Pediatric Cardiology

Assessment of Atrial Septal Defect — Role of Real-Time 3D Color Doppler Echocardiography for Interventional Catheterization

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Background: Atrial septal defect (ASD) is easily thought to be a round hole in the atrial septum from the image of two-dimensional (2D) echocardiography. Even surgeons can not get the true morphology of an atrial septal defect because they only see the defect when the heart is already in a collapsed, non-beating condition. Pediatric interventional cardiologists, on the contrary, need to know the exact morphology in the beating heart so that a therapeutic device can be safely deployed. The purpose of this study was to evaluate the accuracy of real-time three-dimensional echocardiography (RT-3D Echo) in visualizing the morphological characteristics of ASD and its potential as a new method for selecting the size of the Amplatzer septal occluder.

Materials and Methods: Between February 2003 and December 2003, a total of 12 patients with secundum-type ASD underwent simultaneously 2D transesophageal echocardiography (TEE) and RT-3D Echo during interventional catheterization. The stretched balloon diameter, 2D TEE images, and RT-3D Echo images were recorded and analyzed in detail.

Results: Twelve patients, aged from 3.0 to 36.0 years (mean 11.6 ± 8.2 years), safely underwent the interventional catheterization. The mean Qp/Qs was 2.4 ± 1.9 (range 1.6-4.5). The mean size (waist) of the 12 devices was 23.1± 9.2 mm (range 7-36 mm). The mean SBD was 19.9 ± 7.6 mm (range 6.0-34.1 mm). The mean 2D-TEE ASD measurement was 19.2 ± 7.1 mm (range 5.4-33.5 mm). The mean RT-3D ASD measurement was 21.2 ± 9.0 mm (range 6.1-34.5 mm). Analyses of the RT-3D Echo imaging showed that the ASD is not a flat hole in the septum. The ASD curves in three dimensions. The curvature varied differently in different directions, thus generating a complex spatial structure. The calculated curvature angles along long axis of defects were 166 ± 5.4 degrees. Good correlations were found between device diameter (waist) and SBD (r = 0.995), 2D diameter (r = 0.987), and 3D diameter (r = 0.997). The best correlation was found between device diameter (waist) and 3D diameter measured by planimetry of RT-3D Echo (r = 0.997).

Conclusions: The complex 3D nature of the ASD in the beating heart could only be well appreciated by the RT Color 3D Echo. The conventional 2D image provided only partial and thus distorted image of ASD. Thus, the application of RT-3D Echo provides a useful tool for evaluation of ASD for those patients undergoing interventional transcatheter closure.

Key Words: Atrial septal defect • Congenital heart disease • Real-time three-dimensional echocardiography • Interventional catheterization

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INTRODUCTION

Morphologic characteristics of atrial septal defect (ASD) including size measurement and spatial relationship between the ASD and neighboring structures are of paramount importance for the successful deployment of a transcatheter septal occluder. Pediatric interventional cardiologists need to know the exact morphology of an ASD in the beating heart so that the therapeutic device can be safely deployed. The traditional non-invasive method for evaluating the size and position of ASD is 2D transthoracic echocardiography (TTE). It usually underestimates maximal ASD size and provides limited ASD imaging because only one cross-sectional image is available at any one time.[1-5] Two-dimensional transesophageal echocardiography (TEE) can provide much clearer ASD imaging than TTE.[5-7] However, this approach has an obvious limitation for clinical routine since it requires general anesthesia in children. New three-dimensional echocardiographic development allows the use of the transthoracic approach for surface imaging.[8-10] The newly introduced real-time three-dimensional echocardiography (RT-3D Echo) can visualize the overall structure of the atrial septum, which provides information including position, size during the cardiac cycle, and the exact morphology of surrounding rims. The aim of this study was to evaluate the accuracy of real-time three-dimensional echocardiography (RT-3D Echo) in visualizing the morphological characteristics of ASD and its potential as a new method for selecting the size of the Amplatzer septal occluder (ASO).

MATERIALS AND METHODS

Twelve consecutive patients diagnosed to have secundum-type ASD with 2D transthoracic echocardiography between Feb. 2003 and Dec. 2003 were enrolled in the protocol of transcatheter device closure using the Amplatzer septal occluder. During interventional catheterization, they simultaneously underwent 2D-TEE and RT-3D Echo. Patients ranged in aged from 3.0 to 36.0 years (mean 11.6 ± 8.2 years), and their weights ranged from 14.1 to 65.2 kg (mean 20.6 ± 10.3 kg). Informed consent was obtained from all patients or their guardians.

RT-3D Echo studies were performed using the Philips Sonos 7500 ultrasound system equipped with xMatrix probe and software package including 3D data acquisition and analysis. All of the images were obtained using a dedicated RT-3D probe (in apical 4-chamber and short-axis view) with 3000 elements for ultra-fast spatial image acquisition and a dedicated computer for on-line image processing and real-time cine-loop display. RT-3D Echo data acquisition was done while the patients were quiet and cooperative during several heartbeats. The reference position was selected based on the whole structure of ASD being in the region of interest. The digital data were stored and then reconstructed for whole anatomical structure of the sector. Maximal ASD size measurements were made on RT-3D Echo imaging using planimetry obtained from the right atrial-sided 3D-curved plane. Analysis of the RT-3D Color Echo image showed that the ASD was not a flat hole in the septum. The view from right atrium and left atrium showed ASD in cine-loop with changing shapes and size during cardiac cycle (Figure 1). Planimetry was performed, including measurement of diameters (Figure 2). The maximal diameter of the defect was measured in each patient by picking up the two farthest points from the 3D-curved plane during the cardiac cycle.[11]

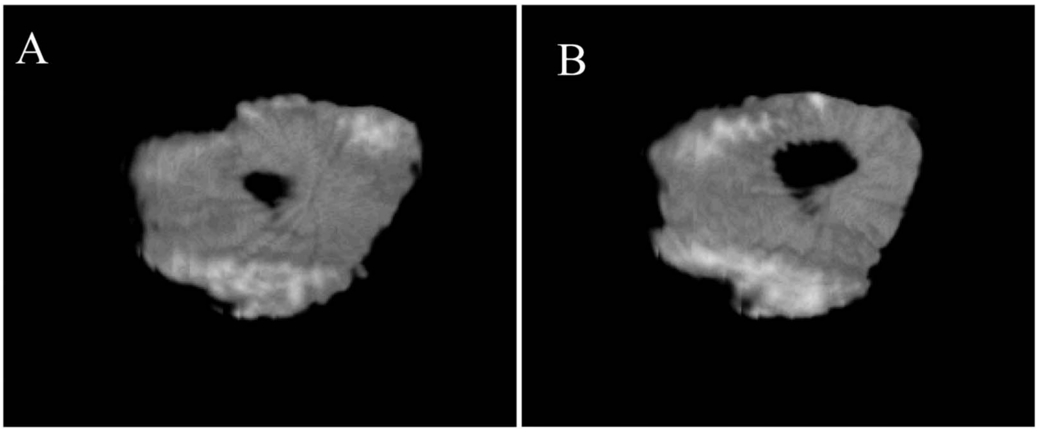

Figure 1. *Changing shapes and size of ASD during cardiac cycle:* ***(A)*** *diastole;* ***(B)*** *systole.*

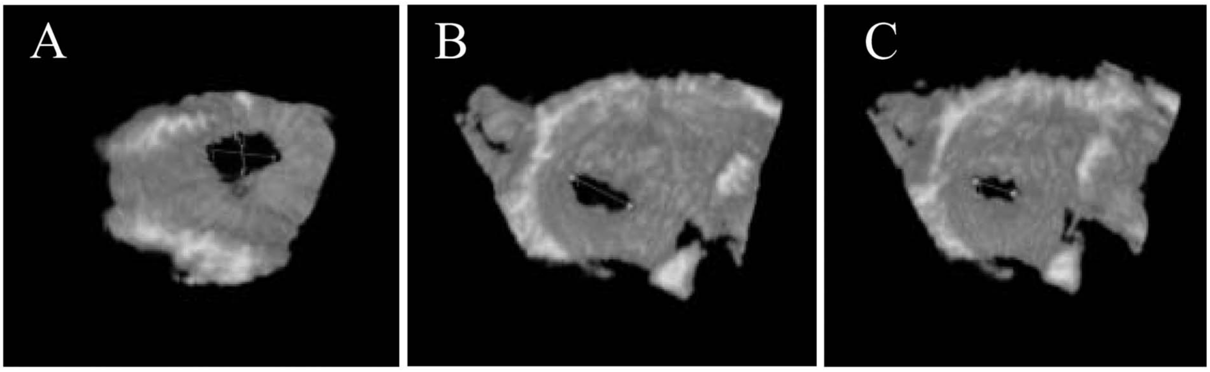

Figure 2. *Planimetry of diameters:* ***(A)*** *diameters of maximal area;* ***(B)*** *maximal diameter of systole;* ***(C)*** *maximal diameter of diastole.*

The catheterization protocol for deployment of the ASO was described previously.[12] The stretched balloon diameter (SBD) was measured by the balloon sizing maneuver.[13] In left anterior oblique view, the balloon was inflated with diluted contrast until a waist appeared. The SBD was determined outside the body by passing the same amount of contrast medium into the balloon and measuring the size by passing it through a calibrated sizing plate. The size of ASO was determined according to measurement of SBD on the basis of known surrounding anatomical structures by RT-3D Echo.

Statistical analysis

All data were expressed as mean ± SD. Measurements of maximal ASD size obtained by 2D TEE, balloon sizing method, and RT-3D Echo were compared with the deployed device size using linear regression analysis and paired t-test for continuous variables. $p < 0.05$ was considered statistically significant.

RESULTS

All of the 12 patients underwent successful transcatheter closure with no residual shunt. All patients underwent 2D-TEE and RT-3D Echo. Balloon sizing measurements were done for 12 devices. The mean Qp/Qs was 2.4 ± 1.9 (range 1.6-4.5). The mean size (waist) of the 12 devices was 23.1 ± 9.2 mm (range 7-36 mm). The mean SBD was 19.9 ± 7.6 mm (range 6.0-34.1 mm). The mean 2D-TEE ASD measurement was 19.2 ± 7.1 mm (range 5.4-33.5 mm). The RT-3D ASD measurement was 21.2 ± 9.0 mm (range 6.1-34.5 mm). RT-3D Echo reconstruction was successfully done in all twelve patients. RT-3D Echo imaging provided an en face view demonstrating the size, position, number of defects, and surrounding rims of the ASD anatomy. This made the measurements more accurate and reliable. RT-3D Echo showed that ASDs curved in three dimensions. The curvature varied differently in different directions, thus generating a complex spatial structure.

The surface area of the ASD changed significantly during the cardiac cycle, with a maximum size in late ventricular systole and a minimum size in late left ventricular diastole.[13] To express the curved 3D-plane of ASD as digitized value, curvature angles were calculated (Figure 3). The calculated curvature angles along long axis of defects were 166 ± 5.4 degrees (Figure 4).

As seen in Table 1, good correlations were found between device diameter (waist) and SBD ($r = 0.995$), 2D diameter ($r = 0.987$), and 3D diameter ($r = 0.997$). The best correlation was found between device diameter (waist) and 3D diameter measured by planimetry of RT-3D Echo ($r = 0.997$).

DISCUSSION

Transcatheter closure of ASDs has recently become an increasingly attractive alternative to surgical repair in selected cases. The ASO device has a very high complete closure and is effective in closing ASDs up to a stretched diameter of 38 mm.[12,14,15] However, an extremely precise assessment of ASDs is crucial for optimal ASO selection and procedural success.

The most frequently used methods for ASO device

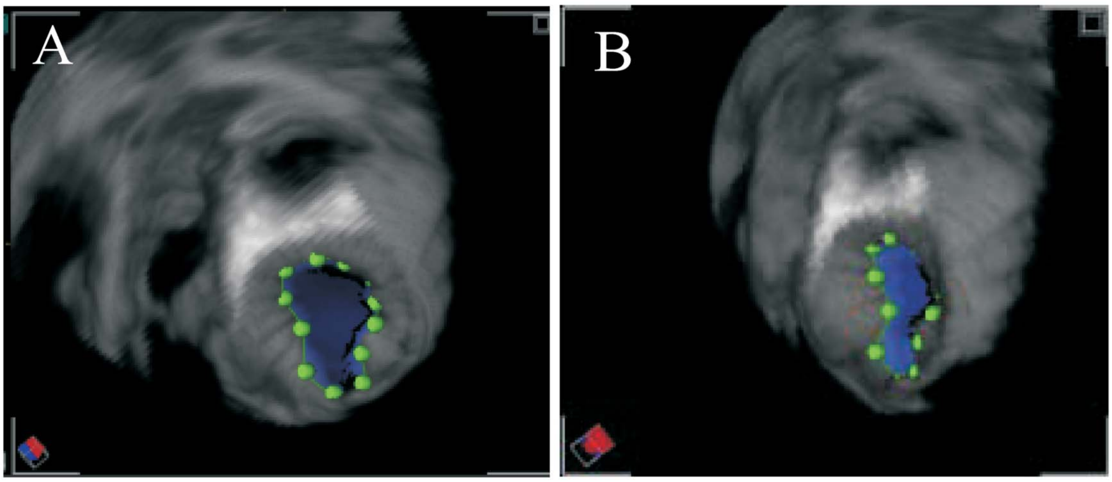

Figure 3. *Curved plane of ASD. Marked points around the margin of defect in the 3D model formed an irregular circle and the curved plane of ASD.* ***(A)*** *front view.* ***(B)*** *oblique view.*

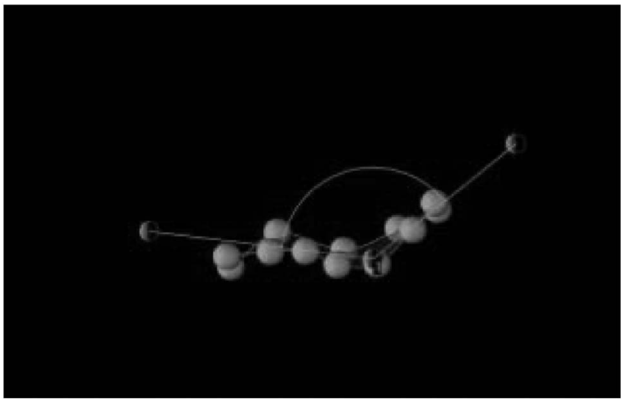

Figure 4. *Angle of curved plane along the long axis. The calculated curvature angles along the long axis of defects were 166 ± 5.4 degrees.*

Table 1. Correlation between device diameter (waist) and ASD size measurements

Measurement	Mean diff. (mm)	*r*	*p*
Device diameter vs SBD	3.19	0.995	< 0.0001
Device diameter vs 2D diameter	3.87	0.987	< 0.0001
Device diameter vs 3D diameter	2.12	0.997	< 0.0001

ASD, atrial septal defect; Mean diff., mean difference; SBD, stretched balloon diameter; 2D diameter, measured by 2D transesophageal echocardiography; 3D diameter, by real-time three-dimensional echocardiography.

selection and deployment include balloon-sizing maneuver[16,17] and transesophageal echocardiography (TEE) monitoring.[12,14,15] However, both of these methods have their disadvantages. Balloon-sizing is not very accurate and may be associated with three pitfalls. First, balloon-sizing can itself cause damage, enlarging the defect by tearing the flap valve of the septum primum. Second, the accuracy of ASD size measurement depends on the force applied in retrieving the balloon through the defect and on the angle of balloon popping through the septum. Third, balloon-sizing may cause arrhythmias or obstruction of venous return. On the other hand, TEE is a technique that needs general anaesthesia with or without endotracheal intubation, owing to the poor acceptance of an esophageal probe for the entire duration of the procedure and has the potential risks of aspiration, airway obstruction, esophageal perforation, and vocal cord dysfuntcion.[18,19]

Two-dimensional TEE imaging is superior to fluoroscopy because it provides clearer imaging.[5] However, only limited structure is shown and the maximal ASD size tends to be underestimated if the probe is not on the line between the longest diameter. In patients with an elongated oval-shaped defect, two-dimensional TEE significantly underestimates the maximal diameter of the ASD. In this series, real-time three-dimensional echocardiography well demonstrated the morphologic characteristics of atrial septal defects. It could present the overall structure of the ASD, which provided information about the position and size in different stage of cardiac cycle, and the actual anatomy of the surrounding rim. It allowed a proper measurement of the ASD and selection of an appropriately sized device, also facilitating all stages of the deployment process monitoring. Our results were compatible with previous findings.[8,20-23]

The SBD has long been regarded as the gold standard for the measurement of maximal ASD size.[1,13,15,24,25] In this series, the size of ASO was determined according to the measured SBD on the basis of the surrounding anatomical structures presented by RT-3D Echo to assure the success of the deployment. We found good correlation (r = 0.997) between 3D diameter and ASO size, which was even better than the correlation (r = 0.995) between SBD and ASO size. These facts represent that RT-3D Echo showed not only the immediate anatomical characteristics, but also the accurate ASD size which successful deployment most needs. Previous reports have confirmed that 3-D echo is a useful method to evaluate ASD size.[8,20-23] Our study adds a new and quantitative use for RT-3D Echo. First, it proposes a standardized plane for accurate measurements of the ASD. Second, it defines a method for the selection of an ASO device, thus eliminating the cumbersome balloon-sizing maneuver. Third, it identifies the RT-3D Echo four-chamber (or short-axis) section as a view that can replace TEE monitoring during the procedure and avoid the need for general anesthesia. Fourth, RT-3D echo imaging establishes the safety and feasibility of using RT-3D echo alone as an adjunct to fluoroscopy and as the primary means of transcatheter closure of ASDs. Fifth, our study supports the accuracy of RT-3D-Echo-derived ASD evaluation, so as to avoid improper deformation of the circular waist of the ASO when it is stretched into ASD. Therefore, the application of RT-3D Echo provides a useful tool for evaluation of patients preparing for transcatheter septal occlusion.

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心房中隔缺損：即時三度立體空間彩色杜卜勒超音波在介入性心導管的處置評估

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背景 傳統上，人們由二維平面心臟超音波影像看，易認為心房中隔缺損是一個圓孔，即使外科醫師也沒有辦法得知心房中隔缺損的真實型態，因為外科醫師所見到的心房中隔缺損是處在一個沒有跳動、而且塌陷的心臟狀態；相對地，小兒心臟專科醫師施行介入性心導管時，得對一個跳動中的心臟置放關閉器，因此需要知道確實的心房中隔缺損型態。這個研究的目的，是用最新進的即時三度立體空間彩色杜卜勒超音波，來評估心房中隔缺損型態和做為選擇心房中隔缺損關閉器大小依據的可行性。

材料與方法 在西元 2003 年二月至十二月之間，總共有十二名第二型心房中隔缺損的病人在介入性心導管治療時，同時接受了二維平面經食道超音波和即時三度立體空間彩色杜卜勒超音波檢查，包含氣球導管測量的缺損直徑跟超音波影像，都被仔細的紀錄下來，並加以分析。

結果 十二位年紀從 3 歲到 36 歲 (平均 11.6 ± 8.2 歲) 的病人，都成功地接受介入性心導管治療。肺循環對體循環血流分流比率平均是 2.4 ± 1.9 (範圍: 1.6-4.5)，心房中隔缺損關閉器的平均大小是 23.1 ± 9.2 公厘 (範圍: 7-36 公厘)，氣球導管測量的平均缺損直徑大小是 19.9 ± 7.6 公厘 (範圍: 6.0-34.1 公厘)，二維平面經食道超音波所量測的平均缺損直徑大小是 19.2 ± 7.1 公厘 (範圍: 5.4-33.5 公厘)，三度立體空間彩色杜卜勒超音波所量測的平均缺損直徑大小是 21.2 ± 9.0 公厘 (範圍: 6.1-34.5 公厘)。即時三度立體空間彩色杜卜勒超音波顯示心房中隔缺損不是一個平坦的圓洞，它是一個立體形狀，有著曲折邊緣的缺損。這些曲折邊緣在不同的方向有不同程度的曲度，因此形成了一個複雜的空間結構。沿著缺損的長軸所計算出來的曲度平均是 166 ± 5.4 度。關閉器大小與三種測量心房中隔缺損直徑之間有著良好的關聯性，相關性如下：與氣球導管量測的直徑 (r = 0.995)、與二維平面經食道超音波量測直徑 (r = 0.987)、與三度立體空間彩色杜卜勒超音波量測直徑 (r = 0.997)。關閉器大小與三度立體空間彩色杜卜勒超音波量測直徑有著最佳的關聯性 (r = 0.997)。

結論 在跳動的心臟中，只有即時三度立體空間彩色杜卜勒超音波才能正確地描述心房中隔缺損的複雜立體型態，傳統的二維平面影像只能提供部分資訊，並扭曲了心房中隔缺損的型態評估，因此即時三度立體空間彩色杜卜勒超音波提供介入性心導管時，置放心房中隔缺損關閉器的一個有用工具。

關鍵詞：心房中隔缺損、先天性心臟病、即時三度立體空間彩色杜卜勒超音波、介入性心導管。