Accuracy of Real Time Three-Dimensional Echocardiography in Assessing Atrial Septal Defect Among Children

Virginia C. Mappala, MD; Ma. Lourdes SR Casas, MD; Juliet J. Balderas, MD

Background --- The selection of patients for transcatheter or surgical closure of atrial septal defect requires accurate information regarding the anatomy of the defect such as its maximal diameter and the amount of circumferential tissue rim. The recent development of dynamic three-dimensional echocardiography (3DE) from two-dimensional (2DE) images has opened new perspectives in the study of cardiac anatomy and pathophysiology. Three-dimensional echocardiography (3DE) allows unique en face views of the atrial septum. The aim of this study is to determine the value of real time three-dimensional echocardiography (RT3DE) in the accurate diagnosis of the anatomic characteristics of atrial septal defect and to correlate with the surgical findings.

Methods --- Nineteen patients with ASD were examined with RT3DE. Three-dimensional image data-base was post-processed using 3D work-station. The results were compared with the results measured by 2-dimensional and intraoperative transesophageal echocardiography and surgical findings

Results --- RT3DE produced novel views of the ASD and improved quantification of the size of the defect. The ASD diameters obtained from 3DE have better correlation with surgical findings as compared to the measurements obtained in the 2DE (r = 0.917 vs. r = 0.281). The findings in the 3DE were likewise closer to the measurements done in IOTEE (mean difference of 0.02)

Conclusion --- RT3DE offers additional special information in ASD without extending examining time, permits quantitative recording of ASD diameter and septal margins. It is a potentially valuable clinical tool for diagnosing and managing patients with ASD and aid in the selection of patients for surgery or interventional closure. *Phil Heart Center J 2008; 14(1):26-33.*

Key Words: Two-dimensional echocardiography ■ Real-time three-dimensional echocardiography ■ intraoperative transesophageal echocardiography ■ atrial septal defect

The selection of patients for transcatheter or surgical closure of atrial septal defect requires accurate information regarding the anatomy of the defect such as its maximal diameter and the amount of circumferential tissue rim. Transthoracic two-dimensional echocardiography (TTE) is wanting as a means to define selection criteria for atrial septal defect closure. Since the defect is visualized from multiple orthogonal planes, maximal atrial septal defect diameter is widely under-estimated. The transcatheter approach measures the stretched diameter, but cannot be applied alone for patient election since it does not provide information on the tissue rim. Previous studies have shown that transesophageal echocardiography (TEE) is more accurate than TTE in this setting (1). However, because it is an invasive procedure, it poses difficulties among uncooperative and younger children. The use of noninvasive methods to visualize the heart has had an extraordinary development over the last decade, with echocardiography demonstrating a particularly fast growth. Despite its unquestionable role in the diagnosis and management of heart disease, 2D echocardiography does have some limitations, both in the morphological visualization, as well as in the functional assessment of the heart, such as blood flow and quantification of intracardiac volumes. The recent development of dynamic three-dimensional echocardiography (3DE) from two-dimensional (2DE) images has opened new perspectives in the study of cardiac anatomy and pathophysiology. Three-dimensional echocardiography (3DE) allows unique en face views of the atrial septum. Previous studies have shown the ability of the 3DE to depict information regarding the shape, the maximal diameter, and the rims surrounding

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the defect.[2]

Three-dimensional echocardiography, using both reconstruction methods and real time 3D, has been used to detect several forms of congenital heart disease. The potential advantages of 3D imaging over 2D echocardiography are its ability to record and analyze the entire cardiac structure and to display complex spatial relationships. Because of this, it may replace the use of TEE. In addition, the decreased examination time afforded by RT3D echocardiography may reduce the need for sedation in some children.

In the study of Cheng and van den Bosch, 3D echocardiographic sizes, location and surrounding tissue of ASD have better correlation with surgical findings than diameter measured by 2DE and it gives additional information of the defect without extending examining time, permits quantitative recording of septal dynamics, and enhance the understanding of complex cardiac anatomy and elucidation of the disease mechanism.[3, 4]

In a previous study by Bemurat et al, 3DE was use for the selection of ASD for occlusive prosthesis. Seventeen patients with ASD underwent 3DE measurements. Data were compared with those of the surgeon in a prospective study. The correlation between the surgical and the echocardiographic measurements varied from 0.82 cm for the maximal diameter to 0.6 for the postero-inferior limits. In the study, 3DE was therefore a non-invasive technique capable of improving the selection of atrial septal defect for interventional closure. The transesophageal approach should be reserved for candidates selected by the transthoracic investigation fort the detection of small structures and when the transthoracic window is poor.[5]

De Castro et al demonstrated the usefulness of transthoracic live 3DE in the evaluation of congenital heart diseases. In this study, 28 (35%) patients from a total of 80 patients provided additional anatomic 3DE information that became useful in the therapeutic planning.[6] Real time 3D (RT-3DE), with shorter imaging time and better reconstruction techniques, can obtain qualitative and quantitative information on heart disorders.

We conducted this research to determine the value of three-dimensional echocardiography in the accurate diagnosis of the anatomic characteristics of atrial septal defect, such as size, shape and location, and to correlate these with the surgical findings.

Methods

We employed a prospective cross-sectional observational study design to determine the value of three-dimensional echocardiography in assessing characteristics of atrial septal defects, with surgery as gold standard. Study was conducted at a tertiary referral center for Pediatric Cardiology. Included were all pediatric patients less than 19 years old that underwent surgical closure of Atrial Septal Defect (ASD) from April 2007 to October 2007. Excluded were pediatric patients wherein transesophageal echocardiography is not feasible and patients with inadequate images due to morbid obesity or poor echocardiographic window.

Echocardiographic study

Upon admission, the subjects underwent the routine comprehensive two-dimensional echocardiographic (2DE) examination as recommended by the American Society of Echocardiography. The location, defect size, and surrounding atrial anatomy of the ASD were assessed in the four standardized echocardiographic planes, the subcostal four chamber (SC4C) and subcostal short axis views (Figure 1A and 1B). The diameters of ASD in 2 different planes were measured. The transverse diameter was measured in the subcostal 4 chamber view and the longitudinal diameter was measured in the subcostal short axis view. Color mapping was used in all patients to assist in the identification of the maximal ASD diameter in each plane. Two anatomically and echocardiographically well-defined septal margins surrounding the ASD were measured. The superior margin (defined as the distance between the superior edge of the ASD and the attachment of the superior vena cava to the right atrium) and the anteroinferior margin (defined as the distance between anteroinferior edge of the ASD and the tricuspid valve annulus) were obtained.

After the standard 2DE, patients were subjected to three-dimensional echocardiography (3DE) by the same echocardiographer using the same machine, the Philips Sonos iE 33 Ultrasound system with an x7 matrix array transducer. The displaying mode of the RT-3DE includes the full volume on the parasternal short-axis, apical four chamber and subcostal 4-chamber views. Three-dimensional echocardiographic color mapping was also done to delineate better the ASD. The size of the defect was measured from the en face view (Figure 2A and 2B). All recordings were taken with the patient on the left lateral decubitus position and during normal breathing. Manipulation of 3D data was performed offline in a computer using the 3D-Q lab software. A single observer analyzes the images using the Q lab software.

Surgical procedure

Intraoperatively, prior to closure of ASD, the character of the ASD was again evaluated via intraoperative

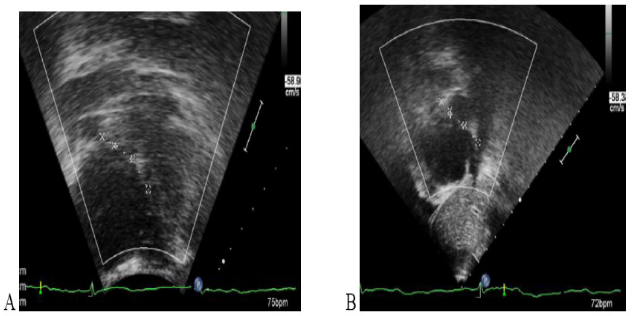

Figure 1. Subcostal 4-chamber (A) and short-axis (B) views of transthoracic two-dimensional echocardiographic measurement of ASD.

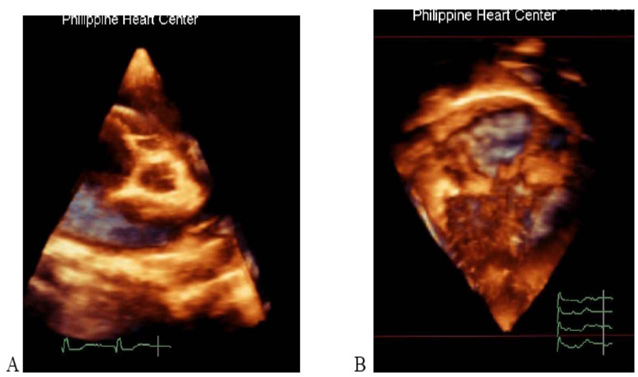

Figure 2. Real-time 3-dimensional echocardiographic display of the atrial septal defect viewed en face from the parasternal short axis (A) and apical four chamber view from the right atrial side.

transesophageal echocardiography (IOTEE). Two standardized echocardiographic planes were also used to evaluate the defect, the horizontal and the vertical planes (Figure 3A and 3B). The transverse diameter and the anteroinferior margin of the ASD were measured in the horizontal plane and the longitudinal diameter and the superior margin were measured in the vertical plane. The characteristics of the ASD were compared with the surgical findings. The defect was considered oval in shape if the ratio of the transverse diameter to longitudinal diameter or vice versa was >1.0. The defect was considered central in location if it was situated in the fossa ovalis, and superior, inferior, posterior and anteroinferior in location if it was eccentric and displaced toward the superior vena cava, inferior vena cava, posterior atrial wall, and tricuspid valve respectively. Without knowing the echocardiographic data of ASD and using the same anatomic landmarks, measurements of ASD diameter and its septal margins corresponding to those obtained by 2DE, 3DE and IOTEE were recorded by the surgeon after commencement of the cardiopulmonary bypass and administration of cardioplegia. The shape and location of the ASD were also recorded. The echocardiographic assessment of the ASD was compared with the surgical findings.

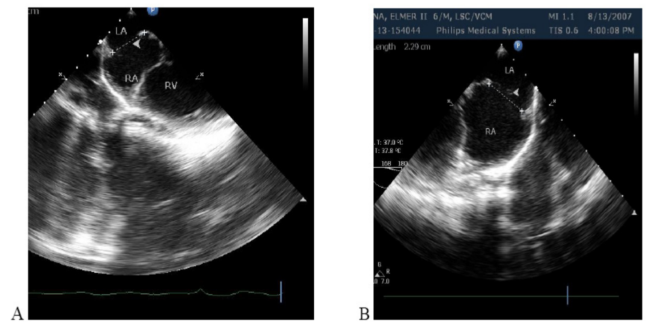

Figure3. Measurement of the ASD diameter and septal margins via intraoperative transesophageal echocardiography: (A) Horizontal plane or the four chamber view and (B) vertical plane or the bicaval view.

Data Analysis

All values were expressed as mean ± SD. Multivariate analysis was used to compare the measurements between different methods. In accordance with the Bland and Altman, plots of the difference versus mean of paired measurements were examined for the presence of relation. Comparison was made using the Paired-T test and P value <0.05 were considered significant.

Results

We have a total of 19 subjects for the study. The study group included 13 (68.4%) female and 6 (31.6%) were male. Complete data and informed consent were obtained from the parents/guardian of all children included in the study. The mean age group was 10.58 years (range 5 to 18 years). Most of the patients have secundum type ASD (94.7%) and only one patient have primum type defect. Table 1 shows the patient demographics.

Table 2 shows the comparison of measurements done between 2DE versus 3DE and IOTEE versus 3DE. Measurement of ASD diameter by 2DE was significantly smaller with a mean of 2.14 cm as compared to the measurement done by 3DE with a mean of 2.80 cm. The mean difference between the 2 measurements was 0.66 cm and p value of 0.001. However, comparisons of measurements ASD diameter done on 3DE and IOTEE showed only a mean difference of 0.02cm with a p value of 0.876. The width of the anteroinferior and superior septal margins of ASD measured on 2DE and 3DE were also significantly different with a mean of 0.28 cm and 0.27 cm respectively. Comparisons of measurements of width of septal margin between IOTEE and 3DE were not significant, with both the anteroinferior and superior margin having a mean difference of 0.006.

Table 1. Demographic Characteristics of Included Patients

		Frequency N=19	Percent
Sex	F	13	68.4%
	M	6	31.6%
Age		Mean: 10.58 years	Range: 5-18yrs
Types of ASD			
Secundum		18	94.7%
Primum		1	5.3%

Table 2. Comparison of measurements between 2DE vs 3DE and IOTEE vs. 3DE

Procedures	ASD diameter		Width of Septal margin			
			anteroinferior		Superior	
	Mean (cm)	*SD*	*Mean (cm)*	*SD*	*Mean (cm)*	*SD*
2DE	2.14	0.61	1.90	0.69	1.20	0.50
3DE	2.80	0.73	2.17	0.73	1.46	0.57
Diff	0.66	0.76	0.28	0.47	0.27	0.29
P value	0.001 (S)		0.17 (S)		0.001 (S)	
IOTEE	2.78	0.68	2.19	0.60	1.50	0.62
3DE	2.8	0.73	2.18	0.73	1.46	0.57
Diff	0.02	0.37	0.006	0.40	0.006	0.17
P value	0.876 (NS)		0.945 (NS)		0.876 (NS)	

Table 3 shows the difference of measurements done between 2DE, 3DE and IOTEE in comparison with the surgical findings. Measurements of ASD diameter done on 2DE in comparison with the surgical findings were smaller with a significant mean difference of 0.85 cm with a p value of 0.001. Measurements of ASD diameter by 3DE and IOTEE in comparison with the surgical findings had a smaller mean difference of 0.19 cm and 0.21 cm respectively. The anteroinferior margin of ASD measured on 2DE was smaller than the surgical findings with a mean difference of 0.32 and this is statistically significant with a p value of 0.007. However, the anteroinferior margin measurements done on 3DE and IOTEE as compared to the surgical findings were not statistically significant with a mean difference of 0.04 cm and 0.03 cm respectively. The width of the superior septal margins measured on 2DE was slightly smaller as compared to the measurement done by surgery with a mean difference of 0.29 cm and a p value of 0.000. The IOTEE and 3DE measurements of the superior margin were closer to the surgical findings with a mean difference of 0.02.

Table 3. Mean difference of measurements between 2DE,

Procedures	ASD diameter		Width of Septal margin			
			Anteroinferior		Superior	
	Mean (cm)	*SD*	*Mean (cm)*	*SD*	*Mean (cm)*	*SD*
2DE	2.14	0.61	1.99	0.69	1.19	0.51
surgery	2.99	0.85	2.22	0.76	1.48	0.58
Diff	0.85	0.90	0.32	0.47	0.29	0.28
P value	0.001 (S)		0.007 (S)		0.000 (S)	
3DE	2.8	0.73	2.18	0.17	1.46	0.57
Surgery	2.99	0.85	2.22	0.76	1.48	0.58
Diff	0.19	0.34	0.04	0.09	0.02	0.8
P value	0.027 (S)		0.067 (NS)		0.190 (NS)	
IOTEE	2.78	0.68	2.19	0.60	1.46	0.62
Surgery	2.99	0.85	2.22	0.76	1.48	0.58
Diff	0.21	0.36	0.03	0.42	0.02	0.15
P Value	0.021 (S)		0.721 (NS)		0.602 (NS)	

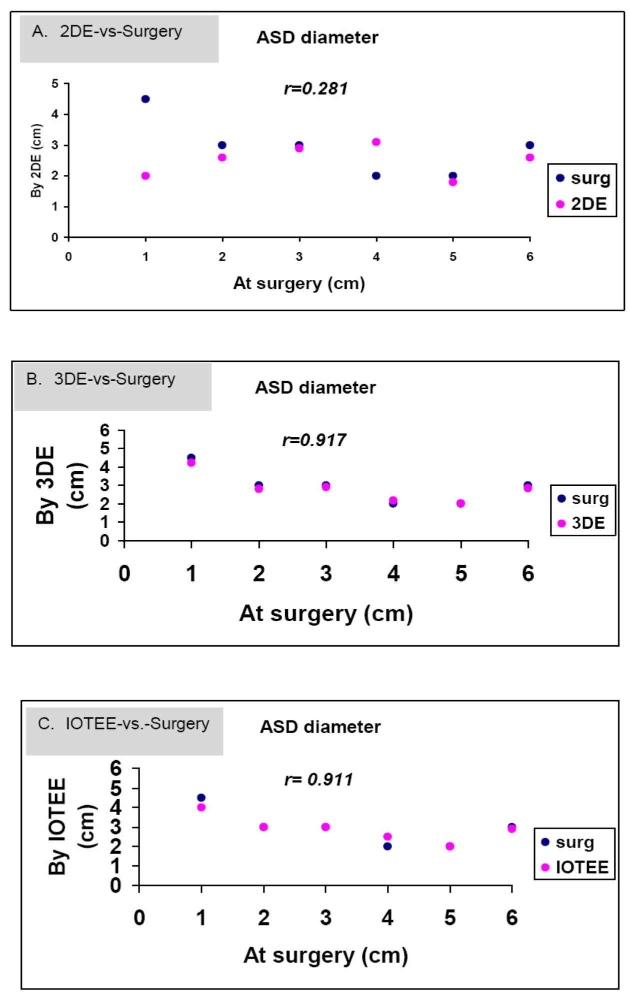

Figure 4. Scatter plots showing the correlation coefficient of the ASD diameter measured at operation compared to (A) 2DE, (B) 3DE and (C) IOTEE.

Figure 4 is a scatter plot showing the correlation coefficient between paired measurements together with the interclass correlation coefficients of ASD diameter. Figure 4A shows poor agreement between measurements done on 2DE and surgery where the mean difference is significantly different from zero with interclass correlation coefficient of 0.281 and p value of 0.001. 3DE and IOTEE measurements had good agreement with surgical measurements of ASD diameter with a good interclass correlation coefficient of 0.971 and 0.911 respectively (Figure 4B and 4C).

Figure 5 shows the correlation coefficient between paired measurements of the width of septal margin together with its interclass correlation coefficient. Figure A1, B1 and C1 shows the correlation of anteroinferior margin measured by 2DE, 3DE and IOTEE as compared with the surgery. Measurement of the anteroinferior on 2DE showed poor correlation with the surgery with an r of 0.794. Measurements done on 3DE and IOTEE had better correlation with the surgical findings with the correlation coefficient nearer to 1.0 with an r of 0.993 and 0.830 respectively. The superior margin of the ASD measured by 2DE showed lack of good agreement with the surgical findings with an r of 0.877; however, there was good agreement between 3DE and IOTEE with surgical measurements.

The 3DE and surgical findings as to the shape and location of the ASD are listed in Table 4. On 3DE, all defects were found to be oval in shape as compared to the surgical findings wherein 2 patients were noted to have very oblong or slit like shape of the ASD. The location of ASD seen on 3DE was similar to the surgical findings. The ASD was central in 13 (86.7%), inferior in 1 (6.7%) and posterior in 1 (6.7%) in the atrial septum. The preoperative predictions by 3DE of the shape and location completely agreed with surgical findings.

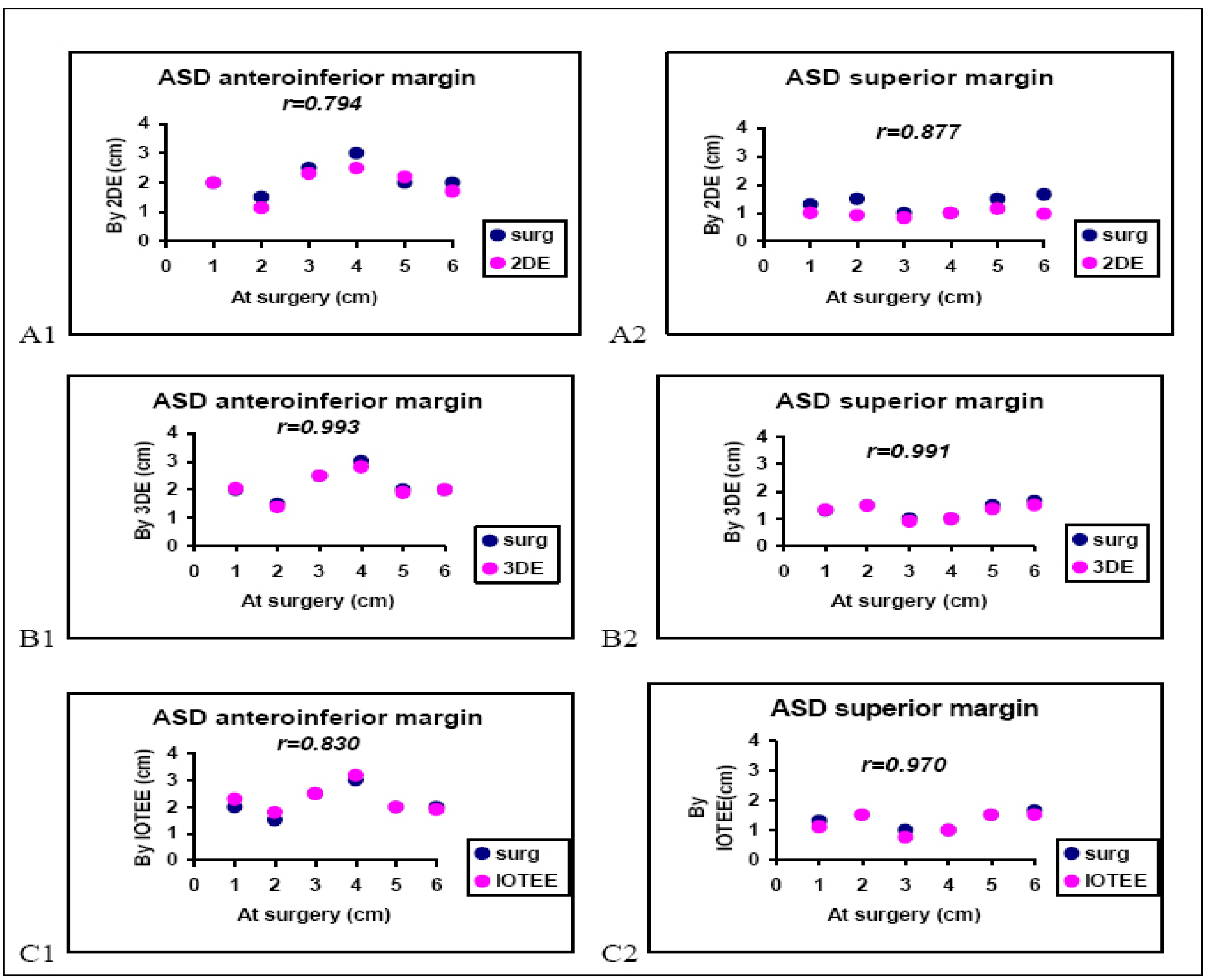

Figure 5. Scatter plot showing the correlation coefficient of the width of septal margins of ASD measured at operation compared to 2DE, 3DE and IOTEE.

Table 4. Shape and Location of Atrial Septal Defects in the Atrial Septum on 3DE and at Operation

	Frequency (%)	
	3DE	Surgery
Shape of ASD		
Oval	19 (100%)	16 (84.2%)
Slit	0 (0%)	2 (10.5%)
Fenestrated	0 (0%)	1 (5.3%)
Location of ASD		
Central	17 (89.4%)	17 (89.4%)
Inferior	1 (5.3%)	1 (5.3%)
Superior	1 (5.3%)	1 (5.3%)

Discussion

At present, traditional 2DE is the most widely used non-invasive method for the diagnosis of congenital septal defects, and its clinical superiority maybe further enhanced by combining color Doppler and acoustic contrast technology. However, limited by imaging principle, 2DE could only display certain planar characteristics of the defect within a relatively fixed 2-dimensional view. The observer has to rely on his interpretative mental skill to compile the 2D slices of the complex 3-dimensional anatomy of the defect --a task that is often difficult even in the experienced eyes. Since septal defect particularly atrial septal defects displayed in the 2DE images are only echo intermissions of the atrial septa, sonographers tend to assume the defect as round in shape. But the true shape of the defect varies significantly, especially in atrial septal defect, and the anatomic morphology has no necessary relationships with the size of the echo intermissions. For this reason, traditional 2DE lacks the ability to display the entire shape of the ASD and cannot quantify them accurately.

In the last few years, investigators have concentrated on combining 2-dimensional images during the different cardiac cycles in 3-dimensions with electrocardiographic and respiratory gating. But it was not regarded as feasible in everyday clinical practice, because of the complexity of image acquisition, the necessity for time consuming off-line data processing, and the impairment of image quality by motion artifacts. Recently, a novel imaging system was introduced which uses a dedicated matrix phased array 3D transducer for rapid beam forming to scan a pyramidal volume. Through adjusting 3-perpendicular planes and slicing the volume data, visualization of cardiac structures, especially regions of interest within planes not generally demonstrated by 2D imaging, could be achieved. In our study, we analyzed the correlation of the diameter of atrial septal defect measurements by 2DE echo intermissions with 3DE and IOTEE and to that of the operative findings. Measurement of ASD diameter by 2DE is significantly smaller than that of the 3DE, IOTEE and operative findings and it did not show positive correlation. However, the diameter of ASD done on both 3DE and IOTEE are closer to the operative measurements with a mean difference of 0.19 cm and 0.21 cm respectively, as compared to the 2DE with a mean difference of 0.85 cm. These results indicate that 2DE lacks the ability to quantify the real size of the defect, although it can measure the diameter of the defect within 1 plane. These findings also indicate that 3DE with good image acquisition can accurately visualized the entire septal defect. In some cases, 2D diameter cannot be regarded as the criterion of the defect size. Adolphus et al validated the use of echocardiography in the accurate measurement of ASD diameter for catheter closure. Adolphus et al compared the measurement of the longitudinal diameter of ASD by 2DE and IOTEE showing good correlation with the surgery, however, the transverse diameter was less satisfactory. They were also able to determine the septal length suitable for transcatheter closure using the TEE (7). The use of TEE to measure the ASD and its surrounding structures has been validated by several researches and it was proven to be accurate in determining septal width of the defect. TEE has also been useful in choosing patients for transcatheter closure. Like the 2DE, TEE has also its limitations of being invasive and not suitable for uncooperative children. In our study, we have shown that the measurements of ASD diameter done by 3DE and IOTEE have good correlation with a very small mean difference of 0.02 cm. This means that 3DE with good data acquisition, can replace TEE in the accurate measurements of ASD diameter especially in uncooperative children.

Cheng et al correlated the measurement of ASD diameter with real-time 3DE to the operative findings. In his study, 38 patients underwent 3DE and compared the data with the surgical findings. The result showed the larger diameter ASD measurement has good correlation with the operative findings (3). In our study, the measurements done on 3DE have better correlation with the surgical findings with a mean difference of only 0.19 cm which is closer to the operative measurements as compared to the 2DE with a mean difference of 0.85cm. This means that with a better correlation of the 3DE with the surgical findings, 3DE is superior to 2DE in septal defect measurements. For the measurements of the length of the septal margins, the antero-inferior and superior margins measured by 2DE are closer to the measurements done on 3DE, IOTEE and at operation. However, as compared with the 2DE, the anterior and superior margins obtained from the 3DE are significantly closer to the IOTEE and surgical findings with a mean difference of 0.006 and 0.04 respectively. Although the difference for each measurements were only small, it should be pointed out that during the surgery the size of the defect is estimated according to the experience of the surgeon through measurement of a static defect while the heart is at standstill.

RT3DE has the advantage of not only displaying the entire shape of the defect and its spatial relationship with its neighboring structures, but also accurately quantifying the defect. Until recently, treatment of an atrial septal defect was exclusively by open heart surgical repair. Thus, the exact assessment of the size of the defect and its relation to the surrounding structures may not be crucial. However, the recent introduction of catheter-based techniques for device closure of ASD requires selection of patients on the basis of specific criteria such as the spatial orientation, the tissue surrounding the defect, the presence or absence of remnants of the foramen ovale within the ASD, and the maximal diameter of the defect in different planes. The importance of knowing these parameters, from either transthoracic or transesophageal 3DE, in selecting patients for transcatheter or surgical closure has been emphasized by Cheng et al (3). Therefore, the significant role played by RT3DE prior to transcatheter device closure of ASD is quite obvious. Finally, the ability of RT3DE in permitting quantitative recording of ASD dynamics during the cardiac cycle may also provide great potential in exploring the dynamic nature of the ASD as well as other shunt anomaly mechanisms. All in all, RT3DE, which represents the study of "virtual" pathologic anatomy, may eventually make routine preoperative cardiac catheterization for patients with ASD unnecessary.

The recent advances in 3-dimensional echocardiography provided a unique frontal view of the ASD: allowing direct visualization of the defect and the whole circumferential rim in one view and also allowing direct measurement of the ASD dimensions, and the width of the septal rim tissues. However, despite these advantages, 3DE is not without limitations. During the study, we initially had problems with the proper acquisition of 3DE images, so that some subjects were dropped from the study. However, with more careful attention to details of the 3DE images, no difficulties were encountered in the rest of the study period. The conceptualization of the 3DE shape and location of the defects, including its size were not difficult and the surgical findings in this study confirmed that excellent predictions can be achieved.

Discussion

In conclusion, we reported our initial experience with the use of RT3DE in assessment of ASD. It enables us to measure the exact ASD diameter and its surrounding tissue rim, giving us a virtual representation of its cardiac pathology. It gives to the clinician new insights on this entity, which should help in decision making for alternative therapeutic strategies. At present, 3DE may have additional clinical value in appropriately selecting patients for catheter-based closure of the atrial septal defect.

Although our results are very promising, the study is limited by the relatively small sample size. The assessment of ASD in a large number of patients with RT3DE and comparison with other standards are desirable before wide clinical use is recommended. Also, for optimal and widespread use of 3DE, technical improvement, such as higher resolution after acquisition and faster computers allowing on-line reconstructions are mandatory. It is also recommended that this study be continued with a larger number of subjects.

With surgical validation of the findings, the present study forms a good 3DE basis for understanding the various morphologic variations of ASD and thus provides useful guidance on patient selection for device closure or surgical correction.

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