Update

The Role of Echocardiography in the Percutaneous Treatment of Septal Defects

Simone Rolim F. Fontes Pedra, Sérgio Cunha Pontes Jr, Renata de Sá Cassar,
Carlos Augusto Cardoso Pedra, Sérgio Luiz Navarro Braga, César Augusto Esteves,
Maria Virgínia Tavares Santana, Valmir Fernandes Fontes

Instituto Dante Pazzanese de Cardiologia - São Paulo, SP - Brazil

In the last few years, percutaneous treatment of atrial and ventricular septal defects has developed significantly, having been established as a feasible, safe and effective therapeutic modality. Echocardiography has a primary role in this scenario, identifying suitable candidates for the procedure, monitoring the device implantation and evaluating the rate of occlusion during follow-up. The available devices for percutaneous occlusion of septal defects have been progressively modified and improved. Similarly, a great technological advancement has also occurred in the echocardiography area, such as the advent of high-resolution transesophageal multiplan probes, on and off-line three-dimensional (3-D echo) and intracardiac echocardiography.

In some centers, the latter has become the procedure of choice for monitoring percutaneous occlusion of atrial septal defect in adult patients, as it does not require general anesthesia, thus making the procedure even simpler.

In this review article, we will discuss the role of echocardiography to evaluate patients before, during and after interventional procedures for occlusion of septal defects, including the *ostium secundum* atrial septal defect type, perimembranous and muscular ventricular septal defects and patent foramen ovale, based on the experience of the group in this type of approach.

In the last few years, ultrasound equipment underwent great technological development, which made echocardiography a mandatory tool in the diagnosis of congenital heart disease. In the area of pediatric interventional cardiology, echocardiography has a primary role in the identification and selection of patients who are candidates to percutaneous procedures, and in the monitoring and late follow-up of such patients. Among the interventional procedures, those that need the support of echocardiography are the occlusion of atrial and ventricular septal defects. In this study, we will discuss the role of echocardiography in the percutaneous treatment of atrial and ventricular septal defects and patent foramen ovale (PFO).

Percutaneous occlusion of atrial septal defects

Atrial septal defects (ASD) correspond to approximately 7% of all congenital heart disease, being more frequently in females, at a proportion of 2:1[1]. The most frequent anatomic type is the one located in the fossa ovalis (75% of the cases), also denominated *ostium secundum* ASD type and occurs due to the deficiency, perforation or absence of the fossa ovalis lamina[2]. The other communications occur due to the deficiency of the fold between the atrial walls and between the tributary veins, with these being *ostium primum* communication types, venous sinus type, and coronary sinus type. Considering these anatomical characteristics, the only interatrial communication that allows treatment with the use of devices is the one located in the fossa ovalis[2].

Patient selection

Patients with clinical suspicion of ASD are initially submitted to a transthoracic echocardiography. In addition to the defect identification, the pulmonary venous return, degree of hemodynamic impact, signs of pulmonary hypertension and the presence of associated defects that need therapeutic approach are also assessed[3]. The more specific information regarding the characteristics of the defects, as well as number and dimension of orifices, their localization in the septum, and characteristics of the rims that surround them are better evaluated by transesophageal echocardiography (TTE), which can be performed at the outpatient clinic basis or immediately before the procedure, in the catheterization laboratory[3-5]. In our experience, performing TEE in the echocardiography laboratory shows advantages concerning the procedure programming, device selection and family counseling.

Indication criteria

Percutaneous treatment of ASD is indicated in the following conditions: a) *ostium secundum* type ASD;

b) diameter of defect varying from 4 to 35 mm; c) flow through the defect predominantly directed from the left to the right atrium; d) signs of right ventricular volume overload (increased right ventricular end-diastolic diameter and presence of paradoxical movement of the interventricular septum); e) distance of the defect rims from adjacent structures (coronary sinus, atrioventricular valves, pulmonary veins and vena cava) of at least 4 mm; f) presence of rims with at least 5 mm around at least 75% of the defect; g) absence of fixed pulmonary hypertension; h) absence of associated defects that need surgical approach.

All these criteria are applied when one intends to use the Amplatzer septal occluder, which is currently the most frequently device utilized in the market. Regarding the implant of the Helex device, the second device most commonly used, the diameter of the ASD must not exceed 15 mm. This device line is available with diameters of 15, 20, 25, 30 and 35 mm. As the choice of size is based on a 1.7-2:1 ratio with stretched diameter (diameter of the ASD obtained in the catheterization laboratory, in which a complacent balloon is inserted into the orifice, distending it until it acquires a circular shape), it is possible to occlude stretched orifices that do not exceed 20 mm[6].

As a result of the increasing global experience in the percutaneous treatment of ASD, as well as the development of occlusion devices and the improvement of the quality of echocardiographic images, including high-resolution TEE, three-dimensional reconstruction and intracardiac echocardiography (ICE), the indications, previously restricted to unquestionably favorable cases, were expanded to include the so-called complex cases, in which the implant is known to be feasible and effective, but with slightly lower success rates and more prolonged procedure time[7].

Complex anatomy ASD is considered when it has the following characteristics: stretched diameter > 26 mm; deficient rims, measuring less than 4 mm in the anterior, posterior or inferior septal region; two orifices that are apart; multifenestrated interatrial septum and interatrial septum aneurysm (redundant and mobile interatrial septum with an excursion > 10 mm)[7]. Figure 1 shows an ASD of complex anatomy.

Regardless of the type of probe utilized (biplane or multiplane), TEE must follow a standard methodology, in order to obtain all necessary information. Our group chooses to start with sectional images at the transverse plane (0º in the multiplane probe), slowly and progressively moving the probe, from the plane that evidences the superior vena cava until the floor of the right atrium is reached, identified by the presence of the coronary sinus and the Eustachian valve. Subsequently, we move on to the longitudinal plane (90º), with the section that contains the left atrial appendix and the mitral valve, using a slow anti-clockwise rotation of the probe in order to obtain a scan of the atrial septum from the anterior to the posterior portion. This standardization allows the examiner to mentally reconstruct a three-dimensional model of the defect, as well as define the characteristics of complex defects with precision[5, 8].

Echocardiography during the procedure

Atrial septal defects occlusion is continuously monitored by TEE or ICE. When this is accomplished
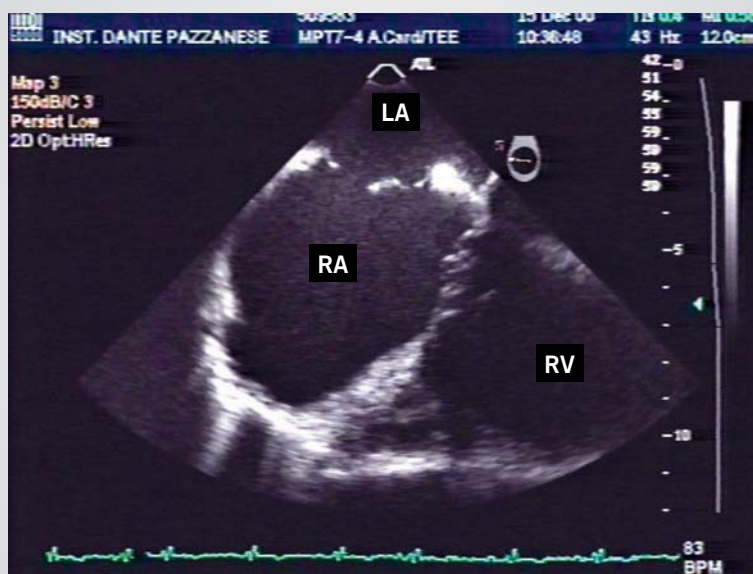

Fig. 1 - Complex ASD with multiple orifices shown by TEE. RA: right atrium; LA: left atrium; RV: right ventricle

by TEE, even in adults, it is necessary to utilize general anesthesia. The main steps of the echocardiography during the implant are:

1. Measurement of the stretched diameter. In addition, it is necessary to verify whether the balloon is obstructing the defect completely and if there are no additional defects with the occlusion of the main defect. The choice of the Amplatzer device size depends on the stretched diameter. The balloon-catheter separates, by compression, the thin rims formed by the *septum primum*, occupying the orifice delimitated by the rigid rims, constituted by the *septum secundum*, which will function as the device support. The balloon-catheter is insufflated until the septum shows resistance, demonstrating a clear waist in the balloon. It is important to remember that the balloon must be insufflated only enough to prevent flow through the defect, avoiding septal hyperextension and consequently, the overestimation of the device size. Measurements of the balloon diameters in the echocardiography and angiography are similar, as long as they are adequately performed. The correct determination of the diameter is essential for an adequate device choice. Although the Amplatzer device can be easily withdrawn and changed by another, the choice of a device with inadequate dimensions results in increased procedure costs.

2. To guide the interventionalist regarding the localization of the left atrium disc before the release of the remaining device components, so it will be near the interatrial septum, without protruding through the defect.

3. To demonstrate the device positioning after the release of all its components. The device can only be released when the presence of interatrial septum tissue between its two discs is demonstrated, and when there is no functional involvement of cardiac venous and valve structures.

4. Scanning for a possible residual shunt, grading it when present. In the period that follows the release, it is possible to identify a low velocity central flow through the device mesh, which normally disappears on the day after the implant[5].

Under special circumstances, such as large ASDs in small children, or those with dimensions > 35 mm in adults, some authors have discontinued the stretched diameter technique for device selection. In these cases, the measurement of the upper-lower length of the interatrial septum is performed, in the four-chamber view (0⁰ by TEE). The device is chosen so that the left disc diameter does not exceed total septum length (Dr. Zahid Amin, personal communication). This new technique, in addition to allowing the percutaneous procedure, prevents the overestimation of the device size, which eventually could result in the erosion of the aorta wall to the right or left atrium, aortic-sinus fistula or pericardial effusion with cardiac tamponade[9]. Following the previously described indications, it is only possible to perform the percutaneous occlusion of these defects if the rims around

the orifice measure at least 5 mm, except for that close to the aorta, which may be absent, although it does not contraindicate the procedure. Figure 2 shows a fossa ovalis ASD with morphological characteristics that are ideal for percutaneous treatment, the stretched diameter and the final result after a Helex device is release.

Fig. 2 - *TEE during percutaneous occlusion of an ASD with a Helex septal occluder a) fossa ovalis type ASD, located in the central part of the septum, with the flow directed from the left atrium to the right; b) Balloon interposition through the defect to measure the stretched diameter; c) Helex occluder well-positioned in the septum, occluding the defect. RA: right atrium; LA: left atrium; ASD: atrial septal defects*

Echocardiography in the follow-up of percutaneous closure of ASD

The follow-up of patients who underwent device closure of ASD is carried out through sequenced clinical evaluations and transthoracic echocardiogram on the day after the implantation, one, three and twelve months after, and every year, thereafter. The main parameters evaluated by echocardiography are device positioning, presence of residual shunt and measurement of right cardiac chamber

dimensions[3]. By assessing the diastolic diameter of the right ventricle at the longitudinal paraesternal axis before the implantation and during the late follow-up, we have observed that the right ventricle returns to its normal dimensions within the first year post-procedure[4].

In the beginning of our experience, we routinely repeated TEE after the third month post-implantation. In face of the excellent late results, not only in our institution but worldwide regarding the low late complication rates, the disappearance of small residual shunts and the reduction of the device profile, we have followed patients with transthoracic echocardiogram only, being TEE utilized only in case of complications. Although complications such as aortic fistula to the right or left atriums, pericardial effusion secondary to atrial perforation and thrombus or vegetation formation in the device have been rarely described in literature, none of these abnormalities were observed in our experience, which consists of 144 cases, including patients treated with Amplatzer and Helex devices. Compromise of the atrioventricular valve function and pulmonary or systemic vein return were not observed either.

Percutaneous occlusion of PFO

Approximately 25% of the general population has a PFO[10]. In almost all cases, it does not have pathological implications, being just a variation of the normal condition, casually observed during the routine echocardiographic assessment. However, young patients (< 55 yrs) with stroke of undetermined cause after extensive investigation (including neurological, cardiac, vascular, hematological and rheumatological causes), PFO is found in up to 60% of the cases. Based on this epidemiological difference, it was postulated that PFO, functioning as a valve, could allow inversion of shunt at the atrial level (from right to left) in situations of high pressures in the right atrium, associating to embolic events for the systemic circulation (paradoxical embolism)[11]. Thus, looking for PFO is mandatory in individuals who have evidence of cerebral ischemia without other apparent causes. This assessment is performed with TEE. In addition to the anatomical visualization of the orifice in the fossa ovale, it is necessary to document the right to left shunt, using contrast. To obtain a contrast rich in microbubbles, physiological saline solution is agitated with air (9 ml of saline solution and 1 ml of air) and injected rapidly in a peripheral vein. At this moment, the patient is requested to perform the Valsalva maneuver to increase pressure on the right side of the heart. The presence of right to left shunt is confirmed when the contrast, after filling up the right atrial cavity, is found inside the left atrium with an amount of at least 5 microbubbles, during the first three cardiac cycles after the injection[5].

In these patients, percutaneous occlusion of the PFO has been carried out safely and effectively, to prevent recurrences of thromboembolic phenomena[12].

Despite the lack of prospective and randomized studies comparing pharmacological approach (anti-platelet and anti-coagulant drugs) with percutaneous treatment, previously published observational longitudinal studies have shown that occlusion with devices is at least, as effective as the clinical treatment, being more effective in some subgroups of patients, such as those presenting with more than one previous episode of stroke or recurrence during pharmacological treatment[13]. Some anatomical aspects of the interatrial septum are particularly important for appropriate selection of the diameter and shape of the device that will be used, and must be adequately observed during the echocardiographic study. They are: a) the presence of interatrial septum aneurysm (defined by excursion > 10 mm of the septum); b) tunnel-shaped foramen ovale, and c) the presence of other orifices in the interatrial septum. Echocardiographic assessment of interatrial septum is also mandatory for professional divers, as there is a five-fold increased risk of suffering decompression sickness for those who have PFO compared to those with intact interatrial septum[14].

Recently, PFO has been associated to migraine with aura and its occlusion has demonstrated reduction on intensity and frequency of the migraine episodes[15].

Percutaneous occlusion of PFO is, in general, quite rapid and simple, and can be carried out under echocardiographic monitoring, according to the interventionalist's choice. Figure 3 shows echocardiographic pictures of a PFO and right-left flow demonstrated by the presence of microbubbles in the left atrium.

Drug prophylaxis with aspirin is maintained for 6 to 12 months after percutaneous closure. Treatment can be withdrawn only when a new TEE with microbubbles does not reveal any right to left shunting at atrial level. This evaluation is normally carried out six months after the procedure.

Percutaneous occlusion of ASD and PFO guided by ICE

Currently available in the Brazilian market, the AcuNav™ has revolutionized interventional cardiology, especially in the areas of electrophysiology and percutaneous treatment of septal defects. The AcuNav™ is an ultrasound transducer performed to undergo the venous system, which results in high-resolution images and is capable of 12 cm penetration in the heart. The current commercialized catheter is a 90 cm long 10 French catheter, introduced in the venous system through an 11 French sheath. It has a transducer coupled to the distal extremity, which allows capture of section images of 90°. Its tip can be moved to the anterior-posterior and lateral (left-right) directions inside the cardiac chambers, generating bidimensional images and also allowing the utilization of Doppler resources (pulsed, continuous, and color flow mapping). The catheter is compatible with
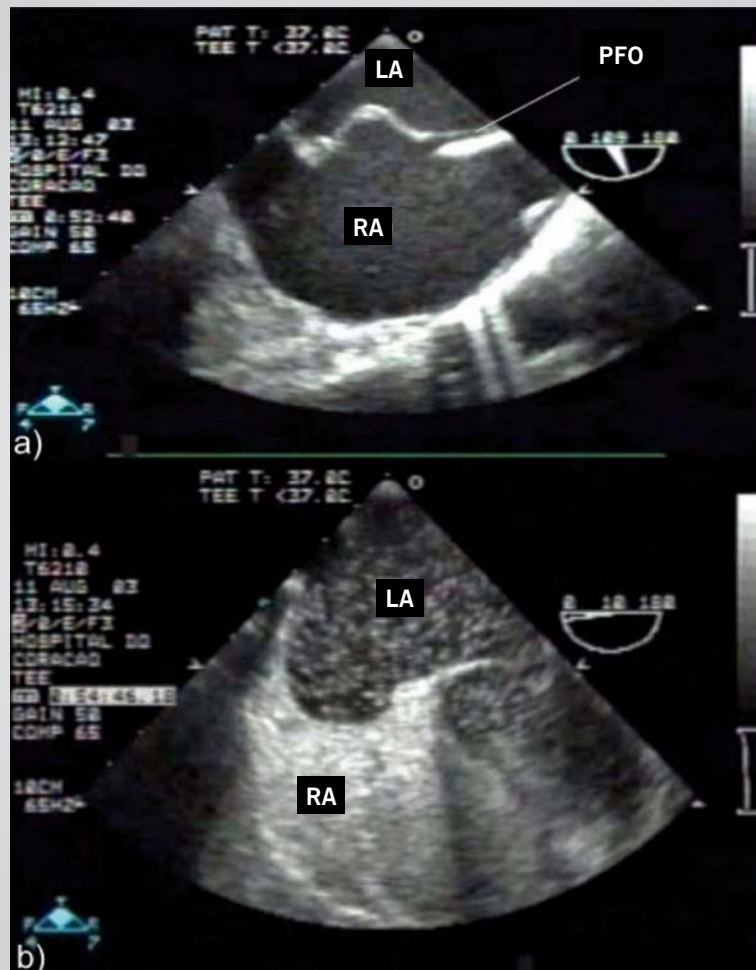
Fig. 3 - *TEE demonstrating a) patent foramen ovale (PFO), associated to an aneurysm of the interatrial septum; b) contrast study, delineating the aneurysm and showing a large amount of microbubbles crossing from the right atrium to left atrium. RA: right atrium; LA: left atrium*

Sequoia™, Aspen™ and Cypress™ (*Acuson Corporation*, Mountain View, CA) equipment, having been approved for intracardiac and intraluminal use by the FDA (Food and Drug Administration).

The main advantages of ICE for percutaneous treatment of ASD and PFO are the acquisition of better quality images, as the transducer is placed inside the right atrium, the best view of the posterior-inferior portion of the interatrial septum (the rim that is the hardest to visualize at the TEE), lower exposition to radiation by reducing the duration of the procedure, necessity of only one operator (the interventionalist can obtain the echocardiographic images him or herself) and the preclusion of general anesthesia in adolescents and adults, since TEE is not required[16-20].

Recent studies have shown that all measurements obtained on ICE have excellent correlation with those obtained by TEE, with better demonstration of guidewires, catheters and device discs[21, 22]. Due to such advantages, ICE monitoring of percutaneous occlusion of ASD and PFO has become the standard of care for adolescents and adults in North America and Europe. In developing countries, however, due to the high cost of the transducer, it has been more uncommonly employed. Theoretically the transducer must be used only once. In day by day practice however, the equipment can be re-sterilized and re-utilized around 10 times, depending how carefully its handled (Carlos Zabal, personal communication). Figure 4 shows some images obtained during our initial experience with ICE at Dante Pazzanese Institute of Cardiology and *Hospital do Coração*.

Percutaneous occlusion of ventricular septal defect (VSD)

Ventricular septal defect is the most frequent congenital heart disease, corresponding to around 20% of them[23]. In approximately 80% of the cases, it is located in the membranous portion of the septum, with variable extensions to the inlet and outlet, being thus denominated perimembranous VSD[23]. With the
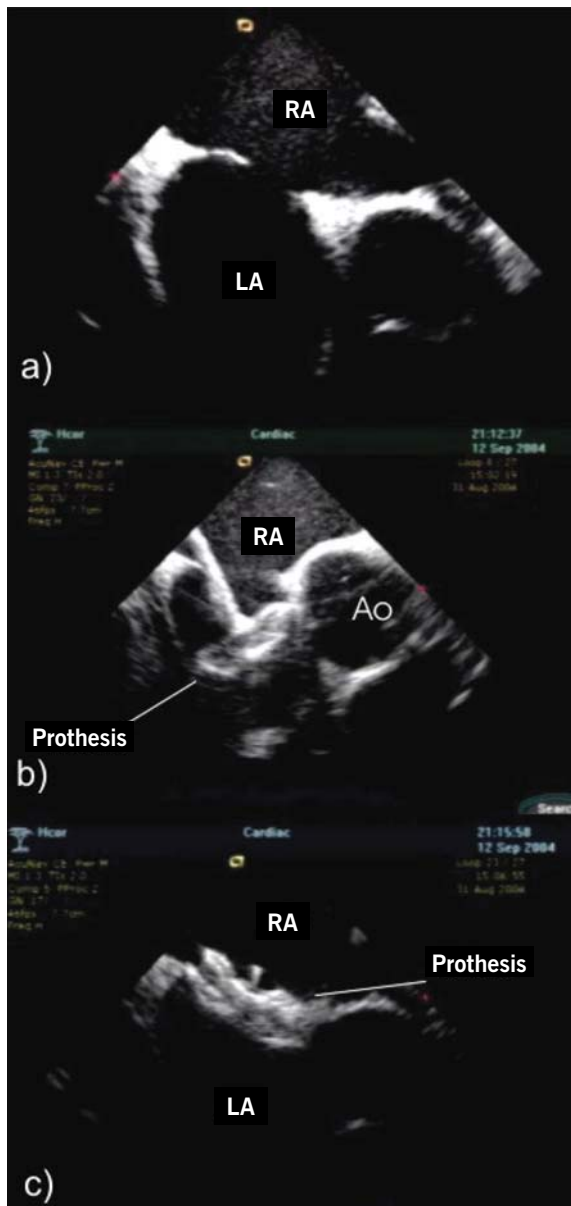
Fig. 4 - ICE during a percutaneous occlusion of an ASD with an Amplatzer® septal occluder demonstrating: a) fossa ovalis type ASD; b) release of the left atrium device disc; c) the final result after device release. RA: Right atrium; LA: left atrium; AO: aorta

development of Amplatzer devices appropriate for this septal region, percutaneous closure of VSD was extended from the muscular region to the membranous area[24, 25]. Although virtually all perimembranous VSDs can be occluded percutaneously, some important features must be carefully assessed by echocardiography. Differently from ASD patient selection, the pre-procedure evaluation is performed by transthoracic echocardiography. In our clinical practice, we have performed TEE only in adults with very unfavorable echocardiographic windows, in whom transthoracic evaluation of the defect is not accurate.

Patient selection

As mentioned previously, some anatomical and functional aspects must be evaluated before the indication of percutaneous treatment of VSD: A) Localization – if the communication is perimembranous, it is important to define if it is located at the ventricular inflow or outflow region. B) Distance from the aortic valve leaflets: Although the absence of tissue separating the aortic valve leaflets from the orifice is not an absolute contraindication for the procedure, it is known that, in this situation, it becomes more complex and requires more care. In general, it is preferable that the defect is at least 2 mm far from the aortic valve. C) Presence of accessory tissue around the defect: sometimes there is a small amount of tricuspid tissue tags around the orifice, which does not significantly reduce flow through it. In these cases, the prosthesis must be attached to the muscular septum. On the other hand, there are defects that present large amounts of tissue around it, forming an aneurysm, which significantly reduces the original flow orifice. These defects may be occluded with smaller devices, which are positioned inside the aneurysmatic sac and do not compromise tricuspid and aortic valves function. D) Presence of aortic valve prolapse. It is known that 2 to 7% of the VSDs can be associated to a prolapse of the right coronary leaflet of the aortic valve, leading to different degrees of aortic insufficiency. Although this finding is a contraindication to the percutaneous procedure in study protocols in the United States, device implantation under these circumstances has been carried out safely and effectively with excellent medium-term results. In our experience of 29 cases, three patients had such complication, all with successful device implantation. Two of them persisted with no aortic insufficiency and one showed a minimal progression of the previously mild existing insufficiency. Monitoring serially these patients with echocardiography is mandatory. E) Presence of associated defects, such as subaortic membrane and right ventricular muscle band which might need surgical approach. Lesions such as pulmonary or aortic valve stenosis, persistent duct arteriosus and aortic coarctation can also be treated percutaneously, depending on their anatomical features. F) Presence of the left chambers overload that justifies the intervention. G) Absence of fixed pulmonary arterial hypertension.

Muscular VSDs located in the trabecular and apical regions of the septum can also be treated percutaneously. Although there are fewer anatomical variations, the presence of multiple orifices is common, particularly in the ventricular apex. When there is a single orifice, the Amplatzer device is the best choice, as it has small retention discs that occupy little space of the interventricular septum. In case of multiple orifices, CardioSEAL devices are more appropriate, as long as implanted in the most central orifice.

Recently, hybrid approach for the management of very

young patients (< 6 mo) with large muscular defects has been utilized. These patients are taken to the operating room for a thoracotomy to expose the heart and, through a right ventricular free wall puncture a guidewire is introduced in the left ventricle through the VSD. A short sheath is then advanced over the guidewire allowing the device positioning. The procedure is performed under TEE monitoring. This innovative and revolutionary approach, in which interventionalist, echocardiographer and cardiac surgeon work together, prevents the deleterious effects of extracorporeal circulation, resulting in occlusion rates > 90%[26].

Echocardiography during percutaneous closure of VSD

Multiplane probes are more suitable for this procedure, as intermediate planes between 0^0 and 180^0 can provide visualization of the VSD and device positioning. Similarly to ASD closure, echocardiography helps in the orifice measurement and device size choice, monitors the guidewires, catheters and sheaths position inside the heart and determines the location of the devices discs, before and after its release[24]. The primary functions of the echocardiography also include careful evaluation of aortic and tricuspid valves, detection and grading of possible residual shunts. Although echocardiographic pictures are of great help for the procedure, fluoroscopy and angiography are crucial during the intervention.

Echocardiography in the follow-up after VSD percutaneous occlusion

The follow-up of patients who underwent percutaneous occlusion of VSD is carried out through clinical assessments and serial transthoracic echocardiograms, when the following parameters must be evaluated: a) left cardiac cavity dimensions (normally after the first year of treatment, these have returned to normal dimensions[24]); positioning of the device in the interventricular septum; c) presence of residual shunt; d) evaluation and measurement of a possible flow gradient in the left ventricular outflow tract; and e) aortic and tricuspid valve function.

Our current experience consists of 29 cases treated percutaneously for perimembranous VSD and one for muscular VSD. Regardless of the morphological characteristics of the defect, all the procedures were carried out successfully. The presence of immediate residual shunt was noticed in 25% of the cases. Over a mean follow-up period of 10 ± 8.5 months, only two patients persisted with slight residual shunt, with one of them having less than one-month follow-up. Two other cases presented a gradient at the left ventricular outflow tract (17 and 25 mmHg on the day after the procedure) that disappeared during follow-up, possibly due to the spontaneous reduction of the device profile and the

epithelization process which occurs within the first six months after the implant[24,27]. Figure 5 shows a VSD before and after the Amplatzer device implant.

Three-dimensional echocardiography (3-D echo) in the percutaneous occlusion of septal defects

In the mid-90s, several studies showed the feasibility and accuracy of 3-D echo in the assessment of the heart[28]. At the same time, interventional cardiology was established as an effective and safe technique for ASD occlusion. Consequently, several studies were published showing three-dimensional evaluation of the interatrial septum and its defects, and the connections between the implanted device and the adjacent cardiac structures[29-33]. Three-dimensional reconstruction was initially performed from TEE pictures obtained every two to three degrees, from zero to 180º, synchronized to the patient's cardiac and respiratory cycle. Because of total immobilization of the patient was required, most of the studies were performed in the catheterization laboratory under general anesthesia[32,33]. Using the Hewlett-Packard Sonos (Philips, Bothel, WA, EUA) and Echo-Scan TomTec Imaging Systems Inc., (Boulder, CO, EUA), 3 to 10 minutes were required to acquire the pictures, depending on the patient's heart rate. Time for reconstruction was about 3 to 5 minutes, but it could take up to 40 minutes to prepare a set of images[29,32].

3-D echo main advantages to evaluate ASD are the clear demonstration of ASD characteristics, with a particular visualization of the extension of the anterior-superior rim, defining the defect shape and allowing measurement of all orifice dimensions[28,29,34], In this image modality, it is possible evaluate the defect *en face* mimicking the surgeon's view, with the advantage of being dynamic during the cardiac cycle. After device implantation, three-dimensional reconstruction can identify the device positioning, showing and locating possible arms or discs protrusion to the right atrium[33]. Evaluation and measurement of residual defects can also be assessed by this method[29].

Live 3-D echo has recently become available in the market. To date, only thoracic transducers are available, which does not provide ideal assessment of interatrial septum defects in older children and adults. Figure 6 shows an ASD assessed by TEE and the transthoracic 3-D view of the same defect.

Recently a report described the use of this technology to monitor an ASD occlusion in a six-year-old child weighing 22 kg, using subcostal views[35]. Catheters' and guidewires' position, balloon measurement of the defect and discs release were all guided with live 3-D pictures, which accurately identified septal tissue between the discs and provided better pictures of the posterior-inferior rim.
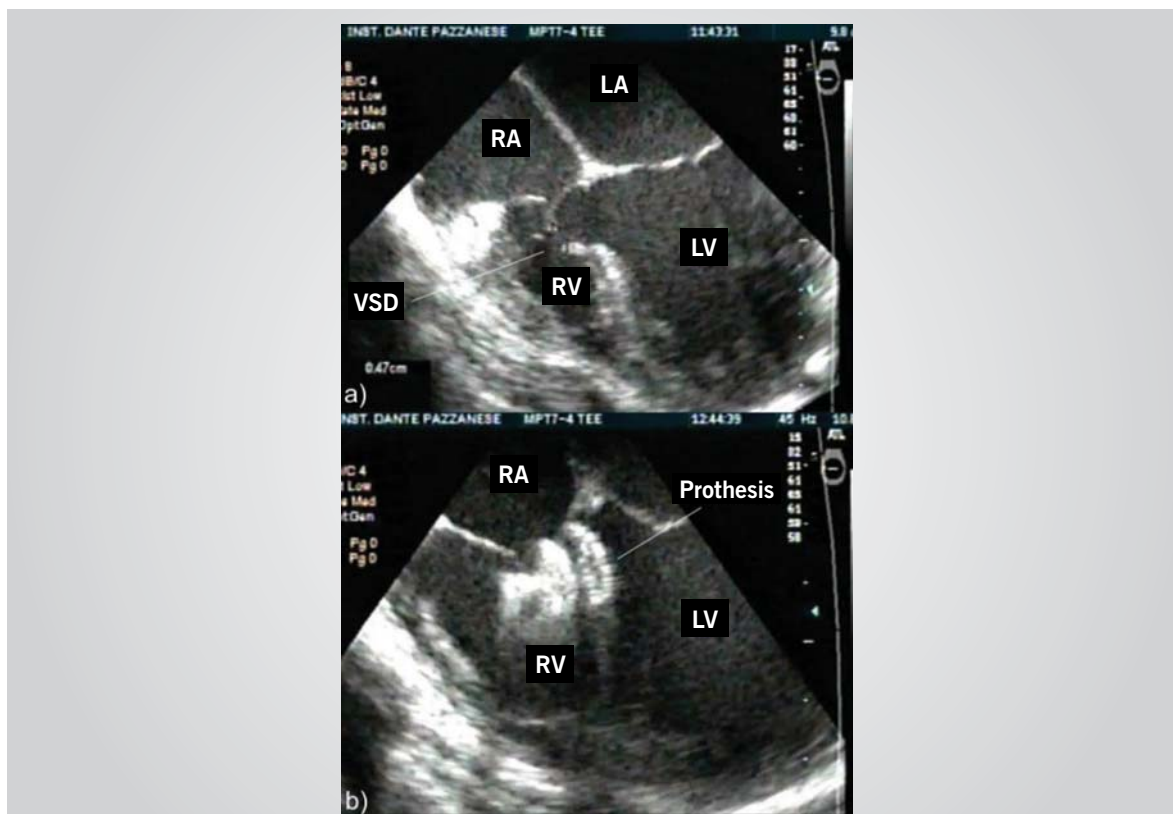
Fig. 5 - *TEE during percutaneous occlusion of a perimembranous ventricular septal defect (VSD); a) the presence of a large VSD in the perimembranous region partially occluded by accessory tissue from septal leaflet of the tricuspid valve; b) Amplatzer device for perimembranous VSD, occluding the defect. RA: right atrium; LA: left atrium; RV: right ventricle; LV: left ventricle*

Fig. 6 - *a) Bidimensional TEE of an ostium secundum ASD; b) live 3-D reconstruction of the same defect that presents an aberrant shape. RA: right atrium; LA: left atrium; ASD: atrial septal defect*

Decreased fluoroscopy time, better outline of the defect shape, elimination of esophageal intubation and more reliability regarding the device positioning were highlighted as the main benefits of this type of monitoring[35]. With the future development of a transesophageal transducer for live 3-D images, the method will be also useful in procedures for older children and adults.

CONCLUSIONS

As described in previous paragraphs, there are different percutaneous techniques to treat septal defects. Technological developments have made the procedures feasible, effective and safe. Echocardiography has a primary role in identifying patients that benefit from such procedures, in monitoring them and in the immediate and late post-occlusion follow-up. Similarly to the advances in the devices and percutaneous field, echocardiography has evolved to provide more complete and precise information for the interventionalist, helping in the procedure and making it even safer and simpler.

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