Review Article

My Approach to Transcatheter Closure of Atrial Septal Defect: Step-by-Step and Current Contraindications

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Abstract

All patients who are candidates for transcatheter closure of an ostium secundum atrial septal defect (ASD) should undergo a detailed echocardiographic assessment using 2D transesophageal echocardiography (TEE) prior to the procedure. It is essential for a comprehensive analysis of interatrial septal anatomy and for determining defect eligibility for the procedure. The type, number, size, location and morphology of the ASD, as well as the quality of the surrounding septal tissue and its relationship with adjacent cardiac structures, should be carefully assessed. 3D TEE may complement this assessment by providing additional relevant anatomical information. During the procedure, TEE plays a fundamental role in real-time guidance, allowing proper deployment of the septal occluder device as well as immediate assessment of the result and early detection of potential complications. This article presents a practical approach to transcatheter closure of ostium secundum ASD, with emphasis on echocardiographic aspects in the pre-procedural, intraprocedural, and post-procedural phases.

Introduction

Ostium secundum atrial septal defect (ASD) is the most common form of interatrial septal defect (IASD) and can often be treated with percutaneous transcatheter closure. Currently, this method is the preferred approach when anatomy is favorable.[1] Pre-procedural transthoracic echocardiography is usually sufficient in most pediatric patients. However, in adults, transesophageal echocardiography (TEE) is recommended for better characterization of septal anatomy. This examination is generally performed in patients previously identified as candidates for closure, based on the following indications:

- Isolated ostium secundum ASD with a pulmonary-to-systemic flow ratio (Q_P/Q_S) > 1.5;
- Signs of right ventricular (RV) volume overload;
- Absence of cyanosis;
- Absence of significant or irreversible pulmonary hypertension.

Guidelines from the American College of Cardiology/ American Heart Association recommend ASD closure in patients with RV dilation, regardless of symptom presence (Class I). On the other hand, small defects (diameter < 5 mm), in the absence of RV dilation, do not require intervention, as they are not considered hemodynamically significant nor capable of altering the clinical course.[2]

In addition, it is essential to exclude the presence of associated congenital anomalies that would indicate surgical correction, such as anomalous pulmonary venous connections, as well as the presence of intracardiac thrombi.

The main aspects of transcatheter closure of ostium secundum ASD will be described below, with emphasis on echocardiographic findings and the role of echocardiography at different stages of the procedure.

Anatomy of the interatrial septum

A detailed understanding of cardiac anatomy is essential for performing structural interventions. Ostium secundum ASD corresponds to a true discontinuity, single or multiple, in the embryonic septum primum, which forms the floor of the fossa ovalis. This structure is located in the central portion of the IAS.

The fossa ovalis is surrounded by the septum secundum, an invagination of the atrial roof filled with epicardial fat. It is considered a "false septum," as this adipose layer lies outside the atrial cavities. Ostium secundum defects are bounded by rims of septal tissue adjacent to the limiting structures of the right atrium (RA).

Among the most relevant adjacent structures are the aortic root, located anteriorly, and the venous inflows draining into the RA, including the superior vena cava (SVC), inferior vena cava (IVC), and the coronary sinus. These structures maintain a close anatomical relationship with the left atrium (LA)[1,3,4] (Central Illustration).

The size of the defect and the integrity of the septal rims are determinants of successful transcatheter ASD closure.

Size and shape of ostium secundum atrial septal defect

Ostium secundum ASDs show wide variation in size and morphology, and may present as elliptical, round, slit-like, or slightly irregular shapes (Figure 1). In some cases, persistent

Keywords

Heart Septal Defects, Atrial; Catheterization; Echocardiography

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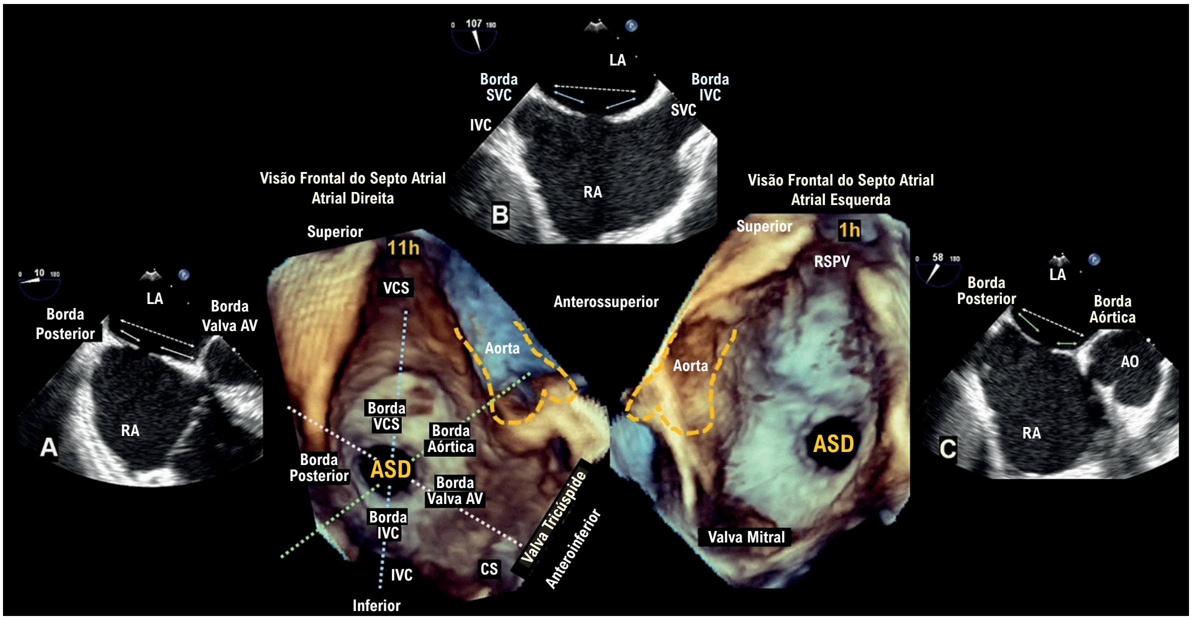
Central Illustration: My Approach to Transcatheter Closure of Atrial Septal Defect: Step-by-Step and Current Contraindications



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Images obtained by TEE illustrate the anatomical assessment of ostium secundum ASD and its suitability for transcatheter closure. The central images show the 3D frontal (en face, zoom mode) view of the ASD and IAS in the recommended anatomical orientation, highlighting adjacent structures from the perspectives of the right and left atria, respectively. The 2D images show the standardized planes for defect measurement: A) four-chamber view; B) bicaval view; C) aortic valve short-axis view. These views allow assessment of ASD diameter and its rims (yellow, blue, and green arrows) as well as IAS length (white arrows). The dashed lines overlaid on the frontal 3D image indicate the cutting planes used to obtain the 2D images. AO: aorta; ASD: atrial septal defect; CS: coronary sinus; IAS: interatrial septum; IVC: inferior vena cava; LA: left atrium; RA: right atrium; RSPV: right superior pulmonary vein; SVC: superior vena cava; TEE: transesophageal echocardiography.

septum primum strands may cross the defect, resulting in multiple communications and the formation of fenestrations. In large defects, the septum primum is often reduced or nearly absent.[1]

The size of these communications may range from a few millimeters to more than 30 mm in diameter. Large defects, defined as > 20 mm in children or > 30 mm in adults, represent greater technical complexity and are often associated with deficient septal rims, which may require modified closure strategies.

Defect measurement is recommended during both systole and diastole. An ASD is considered dynamic when it shows at least a 50% variation in its dimension throughout the cardiac cycle. In general, the size of the septal occluder device (SOD) is determined based on the largest linear diameter of the defect, usually obtained during diastole.

Assessment of ASD size should preferably be performed using 2D echocardiography combined with color Doppler. In addition, these defects may progressively enlarge over time, following cardiac growth and aging.[1,4]

Dimension and quality of ostium secundum atrial septal defect rims

Ostium secundum ASD may be located in different regions of the fossa ovalis, either centrally or peripherally (Figure 2, Panels A and B). This variability determines the amount of surrounding septal tissue, known as rims, that delimit the defect. A detailed assessment of such rims is essential to determine eligibility for transcatheter closure, as this is the tissue where the SOD will be anchored.

Rims are named according to adjacent anatomical structures and are classified as follows[1,4,5] (Central Illustration):

- Aortic rim (anterosuperior): between the ASD and the aortic valve annulus and aortic root;
- Atrioventricular valve rim (anteroinferior): between the ASD and the atrioventricular valves;
- Superior vena cava rim (posterosuperior): between the ASD and the SVC;
- Inferior vena cava rim (posteroinferior): between the ASD and the IVC;

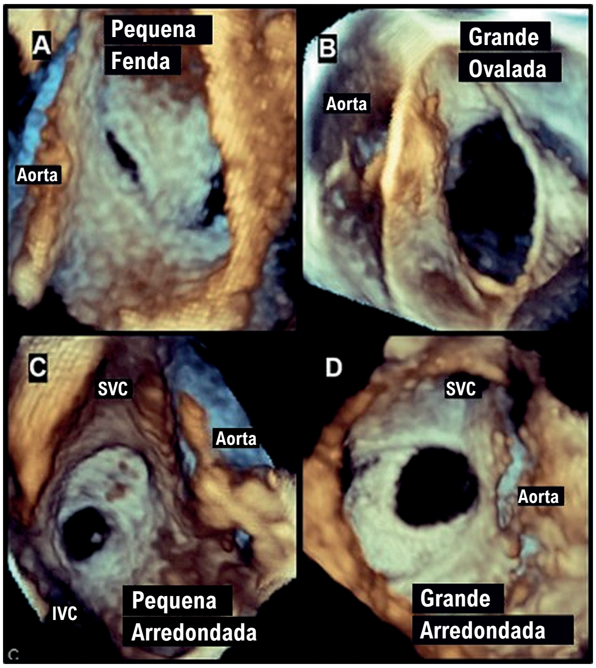

Figure 1 – *3D transesophageal echocardiography images, in zoom mode, illustrate representative examples of different sizes and shapes of ostium secundum ASD, obtained from en face views of the interatrial septum.*

- Posterior rim: between the ASD and the posterior atrial walls.

Additionally, the rim related to the right superior pulmonary vein (RSPV), located posteriorly between the ASD and such a vein, may also be assessed.

By convention, a rim length > 5 mm is considered adequate, representing a favorable feature for transcatheter closure. Rims measuring 3-5 mm are classified as deficient, whereas those < 3 mm are considered insufficient. The presence of rims < 5 mm may make the procedure more challenging and require specific technical strategies, although it is not an absolute contraindication.

The integrity of the posterosuperior, posteroinferior, and anteroinferior rims is particularly relevant for procedural success. In contrast, deficiency of the aortic rim, although associated with a potential risk of erosion, is not a contraindication, and adaptation of the SOD to the aorta is often desirable.[4]

In addition to length, the structural quality of the rims should also be assessed. Thin and redundant rims, especially in the posterior and posteroinferior regions, may be associated with additional fenestrations, characterizing multiple defects (Figure 2C).

General imaging protocol of the interatrial septum

2D transesophageal echocardiography

2D TEE forms the basis of imaging assessment of the IAS. Since ostium secundum ASD may be located anywhere within

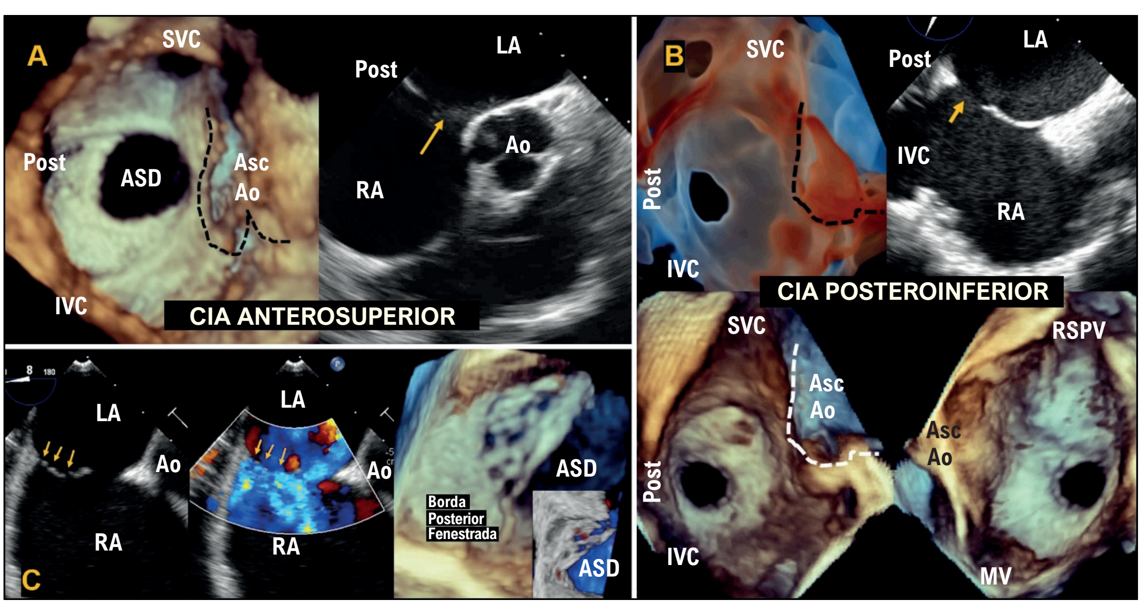

Figure 2 – *Examples of TEE images of ostium secundum ASDs. A) ASD located in the anterosuperior region of the IAS, visualized by 3D TEE from the RA perspective and by 2D TEE (arrow); B) ASD located in the posteroinferior region of the IAS, demonstrated by 3D TEE from multiple perspectives and by 2D TEE (arrow); C) Image of the posterior rim showing multiple small fenestrations, observed on 2D TEE and with greater detail on 3D TEE. Ao: aorta; ASD: atrial septal defect; IAS: interatrial septum; IVC: inferior vena cava; LA: left atrium; Post: posterior; RSPV: right superior pulmonary vein; SVC: superior vena cava; TEE: transesophageal echocardiography.*

the fossa ovalis, image acquisition should begin at 0° and the transducer angle should be progressively increased in 15° increments up to approximately 120°, allowing complete septal evaluation.

2D images should be optimized before applying color Doppler. The color Doppler scale may be adjusted to lower values (≈ 35-40 cm/s) to facilitate detection of low-velocity flows, such as in small fenestrations or smaller defects.

Most standard views are obtained at the mid-esophageal level, including:

- Four-chamber view (0°-30°): allows assessment of the posterior rim and atrioventricular valves;
- Inflow-outflow or aortic valve short-axis view (45°-60°): demonstrates the posterior and aortic (anterosuperior) rims;
- Bicaval view (90°-120°): allows evaluation of the posterosuperior (SVC) and posteroinferior (IVC) rims.

Clockwise rotation of the probe from the aortic valve short-axis view (45°-60°) enables visualization of the right pulmonary veins. Withdrawing the probe to the upper esophagus, combined with progressive angular sweep from 0°, allows better assessment of the superior portion of the septum.

In the bicaval view at 120°, in cases of superiorly located ASD, the posterosuperior rim can be visualized. Additional clockwise rotation allows identification of right pulmonary venous drainage, aiding in the differentiation between superior sinus venosus defect and superiorly located ostium secundum ASD.

When the posteroinferior rim is not adequately visualized in the bicaval view, maneuvers such as probe retroflexion or gradual angle reduction to approximately 60° may bring the IVC into the imaging field. This rim is often the most difficult to delineate by TEE, but its assessment is essential, as its deficiency, observed in approximately 3.3% of cases, is associated with a higher risk of SOD dysfunction. Nevertheless, in selected cases, percutaneous closure may be performed with appropriate technical adjustments.

The deep transgastric position may also be used to obtain a sagittal bicaval view. Initially, the RV inflow is identified at 90°, followed by increasing the angle to 100°-120° and slight clockwise rotation of the probe.[1,4,5]

3D transesophageal echocardiography

The IAS has a complex 3D anatomy, and 3D TEE provides additional relevant anatomical information. This modality allows acquisition of en face views of the ASD from both RA and LA perspectives, enabling detailed evaluation of defect rims and their relationship with adjacent structures.

In addition, 3D TEE allows real-time characterization of defect shape (especially in elliptical or multiple defects) and measurement of its minimum and maximum dimensions throughout the cardiac cycle. It also enables direct visualization of the SOD after implantation, as well as immediate assessment of its positioning and potential complications.

The technique also allows biplanar or triplanar acquisition, with simultaneous display of orthogonal planes (e.g., aortic valve short-axis and bicaval views), with high temporal resolution, which is particularly useful for guiding transcatheter procedures (Figure 4, Panel D).

3D volumetric acquisition is performed from standard 2D projections, such as the aortic short-axis or bicaval views. Before 3D acquisition, it is essential to optimize the 2D image. Proper gain adjustment is critical to avoid artifacts that may falsely simulate multiple defects, which cannot be corrected during post-processing.

3D TEE offers different acquisition modes, particularly real-time (narrow-angle) and wide-sector zoom modes.

3D display

According to anatomical convention, in the en face view, the IAS and ASD should be rotated so that the SVC is positioned at approximately the 11 o'clock position, the IVC along the inferior vertical axis, and the aorta anteriorly, directed toward the upper right corner of the image, from the RA perspective.

From the LA perspective, the 3D image is inverted along the superior-inferior axis. In this configuration, the RSPV, adjacent to the SVC, is positioned superiorly (approximately at the 1 o'clock position), the aortic root occupies the anterosuperior left region, and the mitral valve is located in the anteroinferior portion (Central Illustration).

These orientations should be used as an initial reference for systematic image interpretation.[1]

Complex ostium secundum atrial septal defect

Morphological variables may make transcatheter closure of ostium secundum ASD more challenging (Figure 3). ASD is considered complex, with potential surgical indication, in the following situations:

- Large ASD: diameter > 30 mm;
- Multiple ASDs or multifenestrated IAS: multiple fenestrations are present in approximately 2.7% of cases and are often associated with IAS aneurysm.[1] Characterization of the number, size, and location of the defects is essential for SOD selection and for anticipating procedural complexity;
- IAS aneurysm: may compromise SOD stability and positioning, influencing device selection;
- Deficient or non-firm rims (thin and redundant): may impair proper device anchoring.

These anatomical variations may favor the use of specific devices for multiple fenestrations or, in some cases, require implantation of more than one SOD. Defects exceeding the size of available devices may require surgical management.

In addition, measurement of IAS length (Central Illustration) is recommended, as devices with an occluder disc larger than 90% of this length may be associated with a higher risk of cardiac erosion.

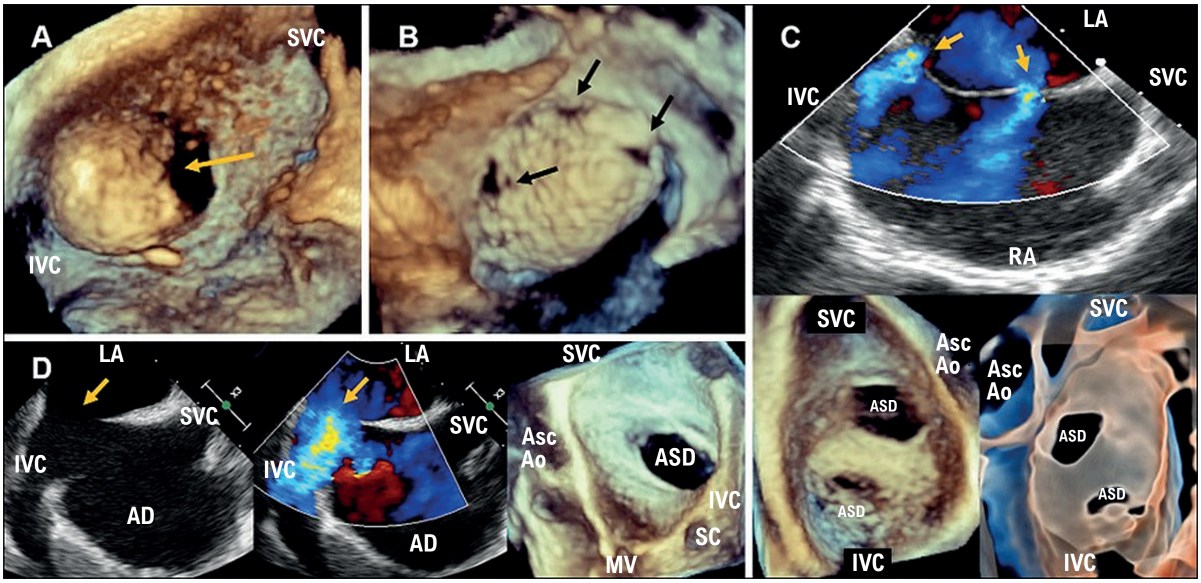

Figure 3 – *Examples of images obtained by TEE of complex ostium secundum ASDs. A) 3D frontal view demonstrating ASD associated with an IAS aneurysm (yellow arrow); B) 3D TEE frontal view showing ASD associated with an aneurysmal and multifenestrated IAS (black arrows); C) 2D TEE images (upper panel, yellow arrows) and 3D TEE images (lower panel) demonstrating an IAS with two ASDs; D) 2D TEE images (right panel, yellow arrow) and 3D TEE images (left panel) showing ASD with absence of the posteroinferior rim. RA: right atrium; LA: left atrium; Asc Ao: ascending aorta; ASD: atrial septal defect; TEE: transesophageal echocardiography; IAS: interatrial septum; IVC: inferior vena cava; SVC: superior vena cava; MV: mitral valve.*

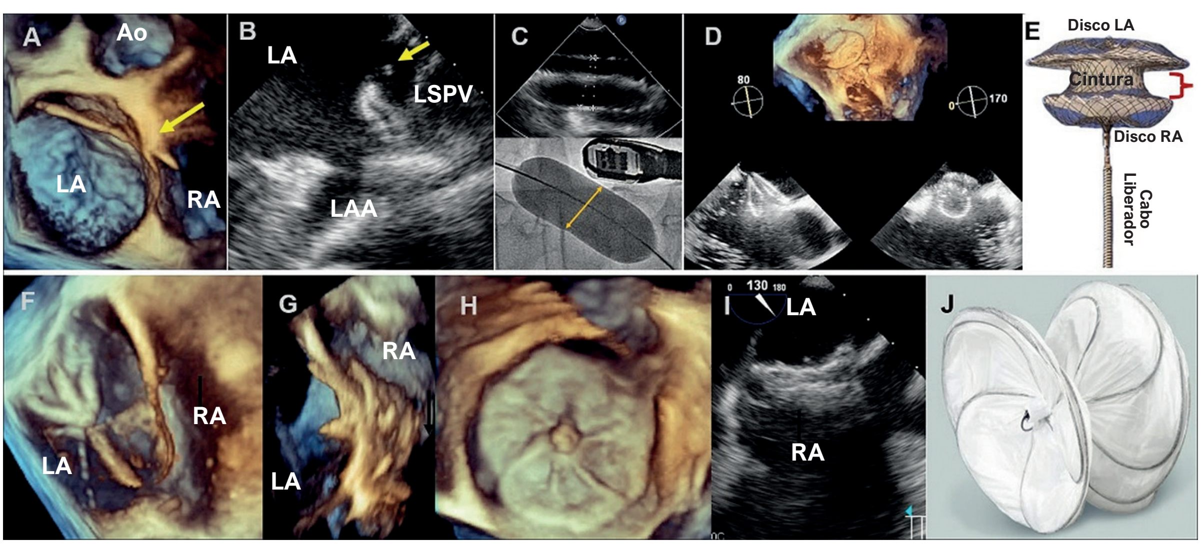

Figure 4 – *mages obtained during the transcatheter closure procedure of ostium secundum ASD. A) 3D TEE image demonstrating the guidewire crossing the IAS; B) 2D TEE image showing the catheter positioned in the LSPV (yellow arrow); C) Measurement of the stretched ASD diameter by TEE (upper panel) and fluoroscopy (lower panel); D) Multiplanar reconstruction by 3D TEE demonstrating the positioning of the Amplatzer septal occluder device in the IAS; E) Schematic illustration of the Amplatzer device; F) Formation of the left atrial disc of a non-self-centering device in the LA, with a "tulip-like" appearance, visualized by 3D TEE; G) Profile view of the device; H) Frontal view of the device; I) 2D TEE image of the implanted device; J) Illustration of a non-self-centering device. RA: right atrium; LA: left atrium; LAA: left atrial appendage; Ao: aorta; ASD: atrial septal defect; TEE: transesophageal echocardiography; IAS: interatrial septum; LSPV: left superior pulmonary vein.*

Septal occluder device

Several SODs are available for percutaneous transcatheter closure of ostium secundum ASD. The Amplatzer-type device consists of two self-expanding discs connected by a self-centering waist, made of nitinol mesh, allowing recapture and repositioning during implantation. The LA disc has a larger diameter due to higher pressure in this chamber compared to the RA. The main reference for device selection is the waist diameter, which should correspond to the defect size (Figure 4, Panel E).

Non-self-centering devices, specifically developed for multifenestrated IAS, consist of two discs of equal diameter connected by a thin waist positioned at the central defect. In this configuration, the disc size on both sides of the septum maximizes coverage of multiple fenestrations. In these cases, the central ASD is the main reference for sizing, and disc diameter is the most relevant parameter (Figure 4, Panel J).

Transcatheter closure of ostium secundum atrial septal defect

Echocardiography provides essential information at all stages of the procedure, including patient selection, SOD choice, intraprocedural guidance, complication monitoring, and outcome assessment.

A key step during the procedure is ASD measurement. This evaluation is performed by echocardiography, as previously described, and complemented by angiography using a sizing balloon.

Balloon sizing is based on the concept of stretched diameter, in which the ASD diameter measured by TEE is smaller than the diameter obtained after balloon inflation. Although TEE is essential for rim assessment, it does not allow precise determination of their structural composition. The sizing balloon is therefore crucial to expand the septal rims until they provide adequate resistance for device anchoring. This measurement defines the minimum SOD size required for proper fixation.[4-6]

Measurement of stretched diameter is performed using the stop-flow technique. This technique consists of gradual balloon inflation until interruption of left-to-right flow, which should be confirmed by echocardiography with color Doppler. Ideally, the balloon presents a central constriction (“waist”), indicating proper positioning and centering within the defect (Figure 4, Panel C). The balloon waist corresponds to the reference for the diameter of the device to be implanted.

The selected balloon should have a diameter larger than initially estimated to allow adequate septal stretching. In general, an increase of approximately 30%-35% compared with the initial measurement is observed. Inflation should not exceed the point of flow interruption or the balloon’s maximum volume to avoid excessive defect distension. The presence of a waist without flow interruption may indicate multiple communications within the fossa ovalis.

After determining defect diameter, SOD size may be selected according to different criteria: diameter equal to the defect, one size larger, stretched diameter plus 0-2 mm, or, in cases of thick and firm rims, 20%-30% larger than the measurement obtained by TEE.

Step-by-step guidance for transcatheter closure of ostium secundum atrial septal defect

1. Initially, TEE should be used to assess the ASD in terms of morphology, location, and rim characteristics;
2. Venous access is generally obtained via the IVC, visualized in the bicaval view. At this stage, the guidewire is directed superiorly toward the IAS, aiming to cross the defect and reach the LA. The course of the wire should be clearly identified in the RA to avoid entry into the RA appendage, a structure adjacent to the SVC and a potential site of atrial perforation. It is also important to check for the presence of a Chiari network due to the risk of wire entanglement; therefore, complex maneuvers within the RA should be avoided;
3. The guidewire is then advanced to cross the IAS (Figure 4A);
4. Once in the LA, the wire is directed posteriorly toward the left superior pulmonary vein (LSPV), a structure considered safe for stabilization. TEE confirms appropriate positioning of the wire in the LSPV and excludes its passage into the left atrial appendage (LAA), a trabeculated, thin-walled structure at risk of perforation (Figure 4, Panel B);
5. The sizing balloon is then advanced;
6. The balloon should be inflated with its center aligned with the defect. Confirmation of the stop-flow technique is performed by TEE, with measurement of the stretched ASD diameter;
7. The SOD is selected;
8. The balloon should only be removed after the selected SOD has been properly prepared for implantation;
9. Subsequently, the guidewire and delivery sheath are advanced through the IAS to the ideal position, usually within the LA body or the LSPV, with confirmation by TEE;
10. The dilator and guidewire are then removed, maintaining the sheath positioned within the LA. The SOD is then advanced through the sheath;
11. Next, the delivery sheath is repositioned in the LA body, and the left atrial disc is deployed under echocardiographic guidance, ensuring that the device remains away from the LAA, mitral valve, and atrial free wall. The LA disc is then pulled back until it is positioned against the IAS at the level of the defect, while the connecting waist is released with continuous traction toward the RA;
12. Finally, the right atrial disc is deployed on the right side of the IAS (Figure 4, Panel D);
13. When using an Amplatzer-type SOD, a stability test (“tug test”) may be performed under echocardiographic and fluoroscopic monitoring to confirm device stability;

14. After confirming positioning and stability, the SOD is released.

In the case of non-self-centering devices, the procedure follows the same general principles as standard ASD closure, with the difference that device selection is primarily guided by echocardiography. In this situation, balloon use is not necessarily mandatory, as defect sealing does not depend on the device waist but rather on its discs. The ratio between SOD diameter and defect diameter should be greater than 2:1, and the selected device diameter should not exceed 90% of the measured septal length.

In these cases, the left atrial disc is initially formed within the LA body under fluoroscopic and echocardiographic guidance (Figure 4F). Once formed, TEE is used to guide its positioning against the left atrial surface of the IAS. The LA disc is kept supported against the septum while the delivery catheter is pulled toward the RA, allowing formation of the right atrial disc (Figure 4, Panels G, H and I).

In cases of multifenestrated ASD, 2D TEE, and especially 3D TEE, should be used to measure the distance between the center of the main defect and the most distant defect, corresponding to the radius. This value is then multiplied by 2 in order to obtain the required device diameter. To verify that the selected SOD will not interfere with adjacent structures, the following should be measured:

- From the center of the central defect to the aortic root;
- From the center of the central defect to the SVC rim;

If the required SOD size exceeds the safely permitted size, the device should not be implanted.

Assessment of final result

Assessment by 2D and 3D TEE of the SOD, IAS, and adjacent structures should be performed from multiple windows before device release, allowing recapture and repositioning if necessary.

Proper positioning of the SOD should be confirmed, as well as the presence of interposed septal tissue between the discs, evidenced by slight separation of the discs on profile view. The device and its rims should be carefully evaluated using color Doppler to detect residual shunts.

Small residual shunts tend to decrease or disappear with progressive endothelialization of the device over a few months; however, they may persist in approximately 3% of cases after 1 year of implantation.[6] In many cases, residual flow is observed along the retroaortic rim immediately after implantation and before device release. This finding results from tension exerted by the delivery cable, which displaces the RA disc inferiorly, separating it from the septum.

This tension and residual flow tend to resolve after the SOD is released from the delivery cable. However, the operator must ensure that residual leakage is not due to device undersizing or slippage from the LA to the RA, especially in the presence of a deficient retroaortic rim.

Interference with pulmonary veins, the coronary sinus, atrioventricular valve function, and potential deformation of the aortic root should be carefully evaluated and excluded before device release. After SOD release, all these assessments should be systematically repeated.

Author Contributions

Conception and design of the research and writing of the manuscript: Mattoso AAA; critical revision of the manuscript for intellectual content: Sena JP, Feitosa-Filho GS, Duarte ML.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

This study is not associated with any thesis or dissertation work.

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants or animals performed by any of the authors.

Use of Artificial Intelligence

The authors did not use any artificial intelligence tools in the development of this work.

Availability of Research Data

The underlying content of the research text is contained within the manuscript.

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