My Approach to Imaging the Atrial Septal Defect by Three-Dimensional Echocardiography

Como Eu Faço a Avaliação Ecocardiográfica Tridimensional da Comunicação Interatrial

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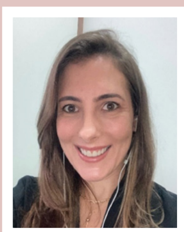

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Atrial septal defects (ASDs) correspond to 6–10% of all congenital heart diseases and are more prevalent in women; moreover, an estimated 60–75% of all cases correspond to ostium secundum (OS) ASDs, a defect affecting the intermediate septal region[1].

Transthoracic echocardiography (TTE) can be used to identify the defect, quantify the hemodynamic repercussions, estimate the pulmonary pressure, and identify other associated anomalies. Transesophageal echocardiography (TEE) is indicated for greater anatomical definitions, mainly in adults or in children with large defects in whom it is necessary to assess eligibility for percutaneous treatment.

Percutaneous treatment using a prosthesis is indicated in the following ASD cases: 1) OS type; 2) diameter less than 35 mm; 3) normal pulmonary venous drainage; 4) favorable borders around the defect (greater than 5 mm) except for the anterosuperior border, which may be absent; 5) hemodynamic repercussions (pulmonary and systemic flow ratio Qp/Qs > 1.5); 5) absence of fixed pulmonary hypertension; and 6) no other anomaly indicated for surgical treatment[1,2].

Three-dimensional (3D) echocardiography has become significantly relevant in this context of percutaneous treatment, since more than 90% of OS ASD cases are eligible for intervention. This technology is used in the echocardiography laboratory, mainly through transesophageal complementation in adults and patients weighting over 30 kg[3]. In our clinical practice, with the advent of more modern, smaller-caliber probes, we can perform this test in patients weighing more than 20 kg despite it not being recommended by the manufacturer.

However, the great advantage of the 3D technique is its use in the hemodynamics laboratory to guide closure of the OS ASD, which has a complex anatomy.

In my view, 3D acquisition in the pediatric population via the transthoracic window is very valuable for analyzing valves, performing volumetric assessments, and identifying particularities of complex heart diseases during surgical planning despite the limitations related to a high heart rate and breathing and movement artifacts. However, the specific anatomical detailing of the interatrial septum is usually insufficient and TEE resolution is superior considering its posterior location. Therefore, when treating a child with a large OS ASD, a candidate for percutaneous closure, I prefer to complement it with TEE, always under anesthesia, which results in a better quality test with fewer artifacts. Also, if the patient's weight allows it, we pass a 3D probe. Another issue of paramount importance is optimization of the two-dimensional (2D) image before 3D acquisition, which requires use of electrocardiography.

Next I will describe OS ASD assessment using the 3D technology aimed at percutaneous closure, i.e., via TTE and consider the different modes of acquisition, their advantages, and their use for this purpose.

Pre-procedural assessment

At the end of a detailed 2D TEE with a full septal analysis from the four-chamber view to bicaval section and color mapping, we commence the 3D image acquisition. The en-face projection of the ASD and the defect's positioning in the anatomic position provide valuable information from a single image: size, shape, location in the interatrial septum, characteristics of the defect's borders, and the presence of additional fenestration[3].

I usually start the 3D evaluation from the perspective of the right atrium to facilitate the identification of anatomical markers[2]. I acquire a medium angle block (3D or 4D zoom) or a large block (full-volume using the two-section tool) starting from an initial bicaval section and proceeding with approximate 90° rotation in the z-plane so that the superior and inferior vena cava are aligned in the vertical plane (i.e., superior vena cava at the 11 o'clock position) and the aorta in the anterior and superior region. I prefer not to use the narrow-angle mode for acquisition (live 3D or bird's eye

Keywords

Heart septal defects, atrial; Echocardiography, Three-Dimensional; Heart Defects, Congenital.

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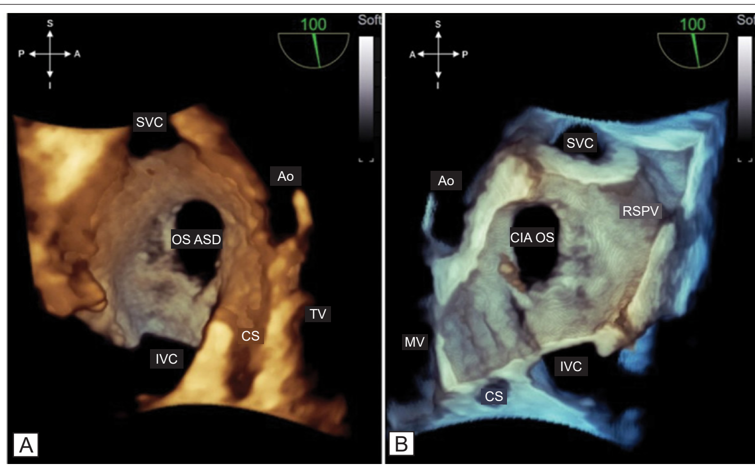
view) or very high magnification due to a loss of anatomical references adjacent to the defect, which can interfere with this fundamental initial analysis[4]. From this reconstruction (Figure 1A), I can characterize the defect as unique, the OS type, having an oval shape, being central, being medium-sized, and having adequate borders. Video 1 shows the same ASD and allows assessment of the occurrence of dynamic variation in its dimension with the cardiac cycle.

We obtain the view of the left atrium[2] after 180° rotation on the axis of the AD panorama in an anatomical position (like turning the pages of a book) (Figure 1B, Video 2). The right superior pulmonary vein is adjacent to the superior vena cava (i.e., right superior pulmonary vein at the 1 o'clock position), the aorta is in a superior but leftward position, and the mitral valve is inferiorly and anteriorly located.

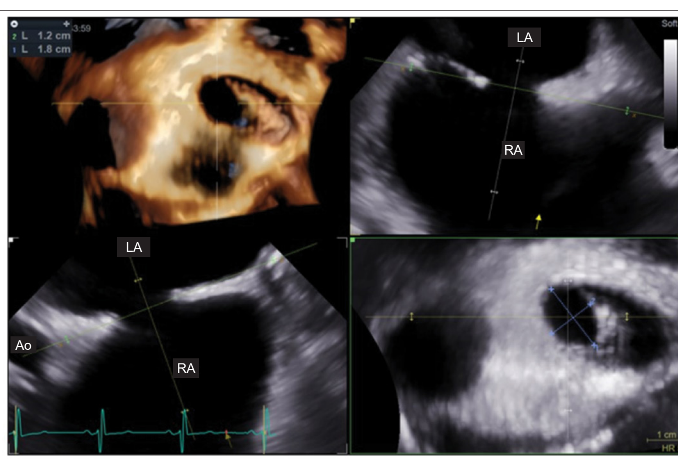
The ASD borders are classified to improve communication between the operator and the hemodynamics professional as follows: anteroinferior and superoposterior (in apical four-chamber view at 0°, border close to the atrioventricular valves and contralateral); anterosuperior and posterior (on the short axis of the aortic valve, at about 45°, border related to the aorta and contralateral); and, finally, posterosuperior and posteroinferior (in bicaval view at about 100° near the superior and inferior vena cava, respectively)[5,6].

Multiplanar reconstruction in three axes is possible after a high-quality 3D image is obtained to quantify measurements such as distance and/or area (Flexi-slice or 3DQ software). Thus, we obtain the true transverse plane of the defect (Figure 2), which allows us to make linear measurements comparable to those performed through standard 2D TEE



A, anterior; Ao, aorta; CS, coronary sinus; I, inferior; IVC, inferior vena cava; MV, mitral valve; OS ASD, ostium secundum atrial septal defect; P, posterior; RSPV, right superior pulmonary vein; S, superior; SVC, superior vena cava; and TV, tricuspid valve.

Figure 1 – *A) Three-dimensional image acquired by large block mode (full-volume) and manipulated by the two-sections tool starting from the bicaval section of the interatrial septum on transesophageal echocardiography. An en-face OS ASD is visible on the right atrial view in the anatomical position with adequate borders that is eligible for percutaneous closure. B) The same image taken from the left atrial perspective.*



Ao, aorta; LA, left atrium; OS ASD, ostium secundum atrial septal defect; RA, right atrium.

Figure 2 – *Multiplanar reconstruction performed in three axes (flexi-slice) from a three-dimensional transesophageal echocardiography image taken in the true transverse plane of an OS ASD to measure the defect in its largest and smallest diameters (bottom right).*

sections[2]. Measuring the largest and smallest diameter of an ASD during atrial diastole is routinely performed. Handling the 3D image substantially improves the 2D understanding of septal defects with time and experience. Figure 3 compares the 3D image of two OS ASDs with their respective 2D sections and borders.

The most inferior and posterior region of the interatrial septum is the most difficult to access since it is closer to the transesophageal probe. However, most OS ASDs are located in the anterosuperior portion of the septum. It is mandatory to search for additional small defects in the presence of a larger anterosuperior OS ASD and a thin and redundant posterior or posteroinferior septum (even aneurysmal), which is present in an estimated 2.7% of cases[7].

Using this technology associated with color mapping (3D color view) to assess a simple OS ASD does not usually add information in the pre-assessment but substantially reduces the image frame rate. On the other hand, the tool with simultaneous 2D sections with color mapping (multidimensional or X-plane), which can be orthogonal in the presence of septa with several fenestrations, can help define the number, location, and proximity of fenestrations to one another.

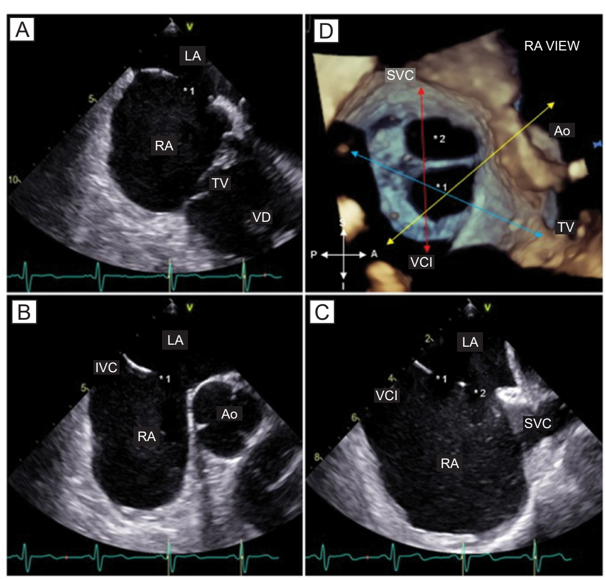
Finally, the 3D assessment of an ASD is not time-consuming and image handling is concomitant with the test and performed by the device.

Intra-procedural assessment

The use of TEE to guide the percutaneous ASD closure requires knowledge of interatrial septal anatomy and the procedure's steps. The echocardiographer must help cross the defect with the catheter, position the guides and catheters in the pulmonary veins (usually in the left superior pulmonary vein), measure the defect in several planes, measure the diameter with a balloon catheter (as described later), open the left disk, waist, and right disk, position the device, and analyze the final result[5]. Videos 3, 4 and, 5 show 3D images of these steps. The imaging professional should inform the decision of which prosthesis is the best for the particular case.

A balloon catheter is usually passed through the ASD and slowly and progressively inflated during the echocardiographic evaluation with color mapping process. The outer to outer border of the balloon is measured at the moment the transseptal flow ceases (stop-flow technique)[2]. The chosen device is usually up to 2 mm above this measurement. Small fenestrations are commonly found in a thin redundant region of the septum (usually posteroinferiorly) after balloon inflation at the largest ASD. However, some hemodynamic professionals skip this step in the presence of a single OS ASD with thick and firm borders and opt for an overestimated prosthesis with a waist 20–30% larger than the baseline ASD measurement obtained by standard TEE sections[8].

The 3D complementation has great value in complex ASD cases such as an aneurysmal interatrial septum with multiple



*A, anterior; Ao, aorta; CS, coronary sinus; I, inferior; IVC, inferior vena cava; LA, left atrium; OS ASDs, ostium secundum atrial septal defects; P, posterior; RA, right atrium; RV, right ventricle; S, superior; SVC, superior vena cava; TV, tricuspid valve; *1, most inferior OS ASD; *2, most superior OS ASD.*

Figure 3 – *Complex case of two OS ASDs assessed by two- and three-dimensional transesophageal echocardiography in the hemodynamics laboratory. A) Apical four-chamber view at 0° demonstrating the lowest ASD with adequate anteroinferior and superoposterior borders. Note that the border related to the atrioventricular valves is thicker and firmer. B) Short-axis view of the aortic valve at approximately 45° demonstrating only one of the ASDs with a deficient anterosuperior border. In this example, note that the inferior vena cava outflow is also considered in the section. C) The bicaval section at approximately 100°, with visualization of the two ASDs in two-dimensional view and posterosuperior and posteroinferior borders of appropriate dimensions. D) Three-dimensional view of the interatrial septum from the perspective of the right atrium showing the two large oval similarly sized ASDs, one superior to the other. Clearer anatomical definition was obtained by three-dimensional technology in this case. The colored arrows represent the corresponding two-dimensional sections: blue (A), yellow (B), and red (C).*

holes, two orifices distant from one another, the absence of one or more borders, and very large holes (>28 mm).

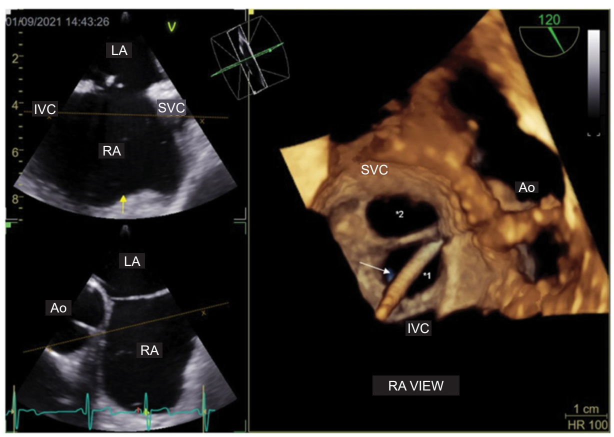
An aneurysmal interatrial septum must be very carefully analyzed and previous gain adjustments made to avoid misinterpretation of a drop-out image (due to a thin and mobile septum) as an additional ASD after 3D acquisition.

It is difficult to locate the hole through which guides or catheters can be passed in 2D tests in the presence of two or more holes, for example, considering that they may be superimposed. In this context, we can use two tricks of 3D technology. First, we can use two simultaneous 2D sections (multidimensional or X-plane) to distinguish the two holes with the advantage of the greater temporal and spatial resolution. Second, we can use the real-time image of a thin 3D slice with direct visualization of the material used by the hemodynamics professional passing through a certain hole. Figure 4 and Video 6 exemplify this procedure.

Another advantage of assessing the entire interatrial septum in the scenario of multiple defects is the decision to use a device for a septum with several fenestrations, a thin waist, or, in the case of defects that are quite distant from each other, the choice of two prostheses for the same patient. Figure 5 and Video 7 show the final result after the implantation of two prostheses in the same patient to close two large defects.

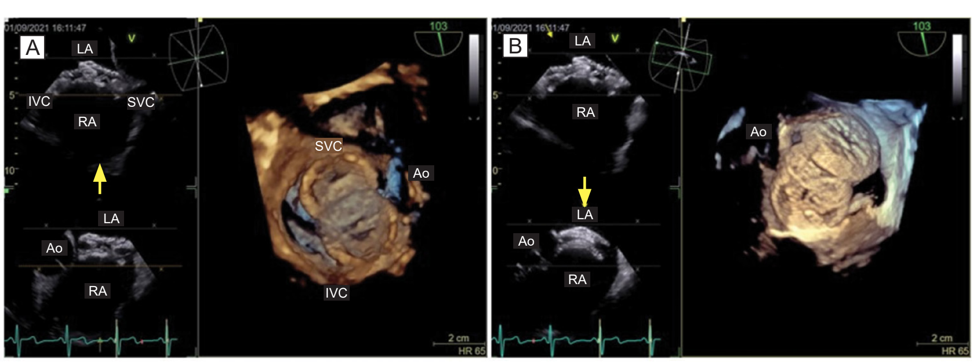
The conventional 2D technique associated with color mapping satisfactorily ensures prosthesis positioning, identifies borders between disks, and assesses heart valve and pericardial effusions at the end of the procedure.

ASDs with a more anterior and superior location in the absence of the aortic borders are more often associated with



*Ao, aorta; IVC: inferior vena cava, LA, left atrium; OS ASDs, ostium secundum atrial septal defects; RA, right atrium; RA VIEW, view of the right atrium; SVC, superior vena cava; *1, most inferior OS ASD; *2, most superior OS ASD.*

Figure 4 – *Three-dimensional view of the interatrial septum from the right atrium showing two large OS ASDs and the catheter (arrow) passing through the most inferior ASD. Note the best anatomical detailing by three-dimensional transesophageal echocardiography technology to guide the interventional procedure of this complex case.*



RA: right atrium; LA: left atrium; Ao: aorta; IVC: inferior vena cava; OS ASDs, ostium secundum atrial septal defects; SVC: superior vena cava.

Figure 5 – *A) Three-dimensional image of the interatrial septum with a right atrial view demonstrating the final result after the occlusion of both OS ASDs with two prostheses, in an anatomical position. B) Same image from left atrium perspective.*

aortic or atrial roof erosion. The 3D analysis of this region, including the transverse sinus, enables close follow-up due to the greater risk in such cases[2].

Device embolization is a rare (0.1–0.4%) but potentially serious event[1,2] that usually occurs early and requires re-catheterization or even surgery. The main cause of embolization is an undersized defect, especially in cases with redundant septa and the absence of one or more borders. Before releasing the device, any major and unusual movement can cause prosthesis instability and increase the risk of embolization.

The 3D assessments with color mapping are used in selected cases. In the presence of residual communication after closing the defect with a prosthesis, this technology defines flow size, shape, and proximity to the disk and estimates possible spontaneous closure during patient follow-up[2]. Another clinical condition is right or left ventricular diastolic dysfunction in which it is necessary to create a hole through the prosthesis to serve as a drain right after defect closure. In cases of congenital heart diseases such as pulmonary atresia with intact interventricular septum associated with OS ASD with repercussion, these holes allow some flow to be directed from the right to left atrium in the presence of diastolic right ventricular dysfunction, thus avoiding right heart failure due to unsaturation. On the other hand, in an older population already presenting with left ventricular diastolic dysfunction, the outflow would be from the left to right atrium to avoid abrupt volume overload in the left atrium and the potential for acute pulmonary edema. Figure 6 shows the case of an older patient with grade II diastolic dysfunction that persisted after an ASD occlusion test with a balloon catheter for ten minutes, during which it was decided to mechanically create two holes through the prosthesis mesh. These holes may close spontaneously during the normal prosthesis epithelialization process, but this benefit would be expected for a short time after the procedure.

Post-procedure assessment

TTE should be performed 24 hours after the procedure to assess device positioning and identify any pericardial effusions. It should then be repeated after 1, 3, 6, and 12 months and annually thereafter[1]. Transesophageal complementation is not necessary in cases of a normal progression and satisfactory acoustic window. The right heart chambers are significantly reduced and greater filling occurs of the left chambers, with cardiac remodeling evident at 3 months after the procedure. Small residual periprosthetic flows may disappear during the prosthesis epithelialization process that occurs during the first 6 months after catheterization. Acetylsalicylic acid anti-aggregation (3–5 mg/kg/day; maximum dose, 100 mg/day) is necessary during this period[8]. However, small residual flow persists in 3% of cases at 1 year after prosthesis implantation[2]. The prophylaxis for bacterial endocarditis should be extended if residual flow persists[8].

TEE is indicated in selected cases, such as in the presence of residual or additional ASD with hemodynamic repercussions. In this scenario, 3'D technology can be used to aggregate information for reintervention discussion purposes.

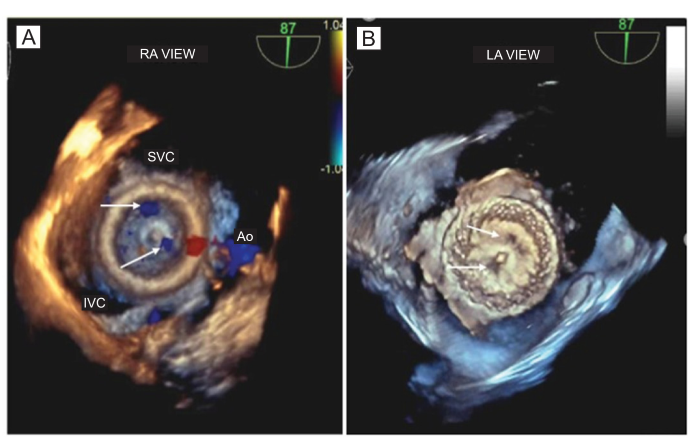
Final considerations

Percutaneous treatment is currently the treatment of choice for OS ASD with a favorable anatomy. The procedure-associated mortality rate is very low (0.05%), below that associated with surgery (0.13%)[2].

Echocardiography for interventional procedures is a growing and evolving area. The role of 3D echocardiography in the context of percutaneous OS ASD closure was highlighted here, especially in complex cases encountered in a hemodynamics laboratory.

Conflict of interest

The author declares a potential conflict of interest for being a consultant for Supri, Invasive, Tecmedic and Boynton.



Ao, aorta; IVC, inferior vena cava; LA VIEW, view of the left atrium; RA VIEW, view of the right atrium; SVC, superior vena cava; white arrows: holes created in the prosthesis.

Figure 6 – *A) Three-dimensional view with color mapping of the interatrial septum in the anatomic position from the right atrial perspective after percutaneous occlusion of an OS ASD in an older patient with grade II diastolic dysfunction who had two holes created through the prosthesis mesh (white arrows). B) Left atrial view without color mapping.*

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