventricle, its inflow and outflow tract, in infants and children with congenital heart disease[9]. In the routine two-dimensional echocardiographic examination, we prefer this approach to a parasternal approach where the sternum or ribs interfere with the whole imaging of the right ventricle.

Next, we selected the sector planes which can image the cross-sectional views equivalent to the frontal and lateral views of the right ventricular angiocardiography. For the frontal view, the cross-sectional image was chosen which included the apex of the right ventricle, pulmonary and tricuspid valves. The lateral view was obtained from the sector plane which was perpendicular to the frontal view. In this view, the left ventricle, pulmonary and mitral valves were visualized. In general, the recording of these two views was not so difficult and not time-consuming in our patients, but in limited children, satisfactory recordings could not be obtained with effort.

The free wall of the right ventricle was the structure which was often difficult to be visualized clearly. In order to obtain a proper cross-sectional image, correct positioning of the transducer, careful selection and the minor adjustment of the sector plane with the fine movement of the transducer were needed.

In patients with right ventricular pressure overload, to outline the cavity of the right ventricle was occasionally erroneous because of the irregular endocardial surface and the thickened myocardium. On the other hand, in patients with left ventricular volume overload, unusual echoes from the left ventricle were frequently recognized in right ventricular cavity, which made it almost impossible to trace the right ventricle. To avoid these unusual echoes, one must rotate the transducer counterclockwise until these echoes disappear.

The correlation between the right ventricular volume determined by angiocardiography and that by two-dimensional echocardiography was good. The right ventricular volume from the echocardiography was somewhat overestimated when calculated by the area-length method. This was because, in this method, the maximal apex-base length was apt to be underestimated. On the contrary, the volume determined by Simpson's rule method was somewhat underestimated.

These results are not satisfactory for the clinical application. The calculation of the volume from the two-dimensional echocardiograms require a programed minicomputer as well as a light pen or other means to introduce the raw data into the computer. This technique was more complicated and time-consuming than the measurement of the right ventricular dimension by M-mode echocardiography. However, the calculated volume is not better than the dimension by M-mode echocardiography.

In spite of these discouraging results, this is still a promising and attractive technique. To calculate right ventricular volume using two-dimensional echocardiography is in the investigative stage. The correlation coefficients with the angiographic right ventricular volume were good considering that these were the preliminary data. With further investigation about the positioning of the transducer, standardization of the proper sector plane, outlining of right ventricular cavity and calculating method, this technique must be proved to be accurate and useful in the clinical practice.

超音波断層法を用いた右室容積の計測

静岡県立こども病院循環器科
斎藤彰博，上田　憲，中野博行

先天性心疾患児31例において，超音波断層法を用いて，右室容積の計測を行った．超音波断層法により，剣状突起下よりアンジオの正，側面像に相当する断面像を求めた．正面像としては，右室心尖，肺動脈弁および三尖弁を同時に検出する面を選び，側面像としては肺動脈弁，僧帽弁および左室短軸断面の得られる断面と定めた．これら正，側面像の心内膜をトレースし，area-length法およびSimpson法により，右室容積を計測した．

症例によっては，右室自由壁よりのエコーが捉えられなかったり，右室腔内に左室由来のエコーの出現など，方法論上の困難を認めた．右室壁の肥厚した例や肺動脈弁描出の困難な例では，右室腔の輪郭をたどることはしばしば困難であった．

こうして求めた右室容積と，心カテ時アンジオ

より Simpson 法を用いて計測した右室容積とを比較すると，area-length 法にては r＝0.86, Simpson 法にては r=0.85 と，良好な相関を認めた．しかし両計測値間のバラツキは大きく，臨床応用には不十分と思われた．

結論としては，超音波断層法を用いて右室容積を求めることは可能であるが，実際の臨床上，正確で信頼できる方法となるには今後の検討が必要と思われた．

文　献

1) Shiller N, Drew D, Acquatella H, Boswell R, Botvinick E, Greenberg B, Carlsson E: Noninvasive biplane quantitation of left ventricular volume and ejection fraction with a real-time two-dimensional echocardiography system. Circulation **53** and **54** (Supp. II): II-234, 1976 (abstr)
2) Chaudry KR, Ogawa S, Pauletto FJ, Hubbard FE, Dreifus LS: Biplane measurements of left and right ventricular volumes using wide angle cross-sectional echocardiography. Am J Cardiol **41**: 391, 1978
3) Silverman NH, Ports TA, Rebecca Snider A, Shiller NB, Carlsson E, Heilbron DC: Determination of left ventricular volume in children: Echocardiographic and angiographic comparison. Circulation **62**: 548, 1980
4) Yagihara T, Kitamura S, Shimazaki Y, Sakakibara T, Sato S, Kishimoto H, Nakatani T, Ogawa M, Kawashima Y: Right ventricular volume measurement using a two-dimensional ultrasonic image of the right ventricle by a subxiphoid approach. Jpn J Med Ultras, Proc. 38th Meeting: 163, 1981 (in Japanese)
5) Hagiwara H, Wakamatsu T, Yana T, Hara H, Nakamura N, Uzawa H: Assessment of variation in two-dimensional echocardiographic determination of the right ventricular volumes. Jpn J Med Ultras, Proc. 38th Meeting: 165, 1981 (in Japanese)
6) Graham TP Jr., Jarmakani JM, Atwood GF, Canent RV Jr: Right ventricular volume determinations in children: Normal values and observations with volume or pressure overload. Circulation **47**: 144, 1973
7) Arcilla RA, Tsai P, Thilenius O, Ranniger K: Angiographic method for volume estimation of right and left ventricles. Chest **60**: 446, 1971
8) Saito A, Ueda K, Nakano H: Methodology and evaluation of the measurement of the right-sided cardiac chambers by M-mode echocardiography. J Cardiography **10**: 967, 1980
9) Lange LW, Sahn DJ, Allen HD, Goldberg SJ: Subxiphoid cross-sectional echocardiography in infants and children with congenital heart disease. Circulation **59**: 513, 1979