Original Research

Real-Time Three-Dimensional Transesophageal Echocardiography Is Useful for Percutaneous Closure of Multiple *Secundum* Atrial Septal Defects

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Key words: **Multiple atrial septal defects, transesophageal echocardiography, transcatheter closure.**

Manuscript received: September 20, 2013; *Accepted:* January 31, 2014.

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Introduction: The purpose of this study was to investigate the clinical value of real-time three-dimensional transesophageal echocardiography (RT-3D-TEE) for percutaneous transcatheter closure of multiple *secundum* atrial septal defects (ASDs) using a Chinese domestic occluder device.

Methods: From July 2008 to September 2011, 37 patients (mean age 28.4 ± 9.7 years; 24 females) with multiple *secundum* ASDs underwent percutaneous transcatheter closure in our institution with custom-made occluder devices. RT-3D-TEE was used to clarify the diagnosis and to help determine the operation scheme before the procedure, for real-time monitoring and guiding the operation during the procedure, and for evaluating the result shortly after the procedure.

Results: The custom-made atrial septal occluders were successfully implanted in 36 patients under RT-3D-TEE guidance. Twenty-seven patients were implanted with two devices and 9 patients with a single device. In two patients where the distance between the two defects was less than 7 mm (5.5 mm and 6 mm), double occluder devices were also successfully implanted. One patient underwent surgery for the complication of unstable occluder and increased residual shunt after closure. No other severe complications were observed.

Conclusions: RT-3D-TEE provides reliable diagnostic evidence of multiple ASDs and can help the clinician to select an appropriate operation scheme according to the number and morphology of multiple defects prior to percutaneous transcatheter closure. It also allows for proper positioning of the devices during the procedure and provides an effective means of evaluating the success of the procedure. For two devices to be implanted simultaneously in multiple ASDs, the usual requirement for the distance between the two defects may differ between our domestically made devices and the Amplatzer occluder.

The Amplatzer septal occluder has been used for the treatment of atrial septal defects (ASDs) for the past 30 years. As a mature technology, it is an effective alternative to surgical thoracotomy.[1-4] The value of two-dimensional (2D) echocardiography, including transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE), has been widely recognized in the percutaneous interventional closure of single ASDs.[5-7] However, a proportion of ASD patients have more than one defect. Multiple defects are often considered unsuitable for transcatheter closure. Furthermore, it is difficult to assess the location, size, shape and rim of the defects, as well as the spatial relationships among the defects using 2D-TEE or 2D-TTE, and these limitations may affect the success rate of closure. Some previous researchers indicate that more than one Amplatzer device can be deployed only when the residual edge between the two defects is more than 7 mm.

Real-time three-dimensional TEE (RT-3D-TEE) is a new echocardiographic technology that was first introduced in China in 2008. RT-3D-TEE can provide real-time 3D images of cardiac structure and function. For patients with multiple ASDs, it can show the spatial relationships among the defects and give the operator precise feedback to help guide device placement during the procedure. In this study, we report our initial experience with RT-3D-TEE for the transcatheter closure of multiple ASDs using our domestic atrial septal occluder. In addition, we evaluate the value of this technology in diagnosis and decision making before the procedure, monitoring during the procedure, and the immediate evaluation of the results of the procedure.

Methods

The study included 37 patients (24 females, 13 males) diagnosed with multiple ASDs by 2D-TTE or 2D-TEE. Their age ranged from 12-53 years (mean 28.4 ± 9.7 years) and their body weight from 33.4-75 kg (mean 56.3 ± 11.5 kg). The number of defects and the rim of tissue between the defects were evaluated by RT-3D-TEE before the procedure. There were 36 patients who had two-hole defects and one who had a three-hole defect (Table 1). Two patients had an atrial septal aneurysm in addition to ASDs. Of the 36 patients with two-hole defects, the large diameter of the defects and the rim between the defects were measured by RT-3D-TEE and 2D-TEE. In "3D zoom" mode, we chose to observe the defects from the right atrial side and measured the rim and the maximum size of the defects in diastole.

Table 1. Clinical data for patients with multiple atrial septal defects (ASDs) who underwent percutaneous closure.

No.	Age (years)	Sex (F/M)	Weight (kg)	No. of ASDs	No. of occluders
1	32	F	40.5	2	2
2	24	F	45.0	2	1
3	22	F	47.6	2	1
4	18	F	48.0	2	2
5	12	F	33.4	2	2
6	16	F	40.2	2	2
7	18	F	50.0	2	2
8	36	F	52.0	3	1
9	36	F	58.2	2	2
10	40	F	62.4	2	2
11	38	F	65.6	2	2
12	44	F	58.2	2	2
13	18	F	48.5	2	1
14	23	F	53.0	2	2
15	22	F	52.0	2	2
16	24	F	50.0	2	1
17	34	F	49.6	2	1
18	32	F	48.2	2	2
19	14	F	39.2	2	2
20	29	F	59.0	2	2
21	32	F	58.6	2	2
22	30	F	55.0	2	2
23	16	F	40.0	2	2
24	25	F	43.0	2	2
25	30	M	68.0	2	2
26	16	M	55.5	2	1
27	34	M	75.0	2	2
28	46	M	70.0	2	1
29	53	M	69.5	2	2
30	28	M	69.4	2	2
31	20	M	68.5	2	0
32	40	M	74.8	2	2
33	34	M	72.0	2	2
34	33	M	68.6	2	2
35	21	M	59.4	2	1
36	25	M	65.0	2	2
37	36	M	73.5	2	2

Instruments, devices and closure procedure

The ultrasound system was a PHILIPS IE33 equipped with a three-dimensional X7-2T multi-plane transesophageal probe. Custom-made atrial septal occluders were used for closure, and they were delivered through a 12 or 14 Fr guiding sheath.

RT-3D-TEE "3D zoom" mode was selected to evaluate the number, location, shape, and size of the defects. In addition, RT-3D-TEE was used to evaluate the residual tissue rims and the distance between the defects. According to the information provided by RT-3D-TEE, the operator could further consider the procedure and choose the appropriate size of occluder device based on the ultrasound evaluation results. The placement of the devices in multiple ASDs simultaneously was similar to the deployment of a single device, as in previous reports.[8] All patients had the procedure performed under RT-3D-TEE guidance alone. Based on our experience, if the distance between the two defects was >5 mm, and the residual edge was solid, we deployed two occluders and used two separate catheters to cross the defects. The smaller device was placed first, then we made sure that one edge of the larger device tightly covered the edge of the smaller device before releasing the larger device. If the distance between the defects was ≤5 mm, we used a single device to close both defects. In these cases, the catheter was positioned in the large

Table 2. Atrial septal defects (ASD) measured by two-dimensional transesophageal echocardiography (2D-TEE) and real-time three dimensional (RT-3D) TEE.

	2D-TEE (n=36)	RT-3D-TEE (n=36)	p
Large ASD (mm)	16.1 ± 6.0	17.4 ± 5.8	0.33
Small ASD (mm)	7.2 ± 3.4	8.1 ± 3.2	0.23
Distance between defects (mm)	7.4 ± 2.8	8.1 ± 2.9	0.35

defect, and the device size (waist diameter) was chosen to equal the sum of the diameters of the two defects and the distance between them. One of our 37 patients had three defects, and RT-3D-TEE showed a thin frenulum rather than a hard tissue rim between the defects, so this was a relatively complex case. Because the frenulum was fragile, the device could not be deployed firmly on the defect, so we decided to deploy one large device to cover all three defects. When the defect was >30 mm, we chose the 14 Fr guiding sheath for delivery; the 12 Fr sheath was used in patients with a defect ≤30 mm in diameter.

After the occluders were completely released in all 37 patients, and the position and shape of the devices were well imaged by RT-3D-TEE, we used color Doppler to check for residual shunt. The closures were considered successful if there was no apparent residual shunt or thrombus formation, and the devices had no influence on the surrounding structures.

Results

The maximum size of the defects and the rim between the defects measured by RT-3D-TEE were larger than with 2D-TEE, but there was no significant difference between these measurements (Tables 1 & 2). Sixty-three occluder devices were successfully deployed in 36 patients. Twenty-seven patients had two devices placed and nine patients had a single device placed (Figure 1). The sizes of the devices used to close the larger and smaller defects ranged from 12-40 mm (mean 24.8 ± 7.8 mm) and 12-22 mm (mean 14.1 ± 2.8 mm), respectively. One patient required surgery because of a moderate residual shunt due to the unstable occluder. Therefore, the immediate successful closure rate was 97.3%, based on RT-3D-TEE.

The complications consisted of trivial residual shunt in 5 patients and transient arrhythmias during the procedure in 11 patients. No other severe complications were observed.

Discussion

With the increase in operators' experience and progress in the development of materials used for closure, percutaneous transcatheter closure of ASDs has become an established alternative to surgery. In recent years, there has been an increase in the detection rate

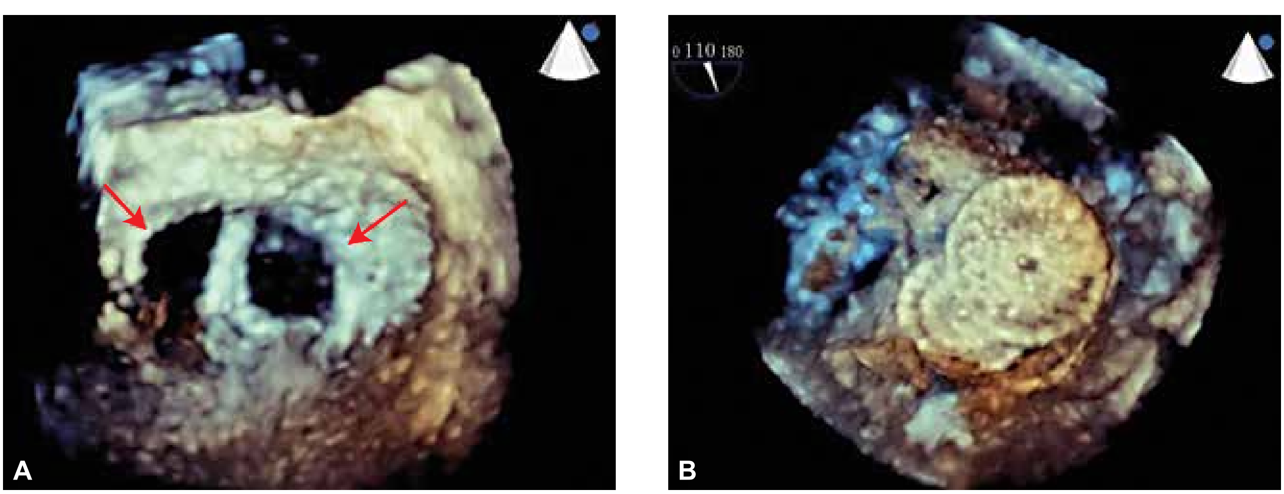

Figure 1. Real-time three-dimensional transesophageal echocardiography used in transcatheter closure of multiple atrial septal defects. (A) Before device deployment, two defects (red arrows) with a sufficient rim between the surrounding structures. (B) After deployment, the two devices can be seen overlapping each other to close the defects.

of multiple ASDs. Podnar et al[9] reported echocardiographic findings in 190 patients with isolated *secundum* ASD referred for device closure and found that 7.3% of these patients had multiple detects. The experience of closing multiple ASDs using more than one Amplatzer septal occluder remains limited.[10-12] Thus, the use of additional devices to close multiple defects has become an important area of clinical investigation.

In percutaneous transcatheter closure of ASD, the "stretched" defect diameter is considered the standard way of measuring ASD size.[13] Many studies have described performing both the measurement of the defect size and the closure process under fluoroscopic or 2D-TEE guidance. However, using a specific catheter that is inflated through the defect increases the damage to blood vessels,[14] while the use of fluoroscopic guidance has the disadvantage of radiation. Fischer et al[15] reported that the "stretched" ASD diameter measured by 2D-TEE and the balloon catheter method had a good correlation with surgical measurement. In recent years, along with the continuing improvement in the level of the interventional closure procedure in our country, many cardiovascular centers have chosen to use 2D-TEE or 2D-TTE to select the appropriate occluder device during the ASD closure operation.

In our center, since 2009, we have tried depending on the ASD large diameter measured by 2D-TEE for choosing the appropriate occluder size, and using 2D-TTE or 2D-TEE only for guiding the transcatheter closure of simple single ASDs. By 2011, we had succeeded in treating 50 patients with a simple single defect, while the ultrasound and catheter operators had accumulated a wealth of experience in selecting indications and cooperating with each other during the procedure. 2D-TEE for diagnosing and assessing multiple ASDs is limited by a narrow scanning range; in particular, it cannot adequately visualize the relationship between the defects and this may led to misdiagnosis. RT-3D-TEE is new echocardiographic technology that has been used to provide a more accurate assessment than 2D-TEE of the heart and valvular structure and function.[16-18] Abdel-Massih et al[19] reported choosing the size of the device based on the balloon-stretched diameter for a single defect and the 3D-TEE maximal diameter for multiple defects. In this study, we describe our initial experience using 2D-TEE with additional help from RT-3D-TEE in selecting the occluder size before operation and guiding percutaneous transcatheter closure using RT-3D-TEE for multiple ASDs. There was no significant difference in the defect size measured by 2D-TEE and RT-3D-TEE. Accordingly, before the procedure, we selected the device size based on the RT-3D-TEE evaluation.

RT-3D-TEE provides a clear overall view of the cardiac structures and allows accurate assessment of the spatial orientation of the defects (Figure 2). Thus, before the procedure, RT-3D-TEE is essential for determining the exact number and position of the defects, and whether patients are suitable candidates for transcatheter closure. RT-3D-TEE also allows an accurate evaluation of the distance between multiple defects and the fragility of the tissue rim, which is essential for determining the closure strategy. Previous studies found that the tissue rim between the two defects should be >7 mm[12] to allow the deployment of two separate Amplatzer devices to close the defects. If the rim was too thin, conventional practice was to use a single large Amplazter device to close both defects. In our study, the distance between the two de-

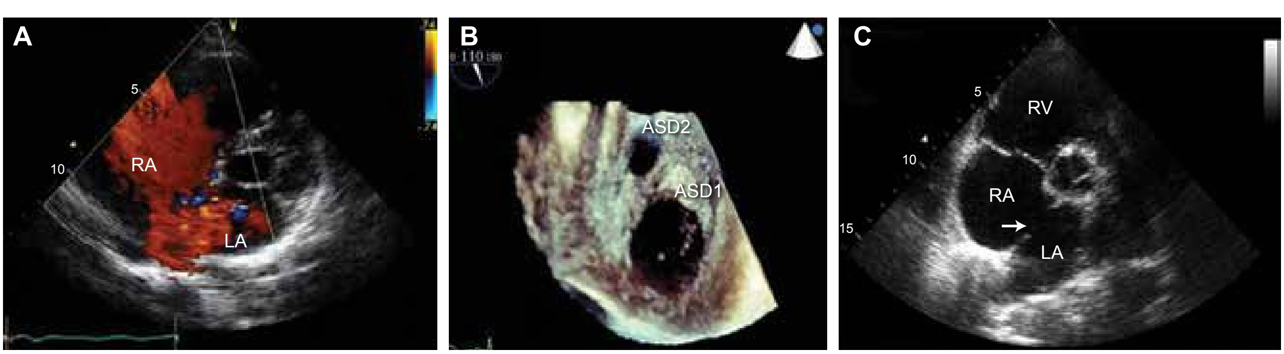

Figure 2. Real-time three-dimensional transesophageal echocardiography (RT-3D-TEE) shows the anterior-to-posterior location of the defects. This type of defect may be missed by two-dimensional echocardiography. (A) Two-dimensional transthoracic echocardiography (color mode) suggests that there is just one defect on the basis of a single shunt from the left to the right atrium. (B) RT-3D-TEE shows the two defects located in the anterior-to-posterior position.

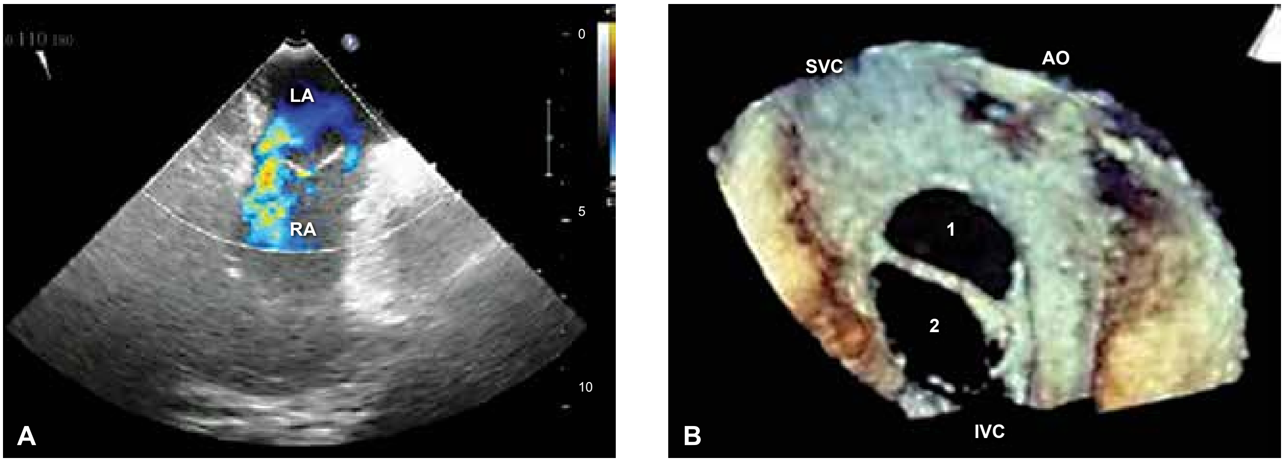

Figure 3. Real-time three-dimensional transesophageal echocardiography (RT-3D-TEE) shows the precise structure of the defects. (A) Two-dimensional transesophageal echocardiography (color mode) shows two left-to-right shunts, indicating two defects, but the tissue between the defects cannot be evaluated. (B) RT-3D-TEE transesophageal echocardiography shows that the structure between the defects is too thin to deploy two devices. LA – left atrium; RA – right atrium; SVC – superior *vena cava*; AO – aorta; IVC – inferior *vena cava*.

fects was 5.5 mm and 6 mm in two patients; however, RT-3D-TEE showed that the residual edge was solid, so we attempted to use two devices to close the defects and satisfactory results were obtained in both cases. This result may be attributed to the fact that our Chinese domestically made occluder is softer than the Amplatzer device. When two or more devices are deployed at the same time they can be easily shaped—thus the residual edge width required is lower. It is worth mentioning that, in some patients, the distance between the two defects was >7 mm based on 2D-TEE, but 3D-TEE showed that the tissue between the defects was a fragile frenulum (Figure 3). Since this frenulum may not support fixation of the two closure devices, RT-3D-TEE can be used to exclude these cases.

Although only two patients in our series had an interatrial septal aneurysm, the presence of an aneurysm can increase the complexity of the shape of the defects. Certainly, RT-3D-TEE should play an important role in evaluating the ASDs in these types of patients.

In addition to preoperative evaluation, RT-3D-TEE is a practical method for guiding and determining the success of the procedure. The deployment of two closure devices simultaneously was similar to deployment of a single occluder. However, the key step was the order of deployment of the two devices and accurate positioning of the delivery sheath. RT-3D-TEE provided immediate feedback to the operator, allowing optimal positioning and deployment of the occluders during the procedure. For patients with defects that have a complex shape and position, the operator can constantly adjust the position of the sheath according to the 3D images provided by RT-3D-TEE. With double-occluder closure, two separate delivery systems were used; we chose to deliver the smaller occluder first, but did not release the occluder until after the larger one had been delivered. If these devices had no impact on the surrounding structures, and both were well shaped, the operator was instructed to release the two occluders simultaneously before withdrawal of the sheath. Once both devices were fixed, RT-3D-TEE was used to immediately assess the device position and the presence of residual shunt.

There are still some limitations to this new technology. It is not currently popular in many ultrasound departments, and it also requires sufficient experience on the part of the operator.

Conclusions

The development of RT-3D-TEE now provides an alternative to 2D-TEE for device closure of multiple ADSs. Through its comprehensive scanning, it allows a more detailed assessment of the anatomy of multiple ASDs and allows selection of the appropriate number and sizes of occlusion devices prior to the procedure. It also allows for proper positioning of the devices during the procedure and provides an effective means of evaluating the success of the procedure. When double devices are implanted simultaneously, the usual requirement for the distance between the two defects may be different using our domestically made devices as opposed to the Amplatzer occluder.

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