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Original Article

Transesophageal 3-dimensional versus cross-sectional echocardiographic assessment of the volume of the right ventricle in children with atrial septal defects

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Abstract The study was designed to investigate the value of assessing right ventricular volume by transoesophageal 3-dimensional echocardiographic techniques compared with the standard transoesophageal cross-sectional approach. Echocardiography was performed using a multiplane probe. The 3-dimensional data sets were reconstructed after electrocardiographic and respiratory gated scanning, calculating the 3-dimensional volumes by the method of multiple slices. Cross-sectional determination of volume was performed using a modified area-length method, and the biplane multiple slice method following Simpson's rule. We studied 15 patients, with ages ranging from 6 to19 years, and body surface areas from 1.1 to 1.67 square metres. It proved possible top determine volumes with both methods in all patients. As determined by 3-dimensional echo, volumes were greater, being 113.0 plus or minus 61.2 millilitres at end-systole, and 61.7 plus or minus 36 millilitres at end-diastole, than those calculated from cross-sectional images using Simpson's rule, which gave values of 92.5 plus or minus 52 millilitres, and 41.3 plus or minus 22 millilitres. Compared to the values obtained using the area-length method, at 116.9 plus or minus 61 millilitres, and 60.3 plus or minus 30 millilitres, there were only small differences at end-systole, with a bias of 1.4, and limits of agreement of 20.9 millilitres, as well as at end-diastole, when bias was minus 3.8, and limits of agreement 22.3 millilitres. Correlation was also good, with coefficients of 0.93, and 0.91, respectively. The mean difference between the volumes by 3-dimensional acquisition and the multiple slice method was larger, with higher limits of agreement, at end-diastole showing bias of 20.5, and limits of agreement of 30.1 millilitres, and for end-systole bias of 20.4, and limits of agreement of 32.2 millilitres. Our data confirm that cross-sectional echocardiographic assessment of right ventricular volumes in children with atrial septal defects is quick, and reasonably reliable in clinical practice when employing the area-length method.

Keywords: Deficient atrial septation; congenital heart disease; non-invasive investigation

The volume of the right ventricle may serve as an estimate of the haemodynamic relevance of atrial septal defects. Determination of such volume by cross-sectional transthoracic echocardiographic techniques, however, is hampered currently by several problems. The right ventricle has an irregular shape, which is difficult to describe on the basis of simple geometrical assumptions.[1] It can also be difficult to image the ventricle from a transthoracic approach, except in small children.[2] Volume overload may further aggregate the problems, since it imposes further changes in right ventricular shape.

Transoesophageal 3-dimensional echocardiography allows determination of the volume of cardiac chambers irrespective of their shape.[3] In addition, transoesophageal scanning, and determination of right ventricular volumes, is possible in patients of all ages.

In the present study, we investigated whether such assessment by transoesophageal 3-dimensional echocardiography is possible in a group of children

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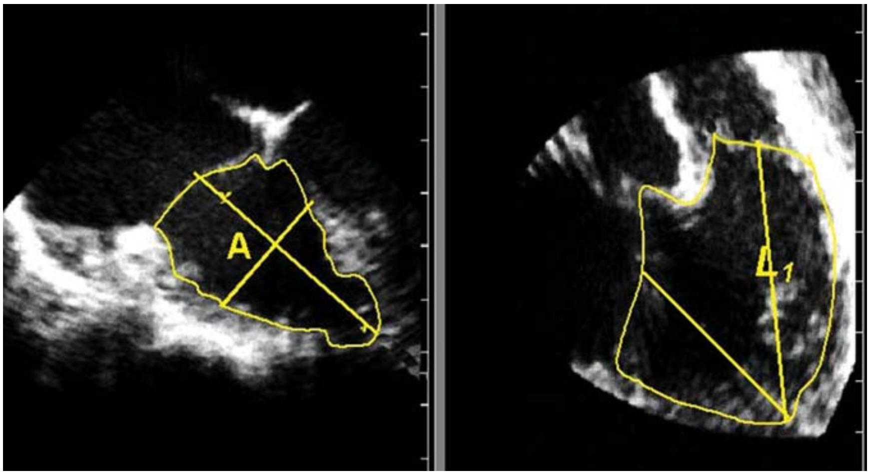

Figure 1.
Four chamber view (left), and the long axis between the pulmonary valve and the right ventricular apex (right).

with volume loading because of deficient atrial septation. We also compared the 3-dimensional measurements with those obtained by conventional transoesophageal cross-sectional echocardiography using two different models.

Methods

Imaging. Transoesophageal echocardiography was performed in all patients prior to interventional closure of atrial septal defects. All patients underwent deep sedation using droperidol, promethazine, and phenobarbital. Echocardiographic sequences were acquired with a commercial available ultrasonic scanner (Sequoia 264, Acuson Inc.) using a multiplane probe (Acuson TE V5M) with a transducer frequency of 6 megahertz.

Electrocardiographic and respiratory gated scanning was employed to acquire images of the entire right ventricle in three dimensions. The 3-dimensional data sets were reconstructed from the video-signal of the ultrasound machine using a Tomtec 3.1 computer system.

Measurement of volume

3-dimensional echocardiography. A complete determination of volume was performed in end-diastole and end-systole in each patient. End-diastolic and end-systolic images were defined with respect to closure of the tricuspid or pulmonary valves, respectively. The endocardial surface was traced manually in multiple short-axis views at intervals of 2 millimetres, excluding the papillary muscles. The short axis was considered to be perpendicular to the long axis, which extended between the ventricular apex and the middle of the pulmonary valve. The right ventricular volumes were calculated by summation of the volumes of the single slices[4] using the equation volume is equal to the thickness of the slices multiplied by the number of slices, a constant Σ, and the traced area.

Cross-sectional echocardiography. Volumes were calculated using images from the same echocardiographic study as for the 3-dimensional assessment. We used two different methods. The modified area-length method is based on use of two different planes.[5,6] The length of the right ventricular area was traced as the long axis between the pulmonary valve and the apex. The area was defined in a four chamber view (Fig. 1). Volumes were calculated using the formula of twice the product of the traced area and the length from the apex to the pulmonary valve divided by three.

The second method was the biplane multiple slice method based on Simpson's rule. The long axis of the ventricle was defined as described above. The area was traced in the lateral and the perpendicular coronal planes. Right ventricular volumes[4] were then calculated as being equal to:

$$\frac{\pi h}{3}\left(\sum^{u} D_R \bullet D_L + \sum^{g} \frac{1}{2} D_R \bullet D_L\right)$$

where h is the thickness of the slices, n is the number of slices, D_R is the frontal diameter, and D_L is the lateral diameter.

Statistical analysis

Data obtained by 3-dimensional and cross-sectional echocardiographic methods are reported as mean values and standard deviations. Differences between data were assessed using the limits of agreement according to Bland and Altmann.[7] In addition, linear regression analysis was performed according to the method of the smallest squares.[8]

Patients studied

We studied 15 patients, 9 female and 6 male, during interventional closure of atrial septal defects. Their age

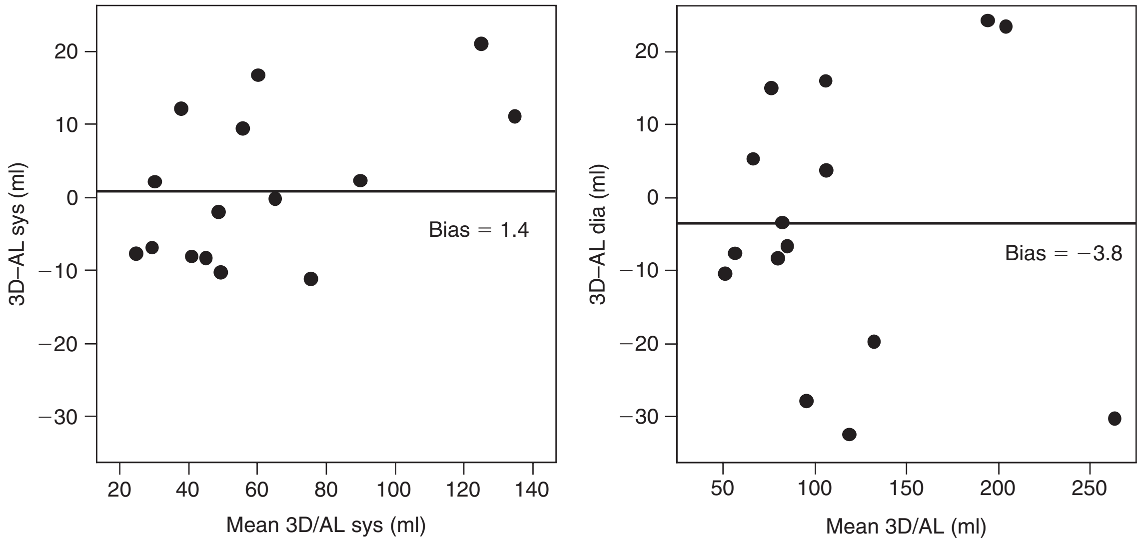

Figure 2.
Differences between measurements using the area-length method (AL) and 3-dimensional echocardiography (3D) in systole (sys) and end-diastole (dia).

ranged from 6 to 19 years, with a median of 10.3 years, and weight from 21 to 89.5 kilograms, with a median of 23.8 kilograms, corresponding to body surface area ranging from 1.1 to 1.67 square metres, with a median of 1.34 square metres.

Results

Using the transoesophageal approach, we were able to acquire a complete set of images of the right ventricle in all patients, thus allowing assessment of volumes using both the 3-dimensional reconstruction as well as conventional cross-sectional echocardiographic methods. The time needed for conventional determination using cross-sectional techniques was about 5 minutes for each method, but when using 3-dimensional reconstruction, it was from 20 to 30 minutes.

End-diastolic and end-systolic volumes determined by the 3-dimensional technique, at 113.0 plus or minus 61.2 millilitres, and 61.7 plus or minus 36 millilitres, respectively, were greater than those calculated from the cross-sectional images using Simpson's rule, at 92.5 plus or minus 52 millilitres, and 41.3 plus or minus 22 millilitres, respectively. Only small differences were found, however, relative to the volumes calculated using the area-length method, at 116.9 plus or minus 61 millilitres, and 60.3 plus or minus 30 millilitres, respectively. Measurements were then repeated by a second observer. Intra-observer variability was 5 plus or minus 3% for systolic, and 3 plus or minus 2% for diastolic measurements.

Comparison of the methods

The mean difference between volumes determined by 3-dimensional and cross-sectional techniques using the area-length method was particularly small at end-systole, with a bias of 1.4, and limits of agreement of plus or minus 20.9 millilitres, and somewhat greater at end-diastole, with bias of minus 3.8, and limits of agreement of 22.3 millilitres (Fig. 2). There was a good correlation between the measurements obtained using the 3-dimensional and cross-sectional techniques, with correlation coefficients of 0.93 at end-systole, and 0.91 at end-diastole (Fig. 3). The mean difference between volumes obtained using the 3-dimensional technique was larger when compared to those calculated using the multiple slice method, and there were higher limits of agreement, with bias of 20.5 at end-diastole, and limits of agreement of 30.1 millilitres, and bias of 20.4 at end-systole, with limits of agreement of 32.3 millilitres (Fig. 4). There was good correlation between the two methods (Fig. 5).

Discussion

Assessment of volumes using cross-sectional echocardiography is usually based on geometrical assumptions. Because the right ventricle has a very complex shape that resembles a distorted pyramid,[1] such assessment has often been inaccurate in older children, and required time-consuming calculations. 3-dimensional techniques, however, which are independent of ventricular geometry, may improve the accuracy of volume calculations. Few reports have dealt thus far with measurement of right ventricular volumes using the 3-dimensional technique.[2,9,10] Earlier work in our institution showed that, for anatomical reasons, 3-dimensional reconstruction of the right ventricular from transthoracic views is limited. It is often difficult, or even impossible, especially in older patients,

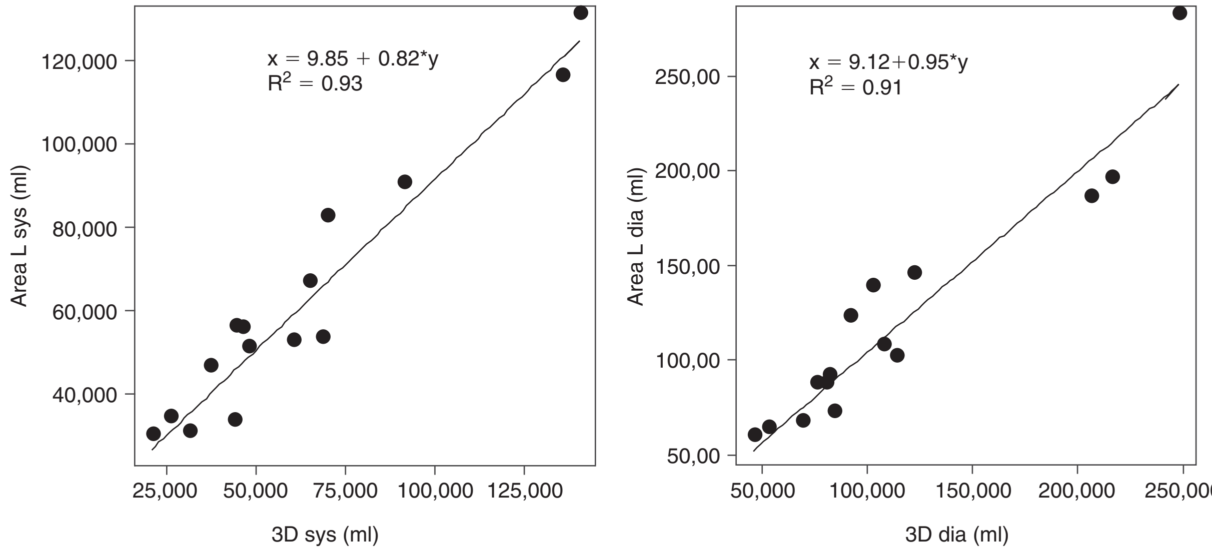

Figure 3.
Regression analysis of measurements using the area-length method (AL) versus 3-dimensional echocardiography (3D) in systole (sys) and end-diastole (dia).

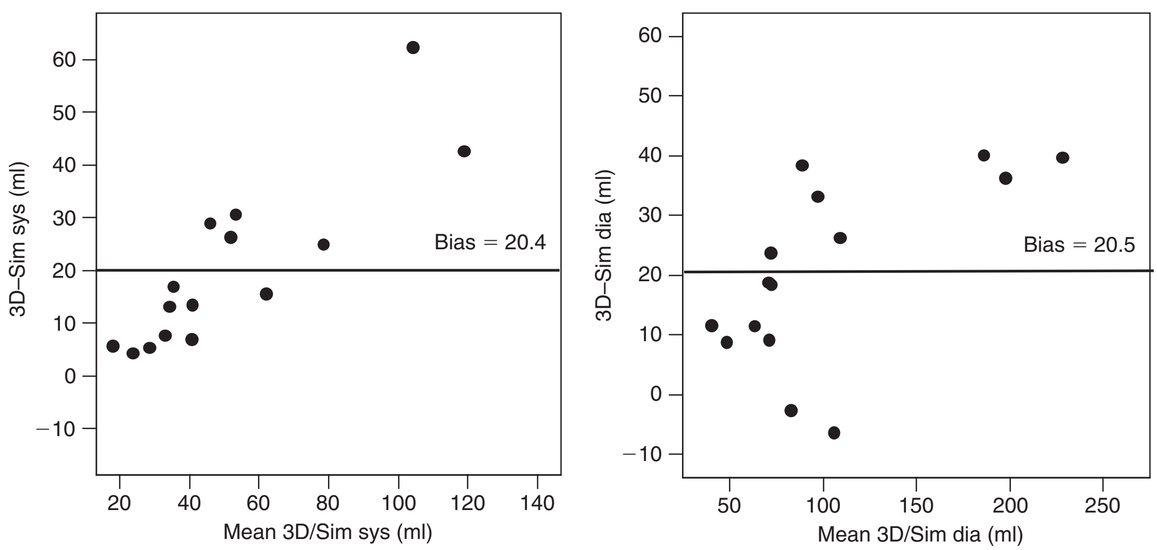

Figure 4.
Differences between measurements using the multiple slice method (Sim) and 3-dimensional echocardiography (3D) in systole (sys) and end-diastole (dia).

to acquire a complete set of images of the chamber during the rotation of the transducer through 180 degrees.[2] Roelandt et al.[11] had previously demonstrated the feasibility of using a transoesophageal approach for 3-dimensional reconstruction of the left ventricle in adult patients using a multiplane transducer. In the present study, therefore, we used this method for imaging the right ventricle, demonstrating the feasibility of assessing right ventricular volume in a group of older children weighing more than 20 kilograms with atrial septal defects and volume-loaded right ventricles. Three-dimensional reconstruction of the entire chamber was possible in all patients.

Several experimental and clinical studies have shown an excellent correlation between such 3-dimensional echocardiographic measurements of the right ventricle and other methods, such as magnet resonance imaging.[9,10,12–14] Based on these studies, we suggest that determinations of volume using 3-dimensional echocardiography are likely to be

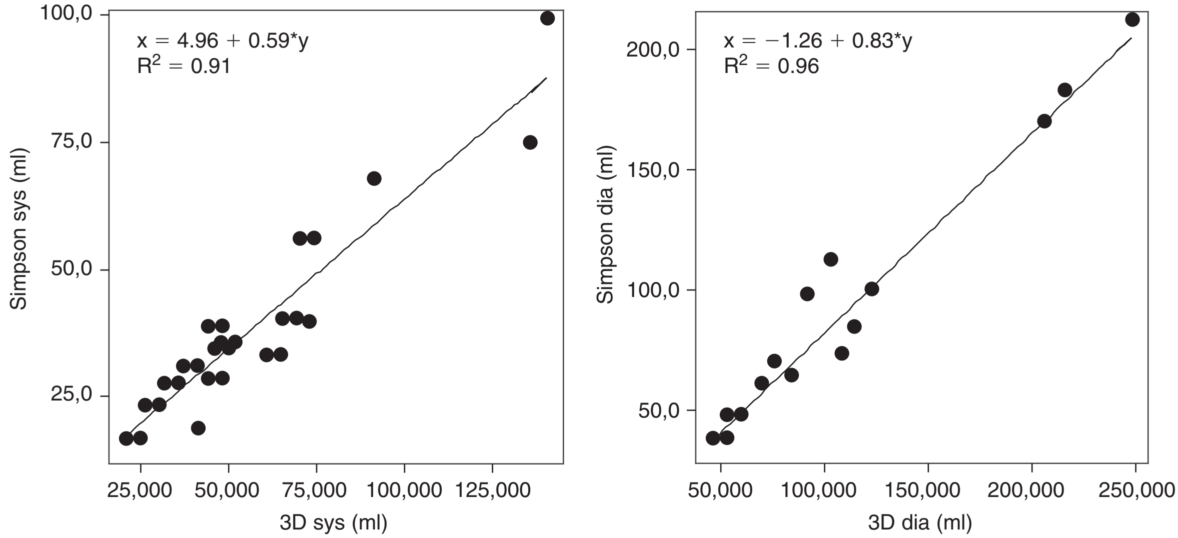

Figure 5.
Regression analysis of measurements using the multiple slice method (Sim) versus 3-dimensional echocardiography (3D) in systole (sys) and end-diastole (dia).

accurate estimates of the true ventricular volumes. This method, however, is very time consuming, and requires a high degree of expertise on part of the investigator. Moreover, special equipment is needed for creating 3-dimensional datasets, and for the calculations of volume. Cross-sectional techniques, therefore, may still have a place in clinical practice, provided the calculations of volume provide results comparable with the true measurements of volume.

Levine et al.[6] described a simple modification of the method based on area and length using two different planes for determination of these values, with good correlations in clinical studies. We used this method from the transoesophageal approach, choosing an image that is similar to the transthoracic subcostal cut of the outflow tract as described by Levine et al.[6] Data obtained by this method correlated well with the results of the 3-dimensional calculations, with very little bias. Previous studies had also demonstrated a good agreement such measurements and those obtained by magnetic resonance imaging, the latter considered the clinical "gold-standard".[15,16] The variability between observers, however, was not as good as found in the studies using resonance imaging. A reasonable correlation had been shown, nonetheless, between different variations of the method based on area and length used transthoracically and angiography.[17,18] Silverman and Hudson[19] also confirmed good results in a group of children with congenital cardiac malformations using a more complicated algorithm.

The accuracy of the method using multiple slices and Simpson's rule was proven by several studies for the left ventricle.[20,21] In our patients, however, volumes were underestimated compared to the results obtained using the 3-dimensional technique. Niederle et al.[22] had shown similar results in comparison to angiographic values. But, while the correlation in the study by Niederle et al.[22] was very poor, correlation between the 3-dimensional and cross-sectional determinations in our study was similar to that obtained for the calculations based on area and length. In our practical experience, assessment of right ventricular volumes using cross-sectional echocardiography may be quick and reasonably reliable when employing the method based on area and length.

Transoesophageal echocardiography is a prerequisite for interventional closure of an atrial septal defect. Acquisition of measurements to calculate volume, therefore, does not require additional sedation in this setting, nor does it prolong the time required for examination. In such patients, right ventricular volume can be determined using the method developed by Levine et al.,[6] which we have now shown to correlate well with 3-dimensional measurements. We concede that our study is limited in that we do not know the true right ventricular volume of our patients. We did not use the "gold standard" of magnetic resonance imaging because of the lack of clinical necessity.

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