A New Method for Evaluating Right Ventricular Dimensions and Volume by Cineangiography

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Ishigaki, H., Shirato, K., Sakuma, M., Oikawa, Y., Katoh, A., Nakagawa, M., Hozawa, H., Komaki, K., Yamamoto, Y. and Takishima, T. A New Method for Evaluating Right Ventricular Dimensions and Volume by Cineangiography. Tohoku J. Exp. Med., 1996, 180 (4), 289-296 — The aim of the present study was to establish a new method to evaluate the right ventricular dimensions and volume. Biplane right ventriculography of steep left anterior oblique view (LAO) and right anterior oblique view perpendicular to LAO were performed in 32 patients. The right ventricular volume and ejection fraction calculated from the three axial dimensions of the right ventricular cavity (the septum-free wall dimension, the anterior-posterior dimension, and either the long axis dimension or the tricuspid valve-apex dimension at end-diastole and end-systole) were well correlated to those from Simpson’s method. In conclusion, we developed a new method for estimating right ventricular dimensions and volume. —— dimensions; ejection fraction; right ventricle; volume

Biplane right ventricular cineangiographies have been used to measure the right ventricular volume (Arcilla et al. 1971; Graham et al. 1973; Gentzler et al. 1974; Ferlinz et al. 1975; Fisher et al. 1975) but could not evaluate the mechanism of right ventricular blood ejection because the ventricular septum, tricuspid valve and right ventricular free wall overlap in 60 degree right anterior oblique and 30 degree left anterior oblique view projections or in anterior and lateral view projections. Moreover, single-plane biventricular angiography of steep left anterior oblique view projection has been used to assess the interventricular septal thickness and motion (Desilets et al. 1968; Redwood et al. 1974; Baltaxe et al. 1976; Banka et al. 1981) but has not been used to assess the right ventricular ejection function.

The aim of the present study was to develop new methods to evaluate the

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Address for reprints: Kunio Shirato, M.D., The First Department of Internal Medicine, Tohoku University School of Medicine, 1-1 Seiryomachi, Aoba-ku, Sendai 980-77, Japan.
right ventricular volume and dimensions and to investigate the relation between them. We also examined whether the right ventricular ejection fraction can be derived from % shortenings of diameters.

Methods

Patients

Thirty-two persons (25 male, 7 female) with and without cardiopulmonary diseases participated in this study. The mean age of the subjects was 52.2 years (ranged 17 to 67). They underwent diagnostic catheterization in our laboratory. Five subjects were chest pain syndrome but had normal hemodynamic parameters and no significant coronary artery stenosis. There were seven cases of valvular heart disease, three of pulmonary disease (chronic obstructive pulmonary disease 2, fibrosing lung disease 1), five of coronary artery disease with 75% or more interluminal stenosis of the coronary artery and twelve of myocardial disease (hypertrophic cardiomyopathy 7, dilated cardiomyopathy 4, secondary myocardial disease 1). All patients were in normal sinus rhythm.

Procedures

Routine left and right catheterization was performed using a standard technique. After left ventricular cineangiography and coronary angiography, biplane right ventricular cineangiography was performed with 35 mm cine film at a rate of 50 frames per second in steep left anterior oblique view (45 degree in 31 patients and 30 degree in one) and right anterior oblique view projection perpendicular to this projection. We chose the angle of left anterior oblique view in which the interventricular septum was seen best by biventriculography. Shallow spontaneous breathing was permitted during the right ventriculography to avoid the Valsalva maneuver, and a contrast medium of iopamidol (75.52%) was injected into the right ventricle through the catheter at a rate of 12 to 13 ml/sec for 3 sec.

Data analysis

Frames of over one cardiac cycle of the right ventriculogram from before the electrocardiographic P wave to behind the next P wave were analyzed. The right ventricular silhouette on each frame of the biplane right ventriculogram was projected and its outline was determined visually and traced by hand. The obtained outline of the right ventricular chamber was then digitized with a magnetic cursor (KD 4300; Graphtec Corp., Tokyo) that was connected to a personal computer (9801RX; NEC, Tokyo), and geometric data were stored on floppy disks. Right ventricular volume was calculated using Simpson's rule (Chapman et al. 1958). From this analysis, we drew a volume-time curve for the right ventricle over one cardiac cycle, and determined right ventricular end-diastolic volume at the maximal volume and right ventricular end-systolic volume at the minimal volume (Fig. 1).
Right ventricular cast studies in dogs. A regression analysis for estimation of right ventricular volume from the right ventriculographic silhouette was derived in the following manner: Silicone rubber casts of the right ventricular cavity in eight mongrel dogs were made and roentgenograms of the cast were then obtained in right anterior oblique and left anterior oblique view projections, in a manner similar to human right ventriculography, as in the present study. Chamber silhouettes were then draw to obtain the outline of each view, and the volume of each cast was calculated using Simpson’s rule. The true volume of all casts was determined by the water displacement method and expressed as the mean of three measurements in each cast. We obtained a regression equation deriving the true volume from the volume obtained by Simpson’s rule.

Right ventricular dimension studies in men. In human subjects, raw data of right ventricular volume obtained by Simpson’s rule were corrected by this regression equation. We determined four axes of the right ventricle as follows (Fig. 2).

1) In left anterior oblique view, septum-free wall dimension (SF) was defined as the distance between the right ventricular septum and the free wall, crossing perpendicularly to a line connecting the left ventricular side of the pulmonary artery valve and the right ventricular apex at the mid-point of this line.

2) In right anterior oblique view, the long axis dimension (LA) was defined as the distance from the mid-point between the anterior side of the pulmonary valve and the inferior side of the tricuspid valve to the right ventricular apex.

3) In right anterior view, the anterior-posterior dimension (AP) was determined as the distance from the anterior wall to the inferior wall crossing the mid-point of long axis diameter, parallel with the line between the anterior side

![Figure 1](image_url)

Fig. 1. Representative right ventricular volume-time curve from a patient with normal hemodynamics. RV volume, right ventricular volume; ED, end-diastole; ES, end-systole.
of the pulmonary valve and the inferior side of the tricuspid valve.

4) In right anterior oblique view, the tricuspid valve-apex dimension (TA) was determined as the distance between the mid-point of the tricuspid valve to the right ventricular apex.

In each dimension, we measured the end-diastolic dimension at end-diastolic volume and end-systolic dimension at the end-systolic volume. Moreover, based on the hypothesis that the right ventricular volume can be calculated by multiplying the three right ventricular dimensions by the specific coefficient, we selected SF, AP and LA (Method 1) or TA (Method 2) as the three axes, and compared the right ventricular volume with the multiplied three dimensions.

Based on the assumption that all % shortenings of a selected axial direction were equal and that the three axial vectors were independent of each other, the following equation was obtained;

\[ \text{predicted EF} = \left\{ 1 - \frac{\text{ESD}(1) \times \text{ESD}(2) \times \text{ESD}(3)}{\text{EDD}(1) \times \text{EDD}(2) \times \text{EDD}(3)} \right\} \times 100 = \]

\[ 100 - \left( \frac{100 - \% \text{shortening}(1)) \times (100 - \% \text{shortening}(2)) \times (100 - \% \text{shortening}(3))}{10000} \right), \]

where EF is ejection fraction, ESD is end-systolic dimension, EDD is end-diastolic dimension, and the added numbers show the axis number. In this study, we selected SF, AP and LA (Method 1) or TA (Method 2) as the three axes.

Statistics

Linear relationships were fitted with a standard least squares linear regression analysis.
RESULTS

Dog studies. The relation between the cast volume calculated using Simpson’s rule \(x\) and the true volume determined by the water displacement method \(y\) demonstrated a close linear correlation \(y = 0.87x - 4.8, r = 0.972, p < 0.01; \text{Fig. 3}\). There was a close correlation between the products of SF, AP and LA, and the true volume \(y = 0.57x + 2.0, r = 0.921, p < 0.01\). When TA was used instead of LA, the close relation was maintained \(y = 0.56x + 1.8, r = 0.935, p < 0.01\).

Human studies. The difference of the volume measurements in several subjects was less than 3\% in intra-observer and less than 6 \% between inter-observers.

As shown in Fig. 4, there were close correlations between the products of SF, AP and LA, and right ventricular volume at end-diastole \(y = 0.57x + 30.8, r = 0.902, p < 0.001\), end-systole \(y = 0.57x + 4.0, r = 0.908, p < 0.001\) and those combined with both phases \(y = 0.69x - 1.8, r = 0.955, p < 0.001\). When TA was used instead of the LA, these close relations were maintained at end-diastole \(y = 0.57x + 24.5, r = 0.904, p < 0.001\), end-systole \(y = 0.55x + 5.2, r = 0.911, p < 0.001\) and combined with both phases \(y = 0.66x - 1.2, r = 0.960, p < 0.001\).

Fig. 5 showed that there was a close correlation between the right ventricular ejection fractions predicted from \% shortenings of SF, AP and LA, and those calculated by right ventricular end-diastolic and end-systolic volumes \(y = 0.80x + 18.0, r = 0.888, p < 0.001\). When TA was used instead of LA, the close relation was maintained \(y = 0.83x + 14.4, r = 0.893, p < 0.001\).

DISCUSSION

In the present study, we showed that right ventricular volume can be calcu-
Fig. 4. Relationship between the product of the three axes dimensions and the right ventricular (RV) volume at end-diastole (open circles) and end-systole (close circles). A solid line shows the relation at both phases. Broken lines are regression lines at end-diastole and end-systole. As the three axes, we selected the septum-free wall dimension (SF), the anterior-posterior dimension (AP) and the long axis dimension (LA) in left panel (Method 1, A), or the tricuspid valve-apex dimension (TA) in right panel (Method 2, B). See text for details.

Fig. 5. Relationship between right ventricular (RV) ejection fractions (EF) derived from % shortenings of dimensions and calculated by right ventricular end-diastolic and end-systolic volumes. The solid line is the regression line and the broken line is identical. As the three axes, we selected the septum-free wall dimension (SF), the anterior-posterior dimension (AP) and the long axis dimension (LA) in the left panel (Method 1, A), or the tricuspid valve-apex dimension (TA) in the right panel (Method 2, B). See text for details.

lated by the products of the three dimensions, and that the right ventricular ejection fraction can be derived from % shortenings of the three axes.

Volume is a three-dimensional component and can be calculated by multiplying the three dimensional diameters by some kind of coefficient that is defined by geometry. For example, when the conventional orthogonal three diameters are used, the coefficient is 1/3 in a quadrangular pyramid, 1/2 in a triangular prism
and \( \pi/6 \) in an ellipsoid. Therefore, we hypothesized that the right ventricular volume can be calculated by multiplying the three right ventricular diameters by a geometrically specific coefficient. The present study indicated that there is a close correlation between the products of SF, AP and either LA (Method 1) or TA (Method 2), and the right ventricular volume. These indicated that the right ventricular volume can be calculated from the three axis diameters, and that our hypothesis is correct. Based on the assumption that all % shortenings of a selected axial direction are equal at any portion and that the three axial vectors are independent of each other, we predicted the right ventricular ejection fraction from % shortenings of each dimension and showed that the predicted one was related to the conventional one calculated by the right ventricular volume. There are many methods for assessing right ventricular volume by cineangiography (Arcilla et al. 1971; Graham et al. 1973; Gentzler et al. 1974; Ferlinz et al. 1975; Fisher et al. 1975). However, these methods cannot estimate ejection style and the degree of the contribution of shortenings of each diameter to right ventricular ejection. In the present study, we chose steep left anterior oblique view and right anterior oblique view perpendicular to left anterior oblique view to analyze the motion of right ventricular dimensions, and showed that the right ventricular dimension is related to the right ventricular volume and ejection fraction. Therefore, our methods may be utilized for the estimation of ejection style and degree of contribution of shortening of each dimension to right ventricular ejection (Ishigaki et al. 1989). Especially, Method 1 (the analysis method using SF, AP and LA) can be used for examining the relation between the right and left ventricular wall motion (Ishigaki et al. 1992), and Method 2 (the analysis method using SF, AP and TA) can be used for estimation of the right ventricular ejection style (Ishigaki et al. 1989) which was proposed by Rushmer (1976). A detailed analysis of the right ventricular time-volume curve made apparent the right ventricular filling pattern (Komaki et al. 1992; Takahashi et al. 1994) in various cardiopulmonary diseases. These methods may be also useful to estimate the right ventricular performance in cardiovascular diseases (Komaki et al. 1993). Further studies will be demonstrated that these methods may be useful to analyze the relation between the right and left ventricular wall motion and the right ventricular ejection style in clinical settings.

References

