Original Article

Volume Measurement of Small Ventricular Model by Real-time Three-dimensional Echocardiography

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Key words :
3D echocardiography, phantom model, volume measurement, fetus, cardiac function

Purpose: Accurate volume measurement of the ventricle by real-time three-dimensional (3D) echocardiography marks a new step in fetal and pediatric cardiovascular diagnosis and treatment. We studied the volume measurement of a ventricular model using real-time 3D echocardiography.
Methods: The ultrasonic diagnostic equipment used in this study was the SONOS 7500 with an electronic sector probe x4 Matrix phased-array transducer. The ventricular model was made from a latex surgical glove; the tip of the 5th finger of the glove was cut off, and then fixed to a manifold. Physiological saline solution, in volumes ranging from 0.5 ml to 10 ml in 0.5 ml increments, was injected into the ventricular model and examined. Twenty ultrasound images of the ventricular model were obtained.
Results: Simple regression analysis showed good correlation between the injected volume values and the calculated volume values (Y = 0.083 + 1.02X, r = 0.989).
Conclusions: Our study demonstrated that real-time 3D echocardiography is highly accurate for volume measurement of a small ventricular model with spherical shape under static conditions.

Introduction

Volume measurement of the ventricle is mandatory for evaluating cardiac function. Echocardiography is a low-cost, noninvasive, portable, easily repeatable modality for evaluating cardiac function. Conventional two-dimensional echocardiographic measurement of ventricular volume is limited by assumptions of ventricular geometry and image positioning.[1] More accurate ventricular volume measurement by real-time three-dimensional (3D) echocardiography marks a new step in fetal and pediatric cardiovascular diagnosis and treatment.[2] We investigated whether real-time 3D echocardiography provides accurate volume measurement of a small ventricular model.

Materials and Methods

1. Ultrasonic diagnostic equipment

The ultrasonic diagnostic equipment used in this study was the SONOS 7500 (Philips Medical Systems Corporation, Washington, USA). The electronic sector probe of an x4 Matrix phased-array transducer (2 MHz) with real-time 3D (full volume) was used.

2. Ventricular model

The ventricular model was made from a latex surgical glove (Ansell Healthcare, Malaysia). The tip of the 5th finger of the glove was cut off, and then fixed to a manifold with 3–0 silk thread. A 10 ml syringe (Terumo syringe, ss-10Sz, Terumo Corporation, Tokyo, Japan) was connected to the other side of the manifold.

3. Techniques

The ventricular model was gently set in a reservoir filled with water at 37 degrees centigrade. Volumes of physiological saline solution ranging from 0.5 ml to 10 ml in 0.5 ml increments were injected into the ventricular model and examined in random order. The manifold side of the ventricular model was assumed to be the left ventricular base, and the opposite

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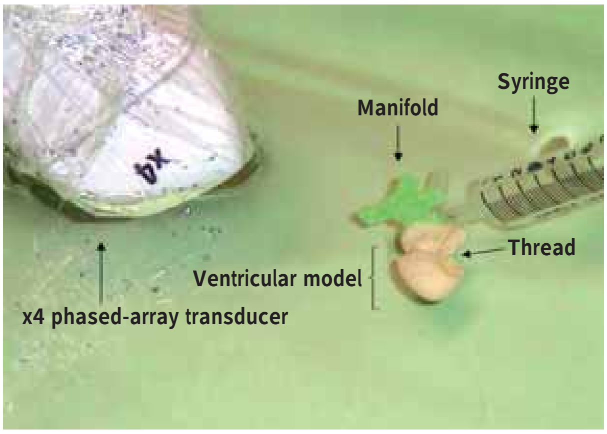

Fig. 1 Ventricular model made from a latex surgical glove. The tip of the 5th finger of the glove was cut off, and then fixed to a manifold with 3–0 silk thread. A 10 ml syringe was connected to the other side of the manifold. The manifold side of the ventricular model was assumed to be the left ventricular base, and the opposite side the apex. The ventricular model was gently set in a reservoir filled with water at 37 degrees centigrade. Volumes of physiological saline solution ranging from 0.5 ml to 10 ml in 0.5 ml increments were injected into the ventricular model and examined in random order. Each ultrasound image of the ventricular model was obtained by real-time 3D echocardiography.

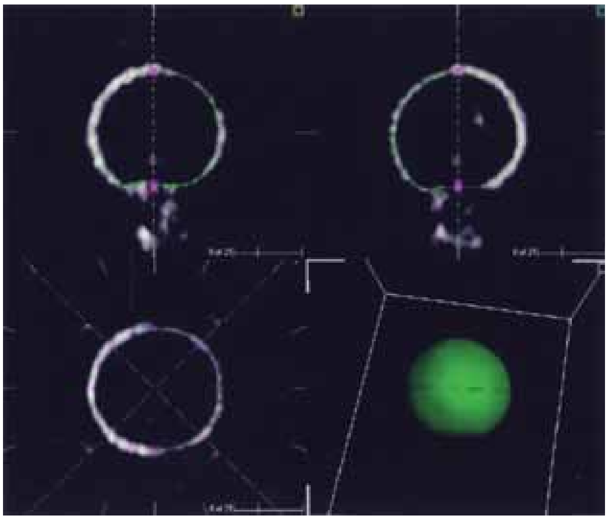

Fig. 2 Ultrasound images of the ventricular model were calculated using 4D Cardio View RT 1.2 software. The two upper images are long-axis images, and left lower image is a short-axis image. The right lower image is a restructured image. Volumes of the ventricular model were calculated by manual tracing around its interior surface on two long-axis images.

side the apex. Each ultrasound image of the ventricular model was obtained by real-time 3D echocardiography (Fig. 1).

4. Calculations

Twenty ultrasound images of the ventricular model were calculated using 4D Cardio View RT 1.2 software (TomTec Imaging Systems GmbH, Germany). This software has Average rotation method; it can set up of center shaft of ventricular model and trace the long axis plane, then it can calcuclate from the upper to the lower plane areas by integral calculus.[3] The accuracy of this method is reported to be greater than that of Simpson's method with 2D echocardiography.[3] This software was equipped to calculate ventricular volumes using 4, 8, and 16 cut planes. Volumes of the ventricular model were calculated by manual tracing around its interior surface on 4 and 8 cut planes (Fig. 2).

5. Inter- and intraobserver variability

To test the variability in ventricular volume value calculations using 3D echocardiography, the first observer and second observer, both of whom were unaware of previous results, repeated 10 randomly selected 3D echocardiographic calculations. Variability was expressed as the difference in the mean of the two results, as a percentage of the mean.

6. Statistical analysis

The injected and calculated volume values were compared. Data were analyzed by simple linear regression test and the Bland-Altman method for the comparison of two volume groups.[4] Moreover, differences between the injected and calculated volume values using 4 cut planes and 8 cut planes were compared. Data were analyzed by the Mann-Whitney U-test to compare two groups. A p-value less than 0.05 was considered significant.

Results

There was an excellent correlation between the injected and calculated volume values, as shown in Fig. 3 ($Y = 0.083 + 1.02X$, $r = 0.989$; 4 cut planes) and Fig. 4 ($Y = 0.087 + 1.029X$, $r = 0.989$; 8 cut planes). There was little difference between the injected and calculated volume values according to the Bland-Altman method. The mean differences between the two volume values were only 0.19 ml (4 cut planes) and only 0.27 ml (8 cut planes). The standard deviations of the differences between the two volume values were 0.45 (4 cut planes) and 0.47 (8 cut planes).

There was no significant difference between values obtained using 4 or 8 cut planes for calculation, as shown in Fig. 5 ($p = 0.67$).

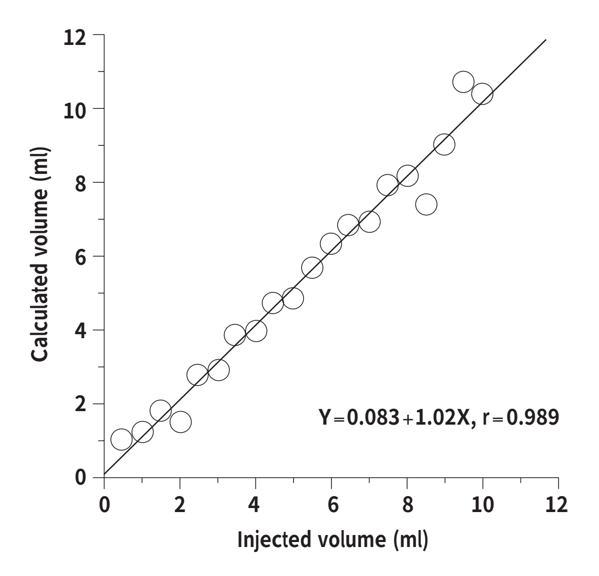

Fig. 3 Scatter plot showing the correlation between the injected volume values (ml) and the calculated volume values (ml) using 4 cut planes; Y=0.083+1.02X, r=0.989.

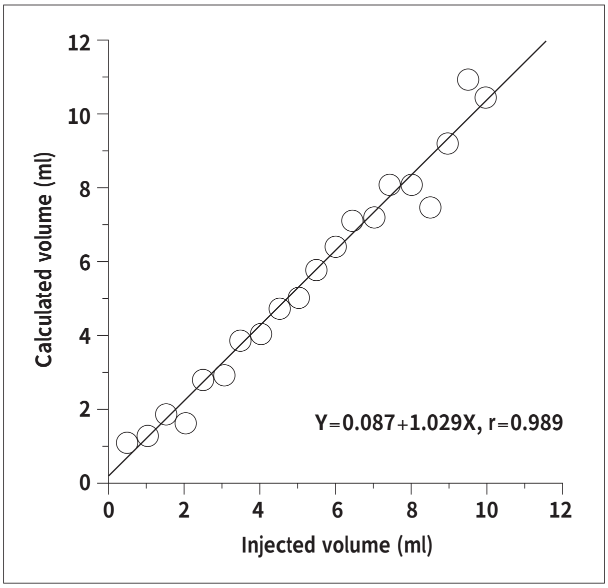

Fig. 4 Scatter plot showing the correlation between the injected volume values (ml) and the calculated volume values (ml) using 8 cut planes; Y=0.087+1.029X, r=0.989.

Rates of interobserver variability in the 3D echocardiographic estimation of ventricular volume value were 7% (4 cut planes) and 6% (8 cut planes). However, the rates for intraobserver variability were 6% (4 cut planes) and 4% (8 cut planes).

Discussion

Our study demonstrated that real-time 3D echocardiography is highly accurate for volume measurement of a small ventricular model under static conditions. Real-time 3D echocardiography provides accurate volume measurement of small ventricles; simple linear regression analysis showed excellent correlation between the injected and calculated volume values, and the Bland-Altman method indicated that there was no bias between the two volume values.

In our study, a small ventricular model was created to investigate whether real-time 3D echocardiography can provide accurate measurement of cardiac cavities in fetuses. Previous studies demonstrated that real-time 3D echocardiography was accurate for volume measurement of the left ventricle in humans, dogs, and phantom models of adults.[3, 5–8] Teupe et al. demonstrated that 3D echocardiography provided accurate volume measurement, but they did not carry out studies using a ventricular model.[5] Esh-Broder et al. estimated ventricular volume and ejection fraction in fetuses at 21–24 weeks by 3D echocardiography, but they did not demonstrate the accuracy of 3D echocardiography in small ventricles.[9] We demonstrated that real-time 3D echocardiography with a 2-MHz phased-array transducer provided accurate volume measurements of a small ventricular model. Bhat et al. demonstrated that 3D echocardiography provided accurate volume measurement in a balloon model and in fetuses.[10] However, they did not demonstrate that 3D echocardiography provided accurate volume

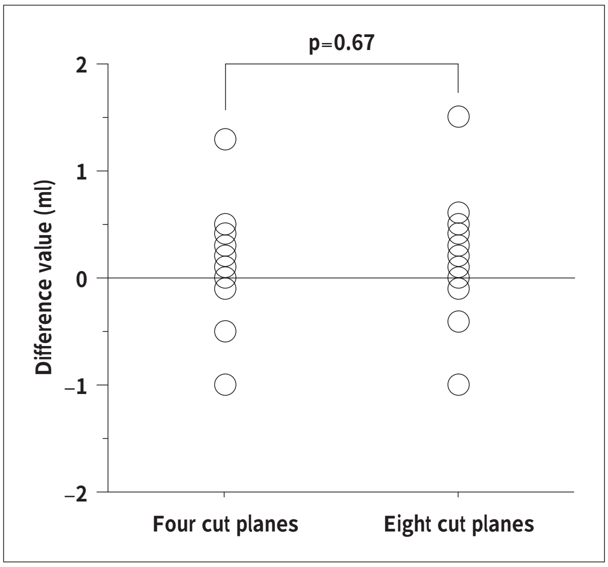

Fig. 5 Scatter plots of the difference values (ml) in the 4-cut-plane group and 8-cut-plane group; p=0.67.

measurement of a very small ventricular volume (less than 5 ml) in their validation test. Therefore, we estimated a very small ventricular model (0.5 ml to 10 ml) in comparison with their model. In fetuses with congenital heart disease or large hemangioma, severe atrioventricular valve regurgitation is associated with heart failure that might cause intrauterine fetal death.[11, 12] An accurate measurement of very small cardiac cavities by real-time 3D echocardiography has important diagnostic and therapeutic implications for fetuses with congenital heart disease.

In this study, there was no significant difference between the volumes obtained using 4 cut planes and 8 cut planes for calculation, as shown in Fig. 5 ($p = 0.67$). Teupe et al. demonstrated that even three planes were sufficient to provide accurate mass measurements in left ventricles with a normal shape.[5] In our study, real-time 3D echocardiography proved accurate for volume measurement of a simple spherical ventricular model, even when 4 cut planes were used for calculation.

There are several limitations in our study. First, this small ventricular model was a simple spherical form. It is necessary to demonstrate that real-time 3D echocardiography provides accurate volume measurement of a distorted cavity, particularly the right ventricle or abnormally shaped ventricles. Therefore, it is mandatory that volume measurement be carried out using a ventricular model with a complicated form. Second, this study was performed *in vitro* under static conditions. To obtain accurate volume measurement of the ventricles, we must consider the influence of cardiac movement and breathing. Finally, all commercially available 3D echocardiography methods currently available require manual tracing of the endocardial and epicardial boundaries. In our study, volumes of the ventricular model were calculated after fine-tuning a manual tracing around the interior surface, which was time consuming. The introduction of automated border detection, if accurate, would make this technique even more attractive in the future.

In conclusion, our study demonstrated that real-time 3D echocardiography provides highly accurate volume measurement of ventricles ranging from 0.5 ml to 10 ml using a small ventricular model with spherical shape under static conditions.

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