Real-time 3D transesophageal echocardiography for the assessment of secundum atrial septal defects in children

Three dimensional transesophageal echocardiography for assessment of atrial septal defects

Pelin Kosger[1], Ayse Sülü[1], Tugcem Akin[2], Hikmet Kiztanir[1], Birsen Ucar[1]
[1]Department of Pediatric Cardiology, Eskisehir Osmangazi University, Faculty of Medicine
[2]Pediatric Cardiology Clinic, Eskisehir State Hospital, Eskisehir, Turkey

Abstract

Aim: The need for more than one cross-section in the imaging of the atrial septum with two-dimensional (2D) echocardiography creates a limitation in determining the morphology of atrial septal defects (ASD) and negatively affects the success of the percutaneous closure procedure. In this study, measurements of ASDs and surrounding rims obtained by 3D transesophageal echocardiography (TEE) were compared with 2D TEE and angiographic balloon sizing measurements.

Material and Methods: The study included 24 pediatric patients with the diagnosis of ASD who were scheduled for transcatheter defect closure. All patients underwent catheter-angiography following a detailed 2D TEE examination.

Results: The data of 17 patients with optimal 3D TEE images were analyzed offline in the Q-lab. The diameter of the defects and surrounding rims, which were measured with two- and three-dimensional TEE were similar (p> 0.05). There was a strong correlation between the two measurement techniques in terms of defect diameter (r = 0.896, p <0.001). While the diameter of the defect measured by the sizing balloon was greater than that measured by 2D TEE, it was similar to that measured by 3D TEE (p <0.001, p = 0.14, respectively). There was also a strong correlation between the defect diameter measured by 3D TEE and balloon sizing diameter (r = 0.844, p <0.001).

Discussion: The "en face" visualization of the atrial septum with 3D TEE provides adequate identification of the defect morphology and adjacent structures. Furthermore, reliable determination of the defect size by 3D imaging may lead to appropriate device selection without the requirement for invasive measurement techniques such as balloon sizing.

Keywords

ASD; Echocardiography; 3D TEE; Percutaneous closure

Introduction

Secundum atrial septal defects (ASDs) are located in the fossa ovale region and are the most common type of ASD that is suitable for closure with a transcatheter [1,2]. Although, transcatheter closure of atrial septal defects has many advantages over the surgical repair, such as the shorter hospital stay, lower risk of complications, and prevention of the morbidity and mortality that can be caused by open heart surgery, the decision of the treatment modality depends on the size, shape, and the surrounding structures [3,4]. A detailed examination of the defect morphology is also necessary to access the best match between the defect and the device in the percutaneous intervention. Thus, complications such as arrhythmia, device embolization, erosion, and obstruction of the adjacent structures can be prevented. The sizing balloon measurement for the determination of the device size is considered the gold standard technique in the percutaneouse closure of ASDs. However, balloon sizing can stretch the defect rims and cause the defect to be measured larger than its size, leading to complications such as rupture of the interatrial septum, balloon rupture, cerebral microembolization, and cardiac perforation [5]. Real-time three-dimensional (3D) echocardiography can provide optimal evaluation of the interatrial septum and adjacent structures, thus the sufficient detection of the defect size, shape, and count during the procedure may eliminate the necessity for balloon sizing and its complications. Therefore, 3D echocardiography, which was claimed to be superior to 2D examination, has gained importance in the management of patients with congenital septal defects, in both children and adults [6-9].

In this study, we aimed to define the advantages and limitations of 3D TEE examination over 2D in evaluating the size, shape, and rims of atrial septal defects, which were considered suitable for closure by transcatheter or surgically in children.

Material and Methods

The study included 24 pediatric patients with the diagnosis of secundum ASD who were scheduled for transcatheter closure in the Department of Pediatric Cardiology, Eskisehir Osmangazi University between February 2019 and May 2020. Transthoracic echocardiographic examination was performed using a 3 MHz probe with a Philips EPIQ CVx (Philips Medical Systems, Andover, USA). A Philips EPIQ CVx device and a TEE probe with X7-2T two- and three-dimensional imaging features were used in the TEE procedure. The total septum, anterosuperior and anteroinferior rims (aortic and atrioventricular valve rims), posterosuperior and posteroinferior rims (VCS and VCI rims), inferior and posterior rims (coronary sinus and pulmonary vein rims) and defect diameter were measured at 0, 30, 90 and 120 degrees with 2D TEE. Rim length was considered deficient if the length was < 5 mm. The Ethics Committee of Eskisehir Osmangazi University approved this study (Approval number: 2020-374). Each patient provided informed consent prior to participating in the study.

Evaluation of three-dimensional images

Prior to the catheter-angiography procedure, 3D TEE images were obtained via X plane and zoom modes [10]. The data were transferred to the Q-lab software (Philips, Best, The Netherlands) for analysis. The en face images of the atrial septum were obtained with the cropping method. On en face images, the measurements were performed for defect diameter, rims, and adjacent structures using a multiview technique for required patients (Figure 1).

The percutaneous closure procedure of the ASDs

All interventional procedures were performed under general anesthesia. After placing a sheath into the right femoral vein, pressures were measured by performing diagnostic catheterization, blood samples were collected, and pulmonary (Qp) and systemic (Qs) flows were calculated. The patients were given 100 IU / kg of heparin (maximum dose of 5000 IU). Activated clotting time (ACT) was kept longer than 200 seconds. The balloon catheter was placed in the defect through a stiff wire inserted into the upper left pulmonary vein by advancing through the femoral vein. The sizing balloon was inflated until the shunt flow was completely cut under the guidance of 2D TEE. The balloon diameter was measured on simultaneous fluoroscopy. Considering the flexibility and dimensions of the adjacent rims, the device diameter was determined to be equal to or 2 mm larger than the balloon diameter. Then, the device was placed under the guidance of 2D TEE and left in the septum.

Statistical analysis

Statistical analysis was performed using the Statistical Package for Social Sciences, version 15 (SPSS, Chicago, USA). The results of descriptive analyses were expressed as mean ± SD for numerical variables. The consistency of variables with normal distribution was assessed using the Shapiro–Wilk test. The groups were compared using Student's t- test for continuous variables, and the Mann–Whitney U test was used for non-normally distributed variables. Comparisons between measurements were performed using paired t-tests and linear regression analysis. The correlation between the continuous variables was performed using the Pearson correlation coefficient. A p- value of less than 0.05 was considered statistically significant.

Results

The mean age of 24 patients (15 females, 9 males) was 6.01 ± 2.99 years (3-13.6 years). The mean ASD diameter of the patients measured by 2D TTE was 14.1 ± 4.59 mm (7 - 24 mm), the mean pulmonary artery pressure measured by catheter-angiography was 20.5 ± 3.51 mmHg, and the mean Qp / Qs ratio was 2.03 ± 0.21. The number of defects was single in 19 patients and multiple in 5 patients. There were additional cardiac anomalies in two patients, one with mild pulmonary stenosis and the other with mild aortic valve insufficiency. In the 16 procedures for transcatheter ASD closure, Amplatzer Septal Occluder was attempted in 8 patients and the Occlutech Flex II Septal Occluder device was attempted in 8 patients. The remaining 8 patients were referred to the surgery due to insufficient interatrial septum size and surrounding rims, especially the posteroinferior rims. The mean defect diameter in those 8 patients was larger than in patients who underwent percutaneous closure (p <0.001) (Table 1). No major complications were observed during the procedure and at the follow-up. In one patient, a minimal residual shunt persisted from the inferior end of the defect following the placement

Table 1. Comparison of demographic data of patients with and without closure of the atrial septal defect percutaneously

Variables	Patients (n = 24)	Patients with only diagnostic catheter angiography (n=8)	Patients who closed atrial septal defect percutaneously (n = 16)	p
Age (year)	5.35 ± 2.51	5.1 ±2.48	5.43 ± 2.61	0.658
Male/female	14/7	4/3	3/11	0.127
Weight (kg)	19.3 ± 7.39	18.42 ± 5.71	19.75 ± 8.27	0.710
Height (cm)	113.7 ± 17.21	111.71 ± 18.84	114.78 ± 16.97	0.723
BMI (kg/m²)	14.55 ± 1.47	14.58 ± 1.12	14.53 ± 1.66	0.947
Defect diameter (mm)	13.59 ± 4.37	18.58 ± 4.31	11.85 ± 2.76	<0.001
Defect number (single/multiple)	19/5	6/2	13/3	0.557
RA dilatation (yes/no)	12/10	6/2	6/10	0.361
Rv dilatation (yes/no)	16/8	7/1	9/7	0.174
PAP (mean) (mmHg)	20.5 ± 3.51	18 ± 3.34	20.14 ± 3.57	0.227
Qp/Qs	2.03 ± 0.21	2.1 ± 0.12	2 ± 0.24	0.351

BMI: Body mass index, RA: right atrium, RV: right ventricle, PAP: pulmonary artery pressure, Qp/Qs: the ratio of total pulmonary blood flow to total systemic blood flow

Table 2. Comparison of two and three- dimensional transesophageal echocardiography measurements in terms of defect diameter and surrounding rims

Variables	2D TEE	3D TEE	p
Defect diameter (mm)			
Maximum	13.12 ± 4.32	13.92 ± 4.54	0.309
Minimum	9.32 ± 3.37	9.82 ± 4.09	0.245
Anterosuperior rim	3.18 ± 2.72	3.53 ± 2.09	0.771
Posteroinferior rim	14.81 ± 3.54	12.83 ± 3.27	0.107
Posterosuperior rim	12.62 ± 2.77	9.76 ± 2.88	0.075

2D TEE: Two- dimensional transesophageal echocardiography, 3D TEE: three- dimensional transesophageal echocardiography

Table 3. Correlation between device diameters, maximum ASD diameters measured by 2D and 3D transesophageal echocardiogram, and diameters measured by sizing balloon

Variables	Sizing balloon diameter (mm)	
	r	p
Device diameter (mm)	0.910	<0.001
2D TEE diameter (mm)	0.960	<0.001
3D TEE diameter (mm)	0.844	<0.001

ASD: Atrial septal defect, 2D TEE: two- dimensional transesophageal echocardiography, 3D TEE: three -dimensional transesophageal echocardiography

of the device. The shunt amount gradually decreased during 1 and 3 months of follow-up, and the residual defect disappeared after 6t- months.

Three-dimensional TEE could not be performed in seven patients due to a bodyweight of <20 kg. In the remaining 17 patients, the minimum and maximum defect diameters measured with 2D and 3D TEE were similar (p> 0.05). In addition, a strong correlation was reviled between the two measurement techniques in terms of defect diameter (r = 0.896, p <0.001). The dimensions of the aorta, vena cava inferior, and vena cava
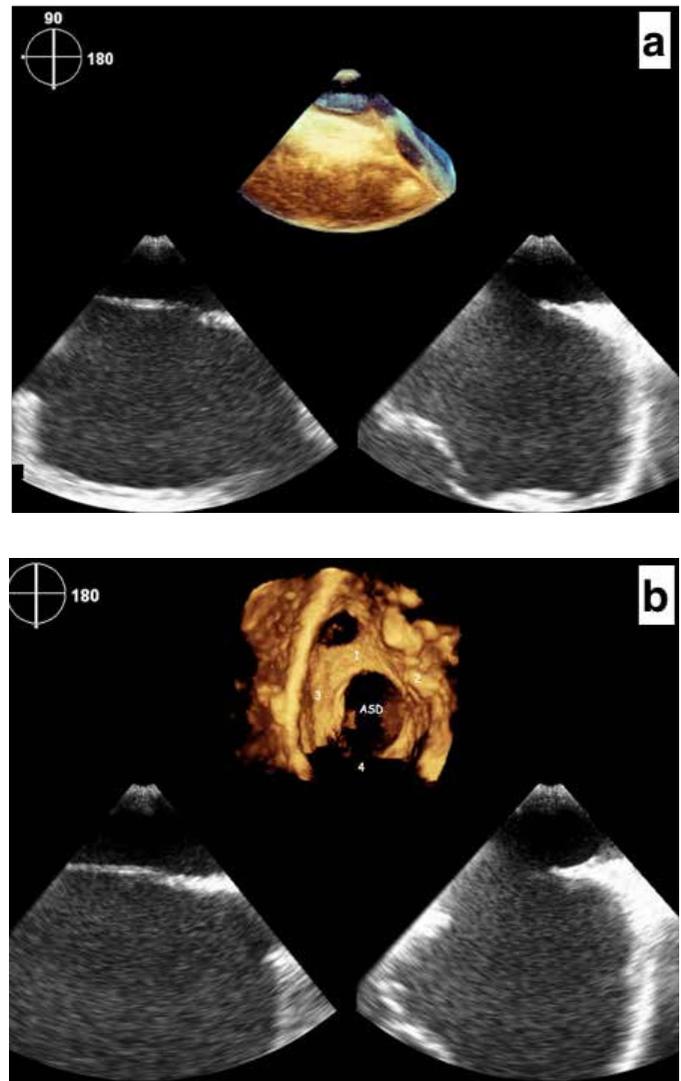
Figure 1. Real- time three-dimensional transesophageal echocardiographic assessment of atrial septal defect and surrounding rims. (a) Real-time 3D TEE image of the atrial septal defect obtained with the guidance of 2D TEE images at 90 and 180 degrees. (b) The "en face" image of the atrial septum and atrial septal defect, obtained by up-down the real-time 3D TEE image 90 degrees counterclockwise and turning it to the left. (ASD: Atrial septal defect; 1: Superior rim; 2: anterior rim; 3: posterior rim; 4: inferior rim.)

superior rims were similar in 11 patients in whom the rims adjacent to the defect could be measured optimally by both 2D and 3D TEE (p> 0.05) (Table 2).

Sizing balloon was not used in 8 patients who did not undergo percutaneous closure, since it was not required. In the remaining 16 patients, the defect diameter measured by sizing balloon was larger than the diameter measured by 2D TEE (13.99 ± 4.23 mm and 12.31 ± 4.17 mm, respectively, p <0.001), while it was similar with the 3D TEE (13.99 ± 4.23 mm and 13.02 ± 4.58 mm, p = 0.14, respectively) (Table 3). There was a strong correlation between sizing balloon and 3D TEE measurements, and the device size (r = 0.960, p <0.001; r = 0.844, p 0.001, r = 0.910, p 0.001; respectively). The defect diameter measured by 3D TEE and the device size were not correlated (r = 0.303, p = 0.314).

Discussion

Transcatheter closure of atrial septal defects in children is a safe and effective method, and the defect should be closed in symptomatic patients with findings of increased volume in the right heart chambers. The presence of pulmonary obstructive disease is a contraindication to defect closure. Therefore, the response to the vasoreactivity test may be a determinant for contraindication [11,12]. In the present cohort, in accordance with the volume overload, the right heart chambers were enlarged and the Qp / Qs ratios were >1.5. Although the pulmonary artery pressure was less than 2/3 of systemic arterial pressure, the response to the vasoreactive test was positive in one patient with 38 mmHg. In 8 of 24 patients, device closure could not be performed due to insufficient surrounding rims and/or total interatrial septum size. One of the indications for surgical closure of atrial septal defects is that the rims and/ or total interatrial septum is insufficient to place the device. It has been reported that this may be related to the larger size of surgically closed defects compared to percutaneously closed defects, and therefore, higher surgical morbidity [13]. In our study, the defect size was significantly larger in patients in whom transcatheter closure could not be performed, compared to those in whom transcatheter closure could be performed. While no intraoperative or postoperative major complication was observed in our patients whose defects were closed with the transcatheter technique, clinical findings that may be compatible with cerebral ischemia were observed in one of the patients who have undergone a surgical procedure. This was in line with the view that morbidity associated with surgical repair may be more serious compared to the transcatheter technique. Recent studies comparing 2D and 3D TEE in terms of appropriate detection of defect size have shown that 3D TEE may have some advantages. [14,15]. Jori et al. reported that 2D TEE measurements were insufficient compared to 3D TEE, especially in determining the size of atrial septal defects with a complex structure [14]. Comparing with 3D TEE images, Lodato et all. stated that the defect size can be measured smaller than its actual size in the long axis and larger than its actual size in the short axis using 2D TEE [15]. The mismatch between the measurements is mainly due to the form of the defect. Atrial septal defects often have different forms, and it can be misleading to determine the maximum size of non-round defects using two-dimensional measurements. In the present study, one of the reasons for the consistency between measurement methods might be that the defects' forms were generally round, and the other one was that 2D measurements could be larger than normal due to the fact that they were performed in color mode.

It is well known that secundum ASDs show morphological variation [16]. Therefore, determining the shape, number, and surrounding rims of the defect is as important as the size of the defect for successful transcatheter closure [17]. Transesophageal echocardiography is a technique that is widely used for this purpose and has very successful results [18]. However, since two-dimensional evaluation requires different angles and multiple appropriate sections, it may cause difficulty in orientation and overlook of anatomical details [19]. Especially the evaluation of the posterior-inferior

rims and some irregular defects may be insufficient. This may result in residual shunt or embolization of the device [20]. On 3D echocardiography, morphology, spatial relationships, and rims of the defect can be evaluated accurately with real-time "en-face" images [19,21]. The use of three-dimensional TEE can increase the success of the procedure by allowing the detection of irregular atrial septal defects that cannot be detected by a two-dimensional examination [22]. When the three-dimensional images of our patient, whose minimal residual shunt was persisted after the transcatheter insertion of the device, were examined, it was observed that the lesion expanded irregularly in the inferior part of the lesion. Therefore, it was thought that the device may not have been able to provide full closure. In the sixth month after the procedure, there was no need for placing a second device due to the disappearance of the shunt with the endothelialization process of the device. In our study, all percutaneous device placement procedures were performed under the guidance of 2D TEE, and 3D TEE images were evaluated offline. Therefore, the interventionist had no knowledge of 3D TEE measurements during the procedure. However, in this patient, examining the "en face" images during the procedure could contribute to a better understanding of the defect morphology and the selection of a more suitable device. Three-dimensional TEE is also very useful for evaluating the relationship of the device placed in the defect with adjacent structures such as the aorta, and the erosion that it may cause. The device can clearly determine the distance between the defect and the aorta prior to placement, and the degree of erosion that may occur after placement. It is known that insufficient anterosuperior rim increases the risk of device erosion in the aorta [23]. In our study, the distance between the aorta and the defect in 3D TEE measurements was greater than in 2D TEE measurements, although there was no statistically significant difference. There was no difference between 2D and 3D TEE measurements in terms of other surrounding rims. However, it was considered an important advantage that 3D TEE enables real-time and high-resolution imaging in the examination of the defect and surrounding structures, as in determining the spatial relationship between the aorta and the defect.

Although "sizing balloon" is an adopted technique for determining the exact diameter of the defect, inflating the balloon more than necessary may lead to estimation of the defect size more than its actual size.

Consequently, using an oversized device increases the risk of erosion. Sizing balloon may lead to the ruptures of the mobile and thin rims of the lesion, increasing the complications associated with the procedure. Therefore, recently, the closure of ASDs with alternative imaging techniques is increasingly preferred without using the "sizing balloon" technique [24]. The use of three-dimensional echocardiography, especially 3D TEE, can enable to determine the accurate defect diameter without the requirement for sizing balloons, thereby preventing possible complications. In our study, the mean defect diameter measured angiographically with "sizing balloon" was similar to 3D TEE measurements, and the positive correlation between the two measurements supports that 3D TEE is a reliable technique and an alternative to sizing balloon.

The main limitation of the present study is being a single-

center study with a small number of patients. Multicenter studies comparing 3D TEE and 2D TEE will be more informative in evaluating ASD morphology. Three-dimensional TEE images were examined offline, not during the percutaneous closure. Therefore, studies including the percutaneous closure of ASDs by the guidance of 3D TEE can provide more information on the effectiveness and reliability of the imaging technique.

With real-time "en face" imaging provided by three-dimensional echocardiography technology, the complex morphology of ASDs and their relationship with adjacent structures can be clearly understood. In addition, device selection can be performed by accurately determining the defect size without the necessity to use invasive techniques that increase the procedure length and time of fluoroscopy such as "sizing balloon". Therefore, 3D TEE, when used by experienced operators, is a useful and non-invasive imaging technique that can increase the success rate of percutaneous procedures along with decreasing complication rates.

Scientific Responsibility Statement
The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement
All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No animal or human studies were carried out by the authors for this article.

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Conflict of interest
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