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Methodology and evaluation of the measurement of the right-sided cardiac chambers by M-mode echocardiography

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Summary

Simple methods to measure the size of the right atrium, right ventricle and right pulmonary artery by M-mode echocardiography were described, and the reliability of which was ascertained by two-dimensional echocardiography and angiocardiography.

Right atrium was recorded with a transducer placed along the left sternal border and directed inward after detecting the anterior leaflet of the tricuspid valve. Right atrial dimension was defined as the distance from the tricuspid valve annulus to the posterior wall of the right atrium.

Right ventricle was visualized using subxiphoid echocardiography. A transducer was placed in the subxiphoid area and tilted until the ultrasonic beam passed through the anterior wall of the right ventricle, the tricuspid and aortic valves. The right ventricular dimension was obtained by measuring the distance between the anterior wall of the right ventricle and the anterior wall of the aorta.

Right pulmonary artery was recorded with the suprasternal notch approach. The ultrasonic beam was directed caudally and somewhat posteriorly so as to obtain three echo-free spaces corresponding to the aorta, right pulmonary artery and left atrium. The diameter of the right pulmonary artery was determined by measuring the echo-free zone at end-diastole.

These techniques were proved to be easy to apply and useful to assess the hemodynamic alterations of the right heart in pediatric patients with cardiac disease, and we recommend these methods to be included in the routine echocardiographic examinations.

Key words

Echocardiography　Right atrial dimension　Right ventricular dimension　Right pulmonary arterial dimension　Hemodynamics of the right heart

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Determination of the size of the cardiac chambers and great vessels is important in the evaluation and management of patients with heart disease. Although the electrocardiogram and chest roentogenogram are used to estimate the size of these structures, there are considerable limitations. Echocardiography also provides a noninvasive technique for the evaluation of the size of the cardiac chambers. Using echocardiography, the size of the left side of the heart, such as the left atrium[1], left ventricle[2] and aorta[3] has been investigated by many workers, whereas the right side of the heart has not been studied extensively. In the literature, few reports[4~6] on the quantitative examination of the right-sided cardiac chambers have appeared.

Recently, we reported a new method to de-

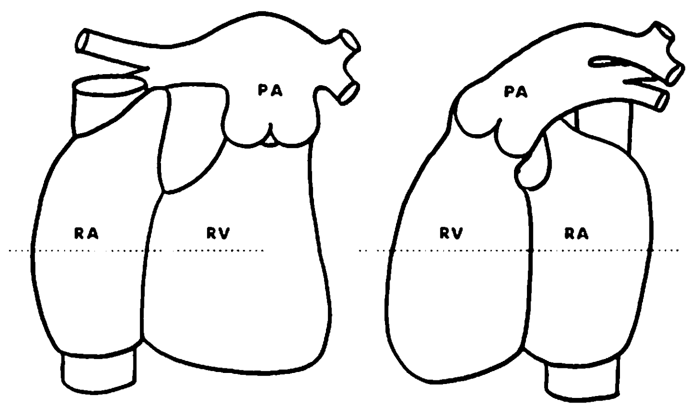


Fig. 1. Anatomical relationship of the right atrium, right ventricle and pulmonary artery.
Dashed lines indicate the pathway of the ultrasonic beam.
RA=right atrium; RV=right ventricle; PA=pulmonary artery.

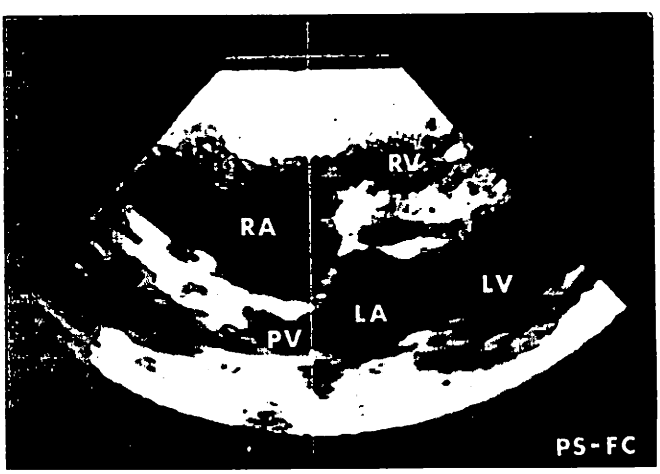


Fig. 2. Parasternal four chamber view.
White line indicates the M-line.
RA=right atrium; RV=right ventricle; LA=left atrium; LV=left ventricle; PV=pulmonary vein.

termine the size of the right atrium[7,8] and right ventricle[9~11] by echocardiography, and studied the reliability of the methodology, clinical utility and application for the analysis of the right ventricular hemodynamics.

In this paper, we aimed to study the adequacy of the technique to estimate the size of the right atrium, right ventricle and right pulmonary artery by echocardiography in comparison with the findings obtained from two-dimensional echocardiography and angiocardiography.

Materials and Methods

M-mode echocardiograms were obtained with a Smith-Kline Ekoline 20-A ultrasonoscope interfaced with an Electronics for Medicine VR-12 optical recorder and nonfocused transducers with a frequency rate of 3.5 or 5 MHz. In the suprasternal notch approach, a 3.5 MHz hammer shaped transducer was used.

Two-dimensional echocardiography was performed using an Advanced Technology Laboratories Mark III system with 3 or 5 MHz transducer. Single images were recorded with a Honeywell fiber-optic recorder 100 A.

The success rate of the recording was studied in 100 children (50 males and 50 females, age ranging from 2 days to 14 years), who were referred to our clinic for cardiac evaluation from July 1979 to February 1980. The diagnosis was established at cardiac catheterization in 91 of them, and in the remainder the diagnosis was made clinically. They consisted of 26 patients with ventricular septal defect, 13 with atrial septal defect, 10 with Fallot's tetralogy, 9 with patent ductus arteriosus, 8 with transposition of the great arteries and 34 with miscellaneous diseases, and were divided into 4 groups according to their age.

Results

I. Right atrium

The right atrium has been rarely studied by echocardiography,[4] mainly because the right atrium was thought to be difficult to detect with ultrasound because of its intrathoracic position, that is, it forms the right border of the heart and is most distant from the left parasternal acoustic window (**Fig. 1**). However, the ultrasonic beam can traverse the right atrium without difficulty when the transducer placed along the left parasternal border is angled toward the right until the ultrasonic beam detects the tricuspid valve annulus. This is ascertained by the parasternal four chamber view two-dimensional echocardiogram (**Fig. 2**) and its diagram (**Fig. 3**).

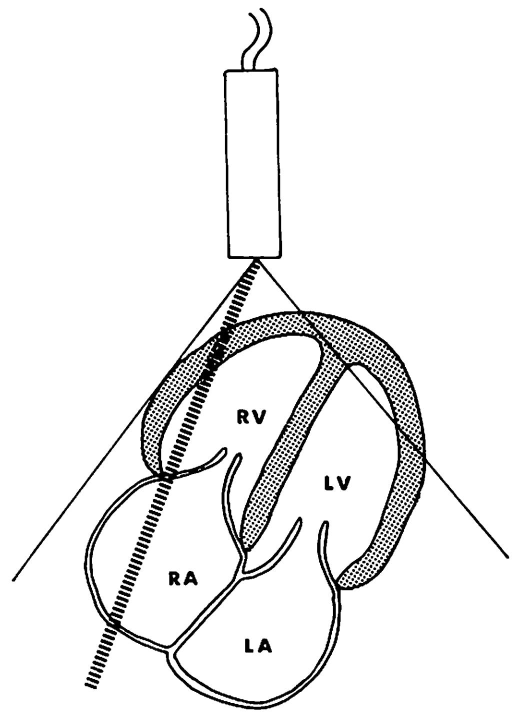


Fig. 3. Diagram of parasternal four chamber view.

Dashed line indicates the pathway of the ultrasonic beam.

RA=right atrium; RV=right ventricle; LA=left atrium; LV=left ventricle.

The right atrium can be detected from other thoracic acoustic windows, such as the third intercostal space along the left parasternal border (**Fig. 4**) and along the right parasternal border (**Fig. 5**). But with the former approach, it is often difficult to outline the interatrial septum accurately, and with the latter technique, un-

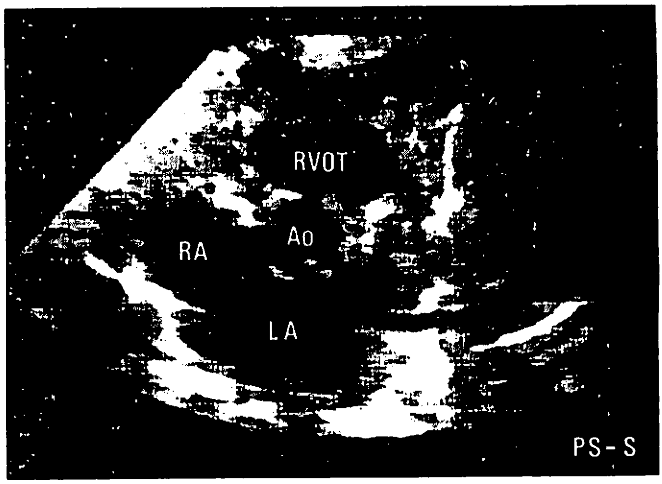


Fig. 4. Parasternal short axis view of the aortic valve.
RVOT=right ventricular outflow tract; Ao=aorta; RA=right atrium; LA=left atrium.

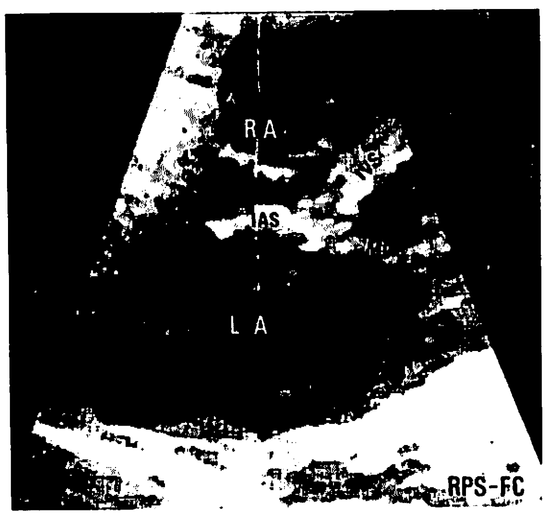


Fig. 5. Right parasternal four chamber view.
RA=right atrium; LA=left atrium; IAS=interatrial septum; IVS=interventricular septum; MV=mitral valve.

equivocal echograms can be obtained only in the limited patients.

From the subcostal acoustic window, four chamber view can be imaged. The right and left atria, right and left ventricles, and interventricular and interatrial septa were visualized clearly (**Fig. 6**). When the transducer is tilted with some rotational adjustment, the right atrium, the right ventricle and the tricuspid valves could be recorded simultaneously (**Fig. 7**). These two subcostal views gave reasonably good echograms for identifying the boundaries and assessing the size of the right atrium if the reliable reference points were established.

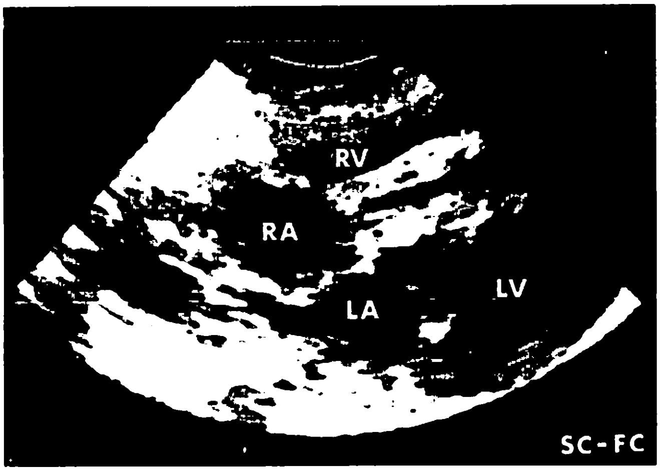


Fig. 6. Subcostal four chamber view.
RA=right atrium; RV=right ventricle; LA=left atrium; LV=left ventricle.

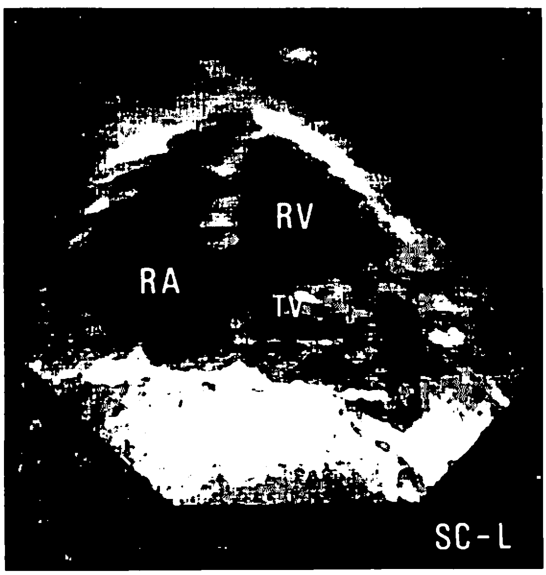


Fig. 7. Subcostal long axis view of the right atrium and right ventricle.
RA=right atrium; RV=right ventricle; TV=tricuspid valve.

The method we proposed to measure the size of the right atrium was as follows: a transducer was placed on the fourth intercostal space along the left sternal border and then it was angled toward the right until the ultrasonic beam detects the tricuspid valve annulus and posterior wall of the right atrium. The simultaneous recording of the parasternal four chamber two-dimensional echocardiogram and M-mode echogram is shown in **Fig. 8**. The pathway of the

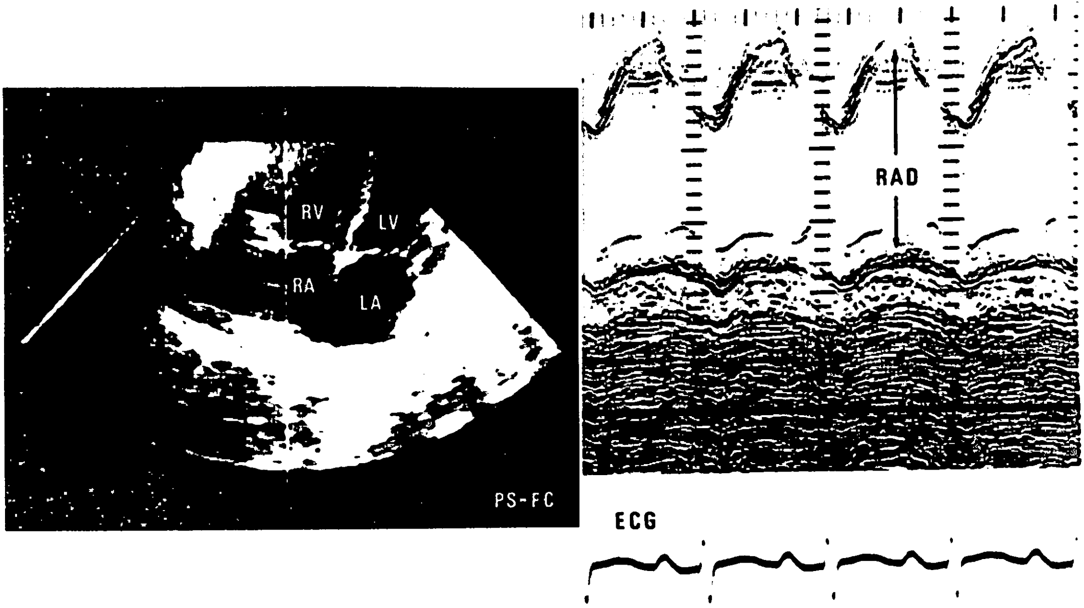


Fig. 8. Simultaneous recording of parasternal four chamber view and corresponding M-mode echogram.
White line indicates the M-line.
RA=right atrium; RV=right ventricle; LA=left atrium; LV=left ventricle; RAD=right atrial dimension; ECG=electrocardiogram.

ultrasonic beam is indicated on the two-dimensional echogram by the white line, which traverses the tricuspid valve annulus, right atrium and posterior wall of the right atrium. On the M-mode echogram, echoes from the tricuspid valve annulus moves upward in systole and downward in diastole and those from the posterior wall of the right atrium show little movement. The right atrial dimension was defined as the maximum distance between these two structures. **Fig. 9** shows a M-mode scan from the tricuspid valve to the right atrium. The echoes from the tricuspid valve shift to that from the tricuspid valve annulus and the echoes from the interatrial septum to that from the posterior wall of the right atrium.

In 58 patients with heart disease, both echocardiographic examinations and diagnostic cardiac catheterization were performed. Right atrial dimension was measured from the echocardiogram and right atrial volume was calculated from the biplane cineangiogram by area-length method. A significant correlation coefficient of 0.92 was present between these two variables (**Fig. 10**). This finding suggested that right atrial dimension reflected the right atrial volume closely and was reliable enough for the clinical application.

The success rate of recording of right atrium was good in those younger than 4 years, and was relatively poor in older children (**Fig. 11**). On the whole, the measurable right atrial echograms were obtained in 99 percent of the children.

II. Right ventricle

Echocardiography has been applied for the estimation of size of right ventricular chamber[5,12]. But dimension measured from the endocardial surface of the right ventricle to the anterior edge of the interventricular septum

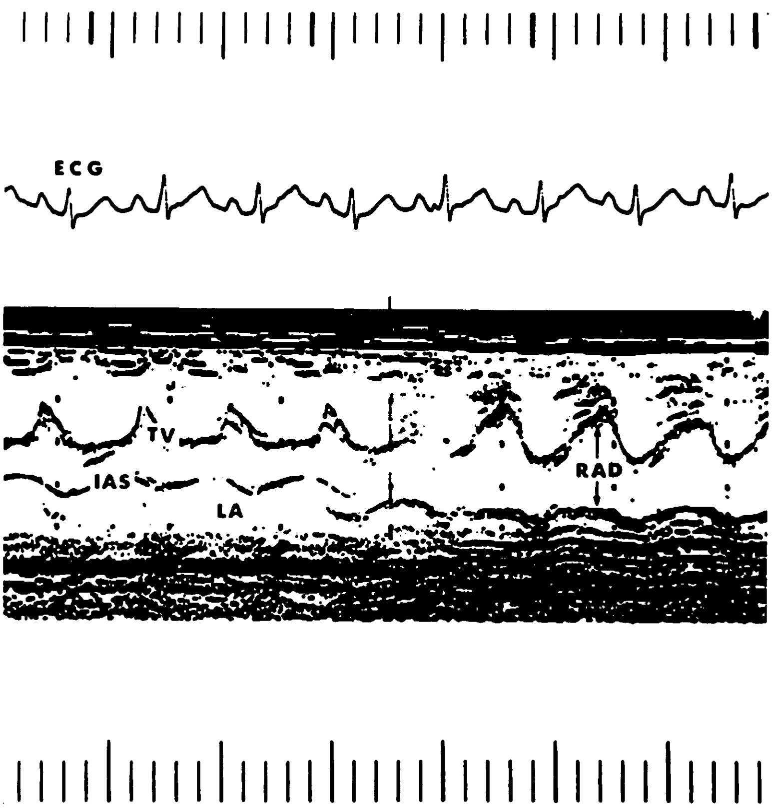


Fig. 9. M-mode scan from the tricuspid valve to the right atrium.
TV=tricuspid valve; IAS=interatrial septum; LA=left atrium; RAD=right atrial dimension; ECG=electrocardiogram.

varies considerably among normal persons and easily affected by the cardiac rotation, angulation of the transducer and position of the patients[5,12,13]. Comparison between the right ventricular dimension measured by this conventional method and the angiocardiographic data revealed that this approach was unsatisfactory for the estimation of right ventricular size[5,10].

Therefore, we have recently proposed a new method for evaluating the size of right ventricular cavity using subxiphoid approach (**Fig. 12**)[9~11]. A transducer was placed in the subxiphoid area and was tilted so as to direct the ultrasonic beam to the aortic valves, then the beam traverses the inflow portion of the right ventricle. This was ascertained by the subcostal two-dimensional echocardiography. The transducer for two-dimensional echocardiography was placed in the subxiphoid area with the plane of ultrasonic beam parallel to the horizontal plane of the trunk and was angled anteriorly with minor rotational adjustment, then the right and left ventricles and left ventricular outflow tract could be imaged (**Fig. 13**). The pathway of the ultrasonic beam is indicated by the white line on a two-dimensional echogram (**Fig. 14**). It is evident from these figures that the ultrasonic beam in our method passes the inflow portion of the right ventricle.

On the contrary, the ultrasonic beam in the conventional method traverses only a small

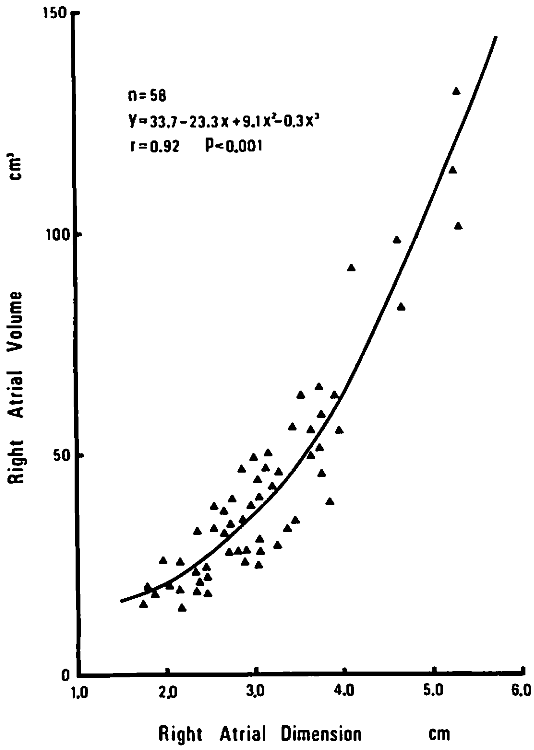


Fig. 10. Correlation between right atrial dimension and volume.

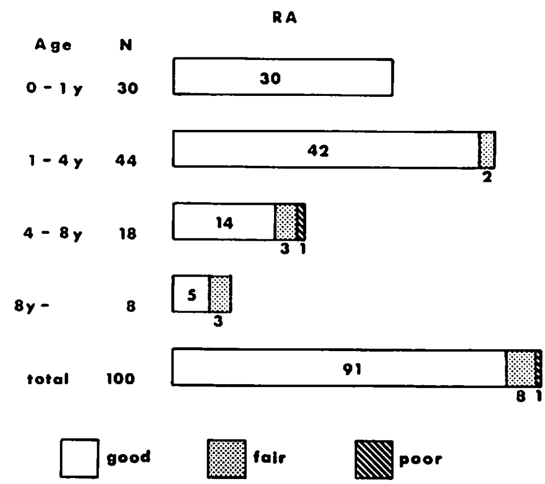


Fig. 11. Success rate of recording of the right atrium.
Numbers in brackets express percentage.

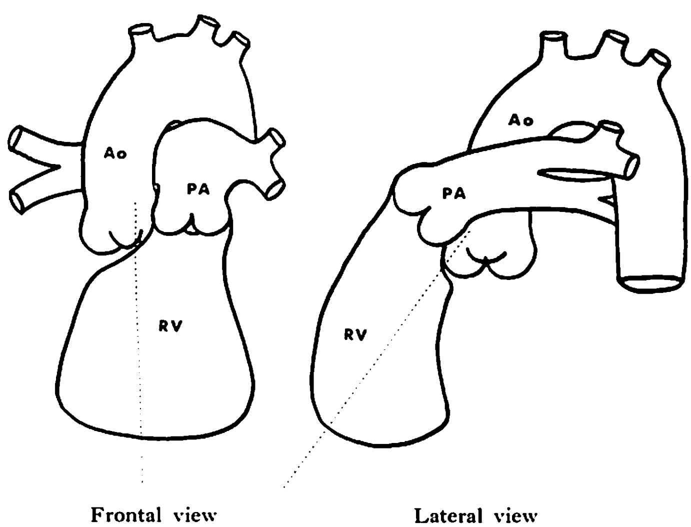


Fig. 12. Anatomical relationship of the right ventricle, pulmonary artery and aorta.
Dashed lines indicate the pathway of the ultrasonic beam.
RV=right ventricle; PA=pulmonary artery; Ao=aorta.

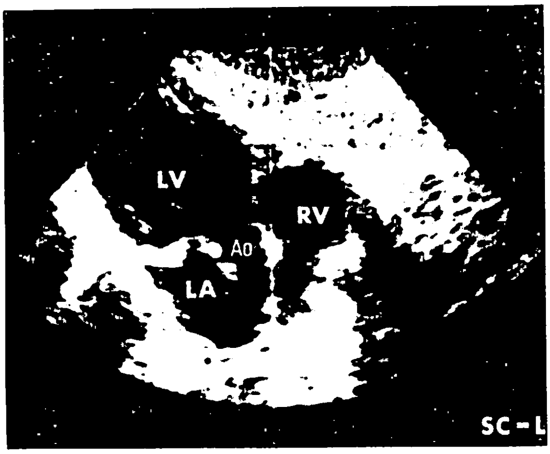


Fig. 13. Subcostal long axis view of the left ventricle.

LA=left atrium; LV=left ventricle; Ao=aorta; RV=right ventricle.

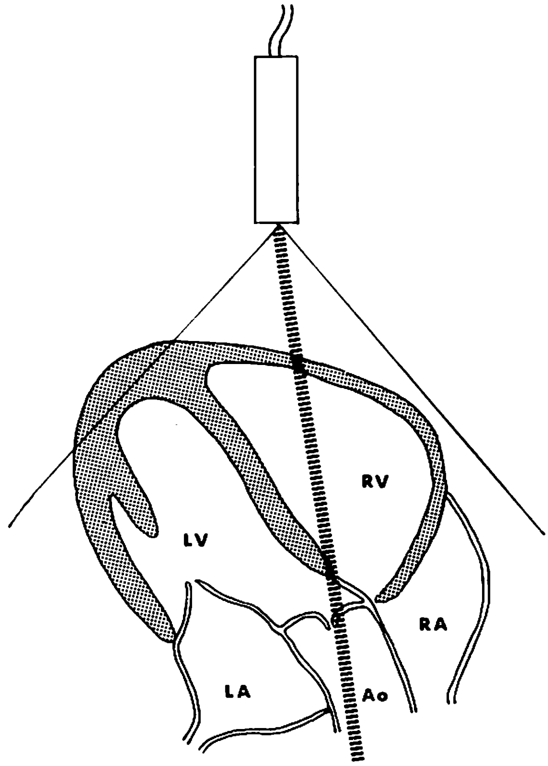


Fig. 14. Diagram of subcostal long axis view of the left ventricle.

Dashed line indicates the pathway of the ultrasonic beam.

LA=left atrium; LV=left ventricle; RA=right atrium; RV=right ventricle; Ao=aorta.

portion of the right ventricle. This is explained by the parasternal long axis two-dimensional echogram with a transducer placed along the left sternal border (**Fig. 15**). The ultrasonic beam of the M-mode echocardiography passes through only a small part of the right ventricle when it is directed to the mitral valve. This finding appears to be the chief drawback in this conventional method.

Fig. 16 is an apical four chamber view demonstrating the right and left ventricles and right and left atria. Using this technique, a new method has been reported to determine the right ventricular size[14]. However, the right ventricular dimension measured by this method did not clearly separate normals from patients with right ventricular volume overload. Although, the area of the right ventricle calculated using planimetry was useful in differentiating these patients, this method appeared to be complicated and time-consuming.

From the subcostal acoustic window, four chamber echograms can be obtained imaging the right and left ventricles, right and left atria and interventricular and interatrial septa (**Fig. 17**). **Fig. 18** is an inverted subcostal long axis view of the right ventricle that approximates a frontal cineangiogram and displays the right and left ventricles, outflow tract of the right ventricle and pulmonary artery. These images seem to be potential views for calculating the size of the right ventricular chamber if the reference points of the beam position are established.

Fig. 19 is the simultaneous recording of the subcostal two-dimensional echogram and corresponding M-mode echogram. The ultrasonic beam indicated on a two-dimensional image passes through the anterior wall of the right ventricle, tricuspid valve and aorta in that order. A representative recording of the subxiphoid M-mode echogram is shown in **Fig. 20.** The

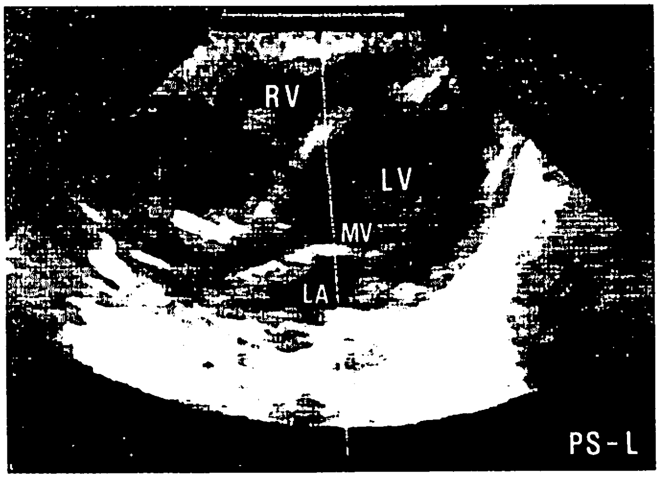


Fig. 15. Parasternal long axis view of the left ventricle.
White line indicates the M-line.
RV=right ventricle; LV=left ventricle; MV=mitral valve; LA=left atrium.

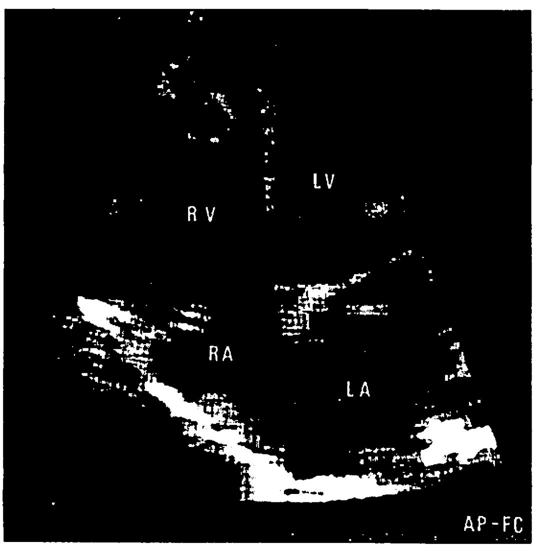


Fig. 16. Apical four chamber view.
RA=right atrium; RV=right ventricle; LA=left atrium; LV=left ventricle.

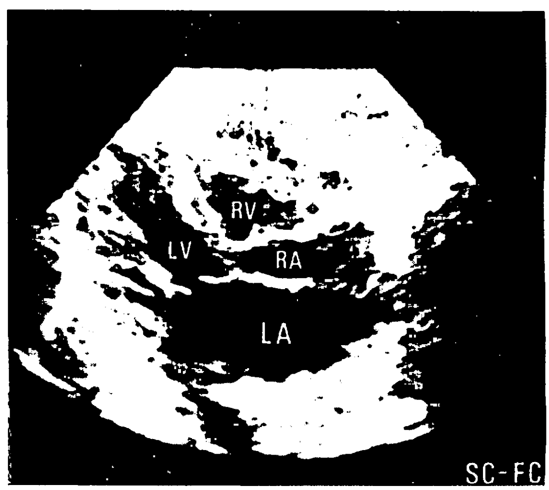
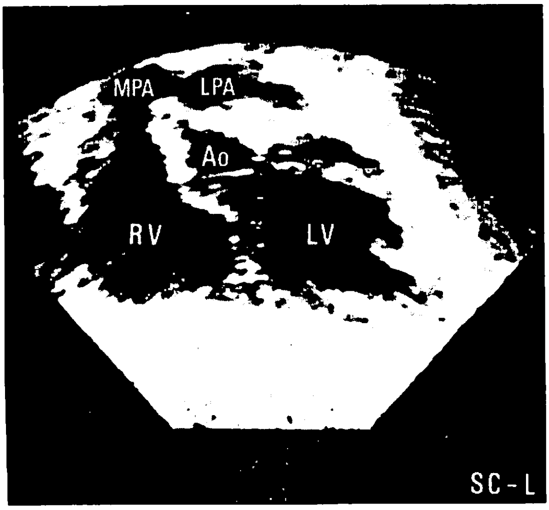


Fig. 17. Subcostal four chamber view.
RA=right atrium; RV=right ventricle; LA=left atrium; LV=left ventricle.



←**Fig. 18. Inverted subcostal long axis view of the right ventricle.**
RV=right ventricle; LV=left ventricle; Ao=aorta; MPA=main pulmonary artery; LPA=left pulmonary artery.

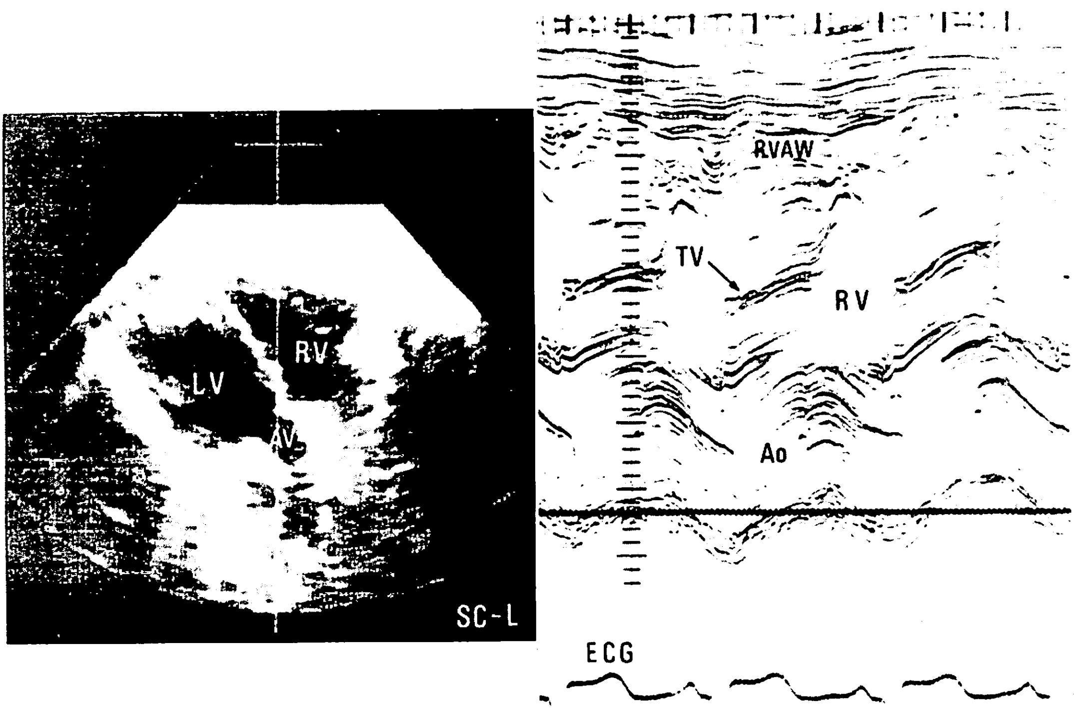


Fig. 19. Simultaneous recording of the subcostal long axis view of the left ventricle and the corresponding M-mode echogram.
White line indicates the M-line.
RV=right ventricle; LV=left ventricle; Ao=aorta; AV=aortic valve; TV=tricuspid valve; RVAW =right ventricular anterior wall; ECG=electrocardiogram.

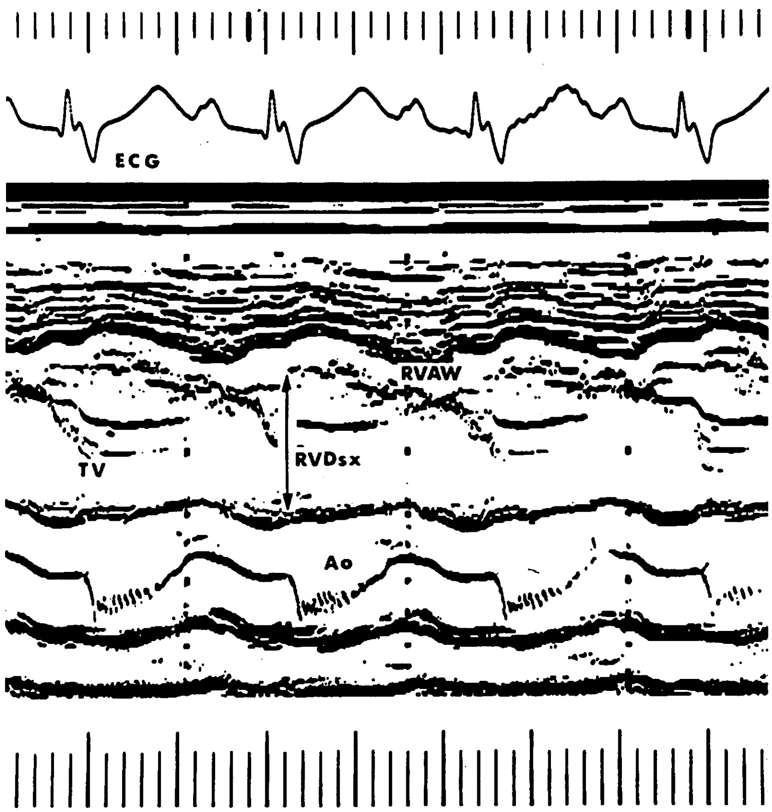


Fig. 20. Representative recording of the subxiphoid M-mode echogram.
RVDsx = right ventricular dimension; RVAW = right ventricular anterior wall; TV = tricuspid valve; Ao = aorta; ECG = electrocardiogram.

right ventricular dimension was measured from the endocardial surface of the right ventricular anterior wall to the anterior border of the aorta at the peak of R wave on the electrocardiogram.

In 55 patients, echocardiography was performed within 24 hours after diagnostic cardiac catheterization and angiocardiography. Right ventricular dimensions were measured from echograms using the present method and were compared with the right ventricular volumes calculated from the biplane cineangiograms using the Simpson's method (**Fig. 21**). The right ventricular dimension demonstrated an excellent correlation ($r = 0.94$) with the right ventricular volume and was suggested to be a reliable estimate for the size of this structure.

The success rate of recording using this subxiphoid technique was studied. In 4 children, the recording of right ventricular cavity was impossible because either the cavity was diminutive (2 children with tricuspid atresia), or the recording of the posterior semilunar valve was difficult (one patient with transposition of the great arteries and pulmonary stenosis) or the ventricle was single (one patient with asplenia syndrome). **Fig. 22** shows the results of the investigation excluding these 4 patients. In general, the recording of the right ventricle was relatively easy in children younger than 4 years and became difficult with increasing age. But poor recordings were obtained only in 4 per cent of the patients and measurable recordings were

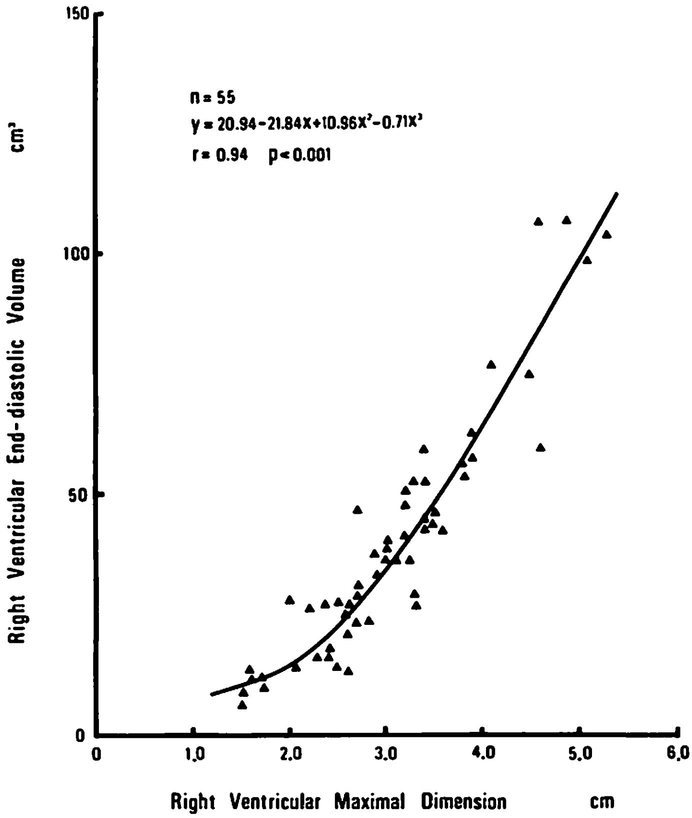


Fig. 21. Correlation between right ventricular dimension and volume.

obtained in the remainder.

III. Right pulmonary artery

Ultrasonic examination from the suprasternal notch was first introduced by Goldberg[6,15]. This method provides the simultaneous recording of the transverse aortic arch, right pulmonary artery and left atrium. The anatomic relationship of these structures is shown in the anterior-posterior and lateral planes with the pathway of the ultrasonic beam in this approach (**Fig. 23**). **Figs. 24 & 25** show two-dimensional echograms approached from the suprasternal notch, and **Fig. 26** shows a diagram of the short axis view of the aortic arch. As is evident from these echograms, the ultrasonic beam can traverse the aortic arch, right pulmonary artery and left atrium.

The simultaneous recording of two-dimensional echogram and M-mode echogram obtained with a suprasternal notch approach is shown in **Fig. 27.** A transducer was directed caudally with some rotational adjustment until 3 echo-free spaces corresponding to the aorta, right pulmonary artery and left atrium were visualized.

In order to establish the standardization, we obtained the echogram only in the plane showing the characteristic motion pattern in which the superior wall of the left atrium was separated from the inferior wall of the right pulmonary artery in the phase of atrial contraction (**Fig. 28**). The diameter of the right pulmonary artery was defined as the internal dimension between the superior and inferior walls at the peak of R

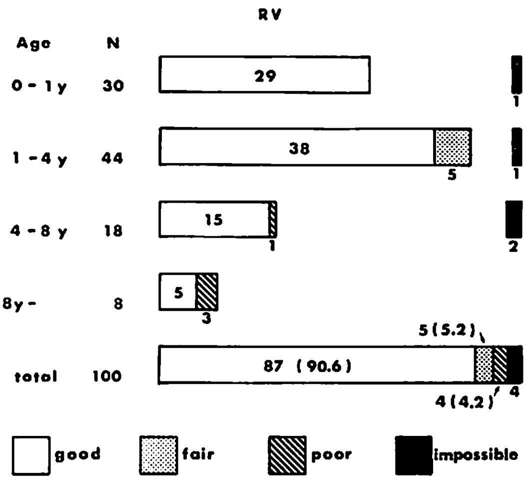


Fig. 22. Success rate of recording of the right ventricle.
Numbers in brackets express percentage.

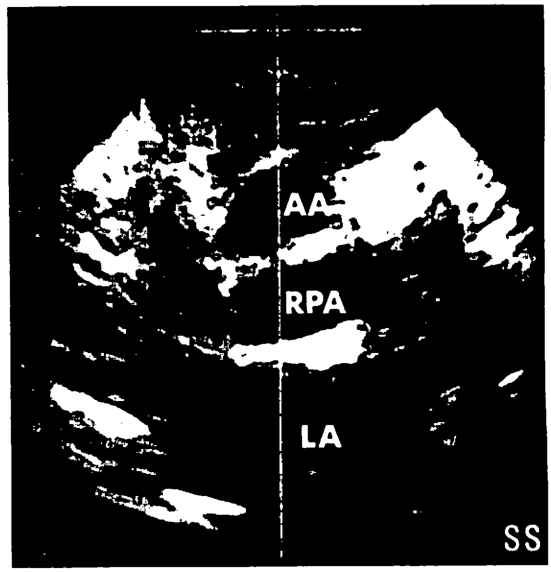


Fig. 24. Suprasternal notch short axis view of the aortic arch.
White line indicates the M-line.
AA=aortic arch; RPA=right pulmonary artery; LA=left atrium.

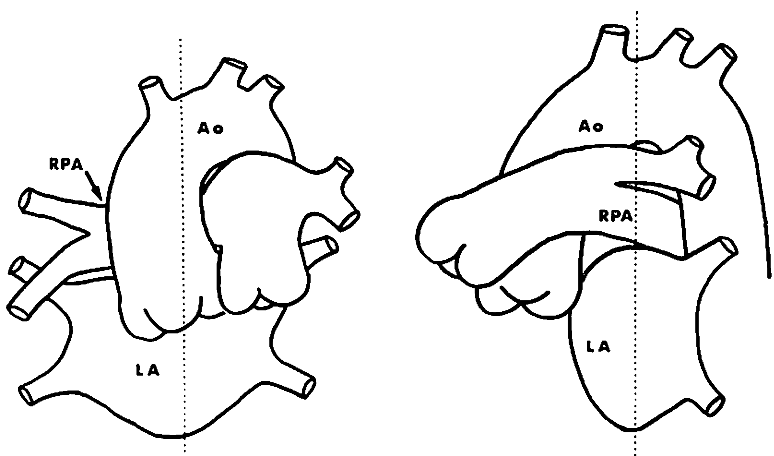


Fig. 23. Anatomical relationship of the right pulmonary artery, left atrium and aorta.
Dashed lines indicate the pathway of the ultrasonic beam.
Ao=aorta; RPA=right pulmonary artery; LA=left atrium.

Fig. 25. Suprasternal notch long axis view of the aortic arch.
White line indicates the M-line.
AA=aortic arch; RPA=right pulmonary artery; LA=left atrium.

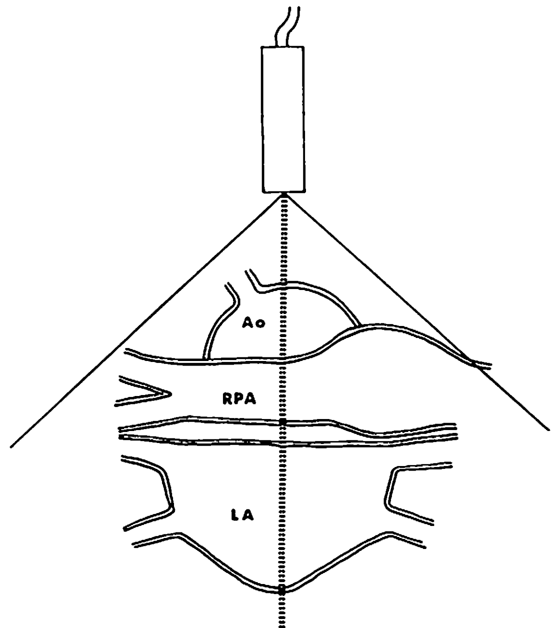


Fig. 26. Diagram of suprasternal notch short axis view of the aortic arch.
Dashed line indicates the pathway of the ultrasonic beam.
Ao=aorta; RPA=right pulmonary artery; LA=left atrium.

wave on the electrocardiogram.

In 28 patients, echocardiography and angiocardiography were performed and the diameter of the right pulmonary artery were determined by both methods. Using angiography, the diameter of the right pulmonary artery was measured from the frontal view of the pulmonary arterial cineangiogram as the vertical distance between the superior and inferior walls on the midline of supine. The right pulmonary arterial dimension was also measured from the echocardiogram. These 2 measurements were compared yielding an excellent correlation coefficient of 0.97 (**Fig. 29**). The echocardiographic dimension was somewhat smaller than the angiographic diameter.

The success rate of recording using this technique was also investigated (**Fig. 30**). In our experience, the suprasternal notch echocardiography is generally easy to perform and the fine M-mode echogram can be obtained in patients with any age.

Discussion

Kawai and his associates[4] first described the method for measuring the right atrial size with echocardiography. They defined the dimension of the right atrium as the distance between the tricuspid valve annulus and the posterior wall of the right atrium in the transducer plane in which the tricuspid valve, interatrial septum and posterior wall of the left atrium were recorded simultaneously. However, in this plane, the structure which they defined as the posterior wall of the right atrium is actually the posterior wall of the left atrium. Therefore, the distance which they measured as the right atrial dimension was in fact the sum of the length of a part of the right atrium and that of a part of the left atrium. Consequently the method described in the present study provides a better means for

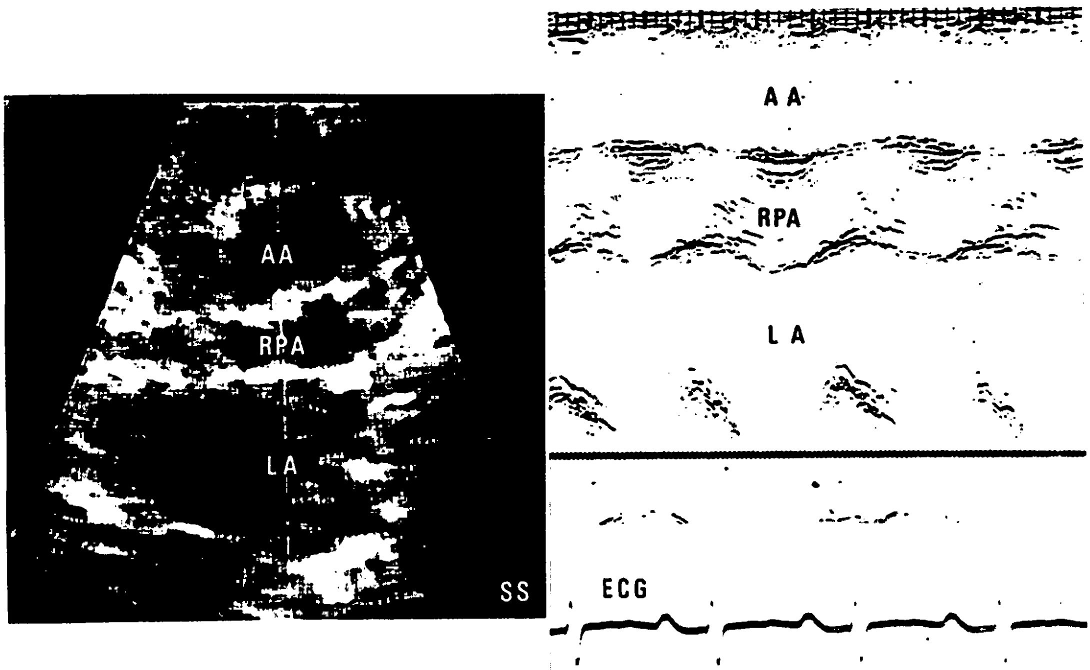


Fig. 27. Simultaneous recording of the suprasternal notch short axis view of the aortic arch and the corresponding M-mode echogram.
White line indicates the M-line.
AA=aortic arch; RPA=right pulmonary artery; LA=left atrium; ECG=electrocardiogram.

measuring the true right atrial chamber.

The two-dimensional echocardiography can also visualize the right atrium, and some workers[14,16] have measured the chamber size of the right atrium using this technique. But there are some limitations to its clinical use, because the images obtained were not clear enough for the quantitative study, the comparative study with the angiocardiographic data has not been performed, the standardization of the reference points was not definitively established and the examination was more complicated than that of M-mode echocardiography. However, further investigation may make it possible to obtain more useful measurements of the size of the right atrium by this method.

The right atrial dimension by the present method showed a close relationship with the right atrial volume. It has also revealed that it is a sensitive measurement for the evaluation of the hemodynamic alterations of the right heart[7,8]. In patients with atrial septal defect, the right atrial dimension correlated well with the pulmonary to systemic flow ratio and was demonstrated to be a noninvasive means for estimating the severity of this disorder[8]. The normal value for this dimension was expressed as an exponential function of the body surface area (BSA)[8];

$$\text{Right atrial dimension (in cm)} = 3.25\ (\text{BSA in m}^2)^{0.54}$$

This technique is generally easy to perform in infants and children, and the satisfactory echograms were obtained in 99 percent of them.

The subxiphoid echocardiography was first introduced by Chang et al.[17] as an alternative method for visualizing the left ventricle in the patients in whom echocardiographic informa-

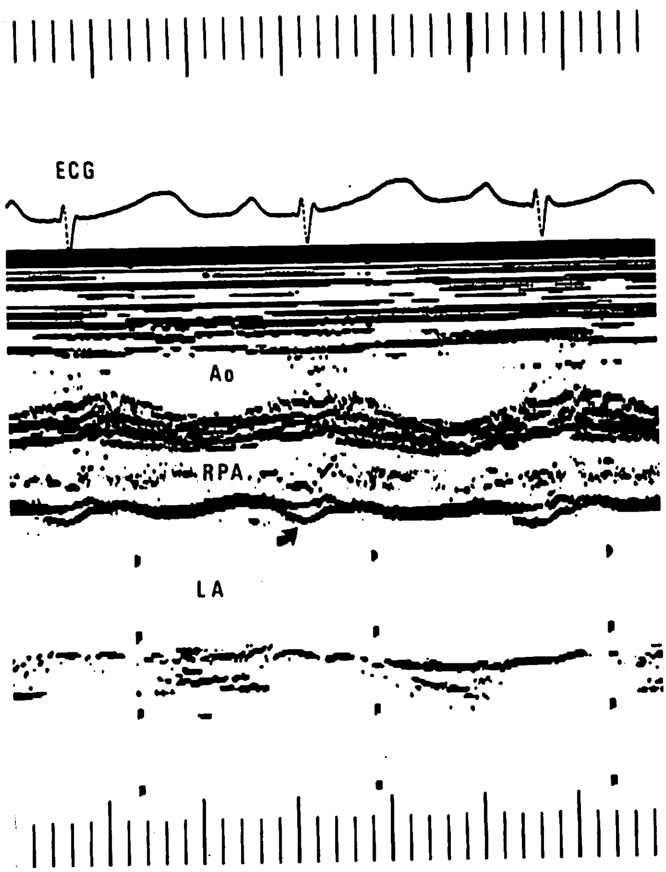


Fig. 28. Representative recording of the suprasternal notch M-mode echogram.
Arrow indicates the characteristic motion pattern.
Ao=aorta; RPA=right pulmonary artery; LA=left atrium.

tion was not obtainable because of lung disease or chest wall deformity. In this paper, we used this technique for visualizing and measuring the right ventricle.

Although right ventricular dimension has been measured using the convensional method with the transducer placed along the left sternal border[5,12], this dimension did not show a close relationship with the angiocardiographic results and was suggested to be unsatisfactory for the quantitative study[5,9]. This fact is generally explained by the pathway of the ultrasonic beam which traverses only a small portion of the right ventricle. On the contrary, the ultrasonic beam in our method traverses a large part of the right ventricle and the measured dimension demonstrated a close relationship with the right ventricular volume.

Two-dimensional echocardiography gives many informations on the size and the shape of the right ventricle. Some investigators have actually measured the size of the right ventricle with this technique[14]. But the measurement was not always satisfactory in the clinical application because the obtained images were not clear enough for the precise measurement and because the minimal angulation or tilting of the transducer might have affected the chamber size on the images. These problems may be solved in the future with the advance of the

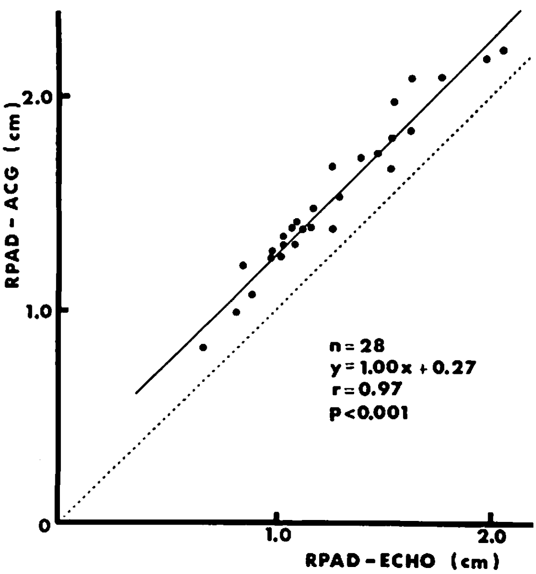


Fig. 29. Correlation between right pulmonary arterial dimensions determined by both echocardiography and angiocardiography.

RPAD-ECHO = right pulmonary arterial dimension determined by echocardiography.; RPAD-ACG = right pulmonary arterial dimension determined by angiocardiography.

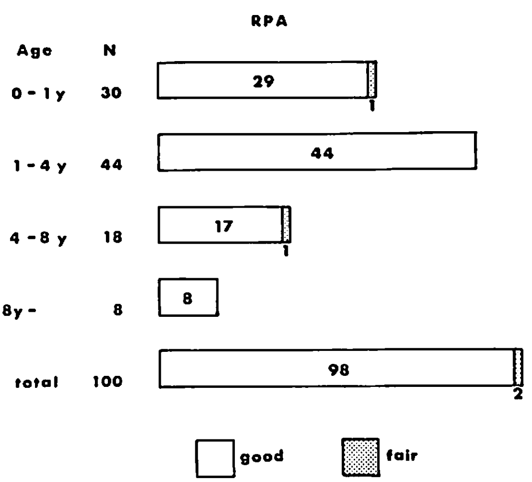


Fig. 30. Success rate of recording of the right pulmonary artery.

Numbers in brackets express precentage.

instrument and the establishment of the standardization.

The measurement of right ventricular dimension has proved to be simple and useful for the evaluation of the hemodynamic changes of the right ventricle[9~11]. The normal value for this dimension was expressed as an exponential function of BSA[10];

$$\text{Right ventricular dimension (in cm)} = 4.3\ (\text{BSA in m}^2)^{0.70}$$

The success rate of the recording was 96 percent in infants and children in our laboratory and this value was high enough for the routine examination.

The right pulmonary artery approach described by Goldberg[6,15] has been shown to be useful in the patients with congenital heart disease[18]. Although the aorta and left atrium can be studied from other acoustic window, the right pulmonary artery can be imaged only with this approach.

For the reference point of this approach, visualization of the characteristic motion pattern was required, in which the inferior wall of the right pulmonary artery was separated from the superior wall of the left atrium only in the late diastolic phase. This separation may be caused by the atrial contraction and the reduction in the diameter of the right pulmonary artery. To ensure the reproducibility of this technique, visualization of this motion is essential.

A comparative study with angiocardiographic data showed that the right pulmonary arterial dimension measured with echocardiography was roughly identical with that determined by cineangiography. The normal value for this dimension was also expressed as a function of BSA[19];

$$\text{Right pulmonary arterial dimension (in cm)} = 1.44\ (\text{BSA in m}^2)^{0.445}$$

The suprasternal notch approach is generally easy to perform and satisfactory echograms can be obtained in all patients.

In our experience, echocardiographic estimation of the right-sided cardiac chambers plays an important role in the management of the patients with heart disease. The technique is easy to perform in infants and children and the obtained results are reliable for the clinical use. We recommend that the quantitative evaluation of the right atrium, right ventricle and right pulmonary artery may be included in the routine echocardiographic examinations.

要　約

M モード心エコー図による右心系計測の方法と評価

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心エコー図を用いた右房，右室，右肺動脈の計測法について述べ，方法の信頼性を心断層エコー図および心血管造影により検討した．

右房は胸骨左縁より三尖弁前尖を捉えた後，トランスジューサーを内方に向け，三尖弁輪を検出する部位で記録した．右房径としては三尖弁輪と右房後壁間を計測した．

右室の記録には剣状突起下心エコー法を用いた．トランスジューサーは剣状突起下に置いた後，頭側に傾け，超音波ビームが右室前壁，三尖弁，大動脈弁を同時に検出する部位を選んだ．右室径としては右室前壁と大動脈前壁間を計測した．

右肺動脈は胸骨上窩心エコー法により記録した．ハンマー型トランスジューサーを胸骨上窩におき，超音波ビームを尾側およびやや後側に向け，大動脈，右肺動脈，左房に相当する3つのエコーフリー域が記録できるようにした．右肺動脈径としては，これに相当するエコーフリー域の拡張末期径を計測した．

これら3つの方法は，小児期心疾患の右心血行動態の変化を評価する上で，簡便かつ有用な方法であることが示され，日常の心エコー検査に加えられるべきものと思われた．

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