Echocardiographic volumetry of the right ventricle

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Abstract

Aims The aim of our study was to define the optimal geometric model for two-dimensional volumetry of the right ventricle and its clinical validation.

Methods and results It has been shown in previous reports that an ellipsoidal shell model best reflects the complex right ventricular geometry. We investigated 82 patients without tricuspid regurgitation and intracardiac shunt. Measurements of right ventricular stroke volume were made in modified apical four chamber and parasternal short axis views both in end-diastole and end-systole. The following controls were used:

1. stroke volume of right ventricle estimated by thermodilution in 22 patients,
2. stroke volume of left ventricle calculated with Teichholz formula in 77 patients,
3. stroke volume of left ventricle estimated by Doppler volumetry in 41 patients.

The correlations between right ventricular stroke volume by echocardiography and thermodilution, left ventricular volumetry by Teichholz and Doppler were $r = 0.87, p < 0.001$; $r = 0.91, p < 0.001$; and $r = 0.83, p < 0.001$, respectively.

Conclusion The ellipsoidal shell model of the right ventricle is a good model for right ventricular volumetry.

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Introduction

Assessment of the right ventricular function remains a challenging clinical problem. This is largely due to the complex right ventricular shape which does not match a simple model for volume calculation. To circumvent this problem a semi-quantitative evaluation of right ventricular function without volume determination is often used. Among various geometric models used in previous clinical studies, the ellipsoidal shell model seemed to be the most suitable. It is quite simple and closely matches the right ventricular shape. The aim of our study was to define the echocardiographic projections, measurements

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and parameters of the ellipsoidal shell model and its clinical validation.

Methods

Study patients

From September 2002 to March 2003 we examined 86 patients (35 males and 51 females) aged 16–83 years. Exclusion criteria were intracardiac shunt disease and tricuspid regurgitation. Four patients (4.65%) were excluded because of poor image quality.

Echocardiographic and invasive evaluation

All examinations were performed with SONOS 5500 (Agilent Technologies, Inc., Andover, Massachusetts) using S3 probe and harmonic imaging. Right ventricular volumes were calculated using a formula derived from ellipsoidal shell model (difference-of-ellipsoids model): $V = \frac{2}{3}Pd$ (Fig. 1)

The plain of area $P$ was defined by two perpendicular axes of the ellipsoid, and distance $d$ was its third axis perpendicular to area $P$. (Fig. 2).

Area $P$ was measured in a modified four chamber projection using manual border tracing. Septomarginal trabeculae were included into the traced area. The optimal view for the measurement of the area $P$ was obtained by 15–30° clockwise rotation of the transducer from classical projection. The degree of rotation was individual in each patient according to the position of the heart. The criterion of the correct view was the largest size of the cross-sectional area of the right ventricle and good imaging of the apex in the same view (Figs. 3 and 4). Incomplete rotation, as well as tilting of the transducer downwards, leads to underestimation of the area.

The diameter $d$ was measured in the parasternal short axis view. From the mitral valve orifice the transducer was tilted upwards so that the aortic valve cusps were visualized. In this view the right ventricular outflow tract bends around the aorta, tricuspid valve being on one side and pulmonic valve on the opposite side of the aorta. Diameter $d$ is then measured as the longest transverse distance between the right ventricular lateral wall near the tricuspid annulus and the right ventricular outflow tract beneath the pulmonic valve (Figs. 5 and 6).

Both the cross-sectional area $P$ and the perpendicular diameter $d$ were measured in end-diastole and end-systole. Right ventricular stroke volume was obtained from the difference of end-diastolic and end-systolic volumes calculated using the above formula. Three measurements in stable rest condition were averaged for each calculation.

Because of lack of an accurate reference method for right ventricular volumetry the following controls were used:

1. stroke volume of the right ventricle estimated by thermodilution in a subgroup of 22 patients,
2. Stroke volume of the left ventricle calculated with Teichholz formula in a subgroup of 77 patients,
3. Stroke volume of the left ventricle estimated by Doppler volumetry in a subgroup of 41 patients.

Stroke volume measurement by thermodilution was performed in patients during routine heart catheterization. An average value of five measurements was used. The invasive studies were performed 5–14 h after the echocardiographic examination.

Figure 3 Modified apical four chamber projection in end-diastole.

Figure 4 Modified apical four chamber projection in end-systole.
Left ventricular stroke volume was estimated with the Teichholz formula using end-diastolic and end-systolic diameters measured in the parasternal long axis view. Patients with mitral or aortic regurgitation were excluded. Estimation of left ventricular stroke volume by Doppler was carried out using velocity time integral and left ventricular outflow diameter measured at the aortic valve hinge points: \( SV = \pi d^2 / 4VTI \). Patients with aortic valve disease were not included in this subgroup.

**Figure 5** Short axis view of right ventricle in end-diastole.

**Figure 6** Short axis view of right ventricle in end-systole.
Results

A good correlation was found between the echocardiographic right ventricular stroke volume and thermodilution ($r = 0.87$, $p < 0.001$) (Fig. 7), left ventricular stroke volume calculated with the Teichholz formula ($r = 0.91$, $p < 0.001$) (Fig. 8), and left ventricular stroke volume obtained by Doppler ($r = 0.83$, $p < 0.001$) (Fig. 9).

Discussion

Right ventricular long axis shortening fraction estimation, right ventricular apical four chamber view cross-sectional area change measurements, right ventricular short axis cross-sectional area change measurement are semiquantitative methods for rough estimation of right ventricular ejection fraction.\(^1\),\(^2\) More recently tissue Doppler imaging is used for evaluation of tricuspid annulus systolic velocity which reflects right ventricular function.\(^3\)

However, none of these methods allows a quantitative assessment of right ventricular volumes, tricuspid regurgitation, shunt calculation and follow up of minor changes in right ventricular function. The major problem is the complex shape of the right ventricle.

To date several methods were tested for right ventricular volume calculation. Simpson method slices the right ventricle into a series of cross-sections perpendicular to its long axis.\(^4\),\(^5\) Total volume is the sum of individual segments calculated using a formula for a portion of ellipsoid. The area length method is based on the formula for an ellipsoid volume, whereas the pyramid method on the formula for a pyramid.\(^4\) Nevertheless none of the above models corresponds to the exact shape of right ventricle. The subtraction method represents a much better definition of the right ventricular shape and volume. The volume of the right ventricle is the difference of two hemiellipsoids. The

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**Figure 7** Correlation between right ventricular stroke volume assessed by echocardiography and thermodilution.
larger hemiellipsoid represents the volume of both ventricles whereas the smaller one the volume of the left ventricle including interventricular septum. A similar method using this principle also called ellipsoidal shell model has been described by Denslow and Wiles. The seemingly complicated right ventricular geometry is then expressed with a simple formula $V = \frac{2}{3}pd$ (see Methods). This formula was verified by other authors. We have chosen this formula for our study because of its simplicity and its close mathematical definition of the real shape of the right ventricle. A prerequisite to successful application of this method is using high quality of echocardiographic imaging and exact projections. Ultrasound system without harmonic imaging cannot clearly delineate the endocardium and results are therefore inaccurate.

Exact adjustment of echocardiographic projections requires experience, so that the results of the first 26 patients were not considered reliable and were not included in this study. Incomplete clockwise rotation in apical four chamber projection and inaccuracy of right ventricular outflow tract imaging may cause false results or complete failure of the method. Right ventricular outflow tract imaging in short axis projection (a standard view in pediatric practice) is easily performed in children. In adults, however, it may be limited by suboptimal quality of imaging.

There is no obligatory gold standard for right ventricular volumetry so that various methods are used as reference, each of them having different degree of reliability.

Direct volume determination of the right ventricular cavity or casting processing from autopsy material depends on both quality of preservation and cast processing and echocardiographic projections in vivo and in vitro are hardly comparable.

Angiographic evaluation is based on the geometric calculations same as echocardiography and is not very accurate as well.
Radionuclide methods are time consuming, quite expensive and require great skill in processing.\(^6,10\) Incomplete separation of right ventricle from surrounding structures (especially right atrium) yields incorrect results.\(^11\)

Thermodilution assessment of right ventricular stroke volume (as a standard) as we used in our study, has not been mentioned in literature yet. Thermodilution is considered reliable in patients without significant tricuspid regurgitation. Good correlation with echocardiographic stroke volumes of right ventricles with various values of ejection fraction is indirect proof of correct estimation of diastolic and systolic volumes. There are similar relations with left ventricular echocardiographic volumetry too.

Magnetic resonance is a new method that is considered the gold standard for right ventricular volumetry.\(^12,16\) However, it is time consuming and expensive and therefore not routinely used in cardiology. Also, differences in estimated right ventricular volumes are described according to the technique of data processing.\(^17–19\)

Three-dimensional echocardiographic assessment is based on off-line processing of the data using a non-geometric approach.\(^12,20–22\) Clinical experience is still limited\(^12,14,20–26\) and right ventricular volumes are underestimated\(^25,26\) or overestimated\(^22\) as compared to magnetic resonance assessment.

Most probably the quantification of right ventricular morphological and functional parameters will always be more complicated than those of the left ventricle even when three-dimensional echocardiography will be routinely used in the future. At present, for echocardiographers skilled in two-dimensional echocardiographic volumetry, the ellipsoidal shell model method appears easy to use and as for accuracy, it is comparable to three-dimensional echocardiography\(^23,24\) bearing in mind its contemporary possibilities.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure9.png}
\caption{Correlation between right ventricular stroke volume assessed by echocardiography and left ventricular stroke volume assessed by Doppler volumetry.}
\end{figure}
Limitations

In about 5% of patients the method is not applicable because of the poor quality of echocardiographic images.

Thermodilution as a standard method for stroke volume determination was used in a minority of patients only because of its invasive nature. Since thermodilution and echocardiographic investigation was not carried out simultaneously some variability of results may appear.

The variability of right ventricular outflow tract in individual patients is not accounted for in the formula used. We considered that this imperfection is partially compensated for by inclusion of septomarginal trabeculae into the right ventricular cavity. In this respect three-dimensional echocardiography should be more precise as it enables to catch more exactly the complexity of right ventricular morphology.

Conclusion

Two-dimensional echocardiography using ellipsoidal shell model for right ventricular volumetry provides results applicable in clinical practice. The tested method appears to provide good basis for the assessment of right ventricular systolic function, tricuspid regurgitation and interatrial shunt defects.

References
