How to Monitor Transseptal Puncture: A Consensus Statement of the Italian Society of Echocardiography and Cardiovascular Imaging

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Abstract

Interest in the anatomy of the interatrial septum (IAS) and the implications for a proper transseptal puncture (TSP) has risen in the past two decades along with the simultaneous evolution of left-sided transcatheter structural heart interventions. A comprehensive understanding of the anatomy of the IAS in relation with the therapeutic target, is essential for performing a safe and effective transseptal puncture. Intra-procedural echocardiography, transoesophageal and/or intracardiac, is recommended in all patients undergoing TSP because it provides fundamental insights into the septum anatomy and, furthermore, allows for tailored puncture. This document aims to describe the essentials of echocardiographic guidance of transseptal puncture (TSP).

Keywords: Interatrial septum, intraprocedural echocardiographic guidance, transseptal puncture

Introduction

Interest in the anatomy of the interatrial septum (IAS) and the implications for a proper transseptal puncture (TSP) has risen in the past two decades, along with the simultaneous evolution of left-sided transcatheter structural heart interventions. As anatomic landmarks are not visible under fluoroscopy, the use of intraprocedural echocardiography has become of utmost importance to ensure safety and allow a more precise detection of the crossing-point location within the atrial septum. Thus, a comprehensive understanding of the anatomy of the IAS in relation to the left-sided therapeutic target is essential for performing a safe and effective TSP.

The anatomic interatrial septum (IAS) is the entire area interposed between the two atria and should be distinguished from the "true" IAS, according to the anatomist's definition, limited to the thin flap (the embryonic septum primum) that constitutes the floor of the fossa ovalis (FO).[1] The latter is the only area that can be crossed without going into the extracardiac space [Figure 1]. Indeed, the extensive muscular area near the superior and posterior margins of the FO (the embryonic septum secundum) is a two-layered muscular structure formed by a folding of the atrial wall, which externally corresponds to the interatrial groove (also called Sondergaard's or Waterston's groove).

The FO is bounded posteriorly by a fold of pericardium between the left atrium (LA) and right atrium (RA), superiorly by the superior vena cava (SVC), anterosuperiorly by the noncoronary sinus (CS) of Valsalva in the aortic valve (AV), anteriorly by the septal tricuspid annulus, antero-inferiorly

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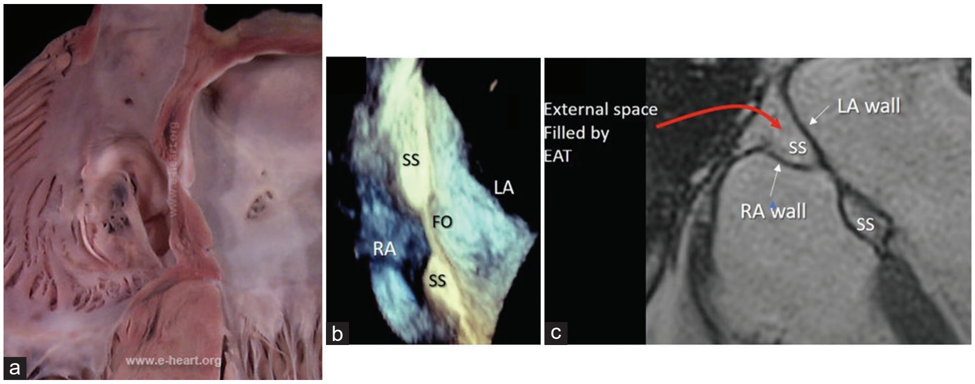

Figure 1: Specimen (a) and three-dimensional lateral perspective view (b) of IAS showing its two components: The septum primum that is membrane-like forming the floor of the fossa ovalis (FO) and the septum secundum that is a muscular rim surrounding the FO. As shown in the computed tomography-scan (c) the septum secundum is an enfolding of atrial wall forming an interatrial groove filled with adipose tissue on the epicardial side and named, Waterston's groove. Thus, the safest area for transseptal puncture is within the limits of the FO floor, which provides direct interatrial access. Curtesy of F. Faletra.[2] FO: Fossa ovalis

by the CS ostium, and inferiorly by the inferior vena cava (IVC) [Figure 2].

Preprocedural transoesophageal echocardiography (TEE) is recommended in all patients undergoing TSP because it provides fundamental insights into the septum anatomy (e.g., challenging septa, patent foramen ovale, and atrial septal defects [ASDs]) and allows detection of the left atrial thrombus or atrial tumours, which represent the only real contraindications to TSP. Preprocedural computed tomography is also usually indicated for transcatheter mitral valve (MV) implantation, providing fundamental information such as aortic-MV angle, preplanning of fluoroscopic landmarks and adjacent structure positions.[3-5]

This document aims to describe the essentials of echocardiographic guidance of TSP.

Two-dimensional/Three-dimensional Transesophageal Imaging of IAS

The FO is usually localized in the middle of the septal wall, but the site, size, and shape can vary among different patients and according to atrial size, pressure, and tissue redundancy. Moreover, instead of the usual tautness, the valve may be floppy, aneurismal, or contain fenestrations. The full comprehension of two-dimensional (2D) and 3D imaging of IAS and its spatial relationship relies on the use of the neighboring structures as spatial landmarks, for easily bearing inside both atrial cavities. The landmarks are represented by the SVC and IVC, which lie adjacent to the superior-posterior and inferior-posterior aspects of the atrial septum, respectively, and the AV/root, which is adjacent to the anterior-superior portion of the atrial septum.

The 2D-TEE standard views used to visualize IAS are the mid-esophageal (ME) Bi-caval view, the short axis at the base view (SAX-B), and the 4-chamber (4Ch) view [Figure 3].

- The standard Bi-caval view, by displaying SVC and IVC, shows the superior and inferior aspects of the more posterior portion of the septum and the FO, and is typically obtained with the multiplane sector angled between 90° and 120°
- The SAX-B view at the AV level shows anterior-superior (represented by AV/root) and inferior–posterior septal landmarks and is typically obtained with the multiplane sector angled at 30° to 60°
- The 4-Ch view will display antero-inferior (marked by MV plane) and postero-superior aspects of IAS. This view is of utmost importance during TSP because it allows for the height definition of the puncture site from MV plane.

Obviously, starting from these standard views, several 2D planes can display the septum at different levels from the anterior to posterior portion of FO by Bi-caval view and from superior to inferior portion of FO by SAX view, according to different multiple degrees of anteroflection/retroflection and rotational movements of the probe, respectively.

The two 3D modalities, simultaneous biplane view and volume rendering, are useful imaging tools because they allow for easier visualization of the entire structure of interest, providing optimal comprehension of IAS morphology, dimensions, anatomical boundaries, and relationship [Figure 4].

- Simultaneous biplane views provide simultaneous visualization not only of the two standard TEE views of IAS, which are the Bi-caval and SAX-B views, but also simultaneous view of 2D infinite planes by manipulating the probe for imaging adjustment. This implies two major advantages
    1. Simultaneously, more immediate display of two different 2D image planes with optimal spatial and temporal resolution and the contemporary evaluation of all relevant structures
    2. Easier acquisition of anatomically correct imaging views, avoiding foreshortening. Indeed, by changing the elevation and angles on the "reference plane" it is possible to achieve the most effective and proper view in the "derived plane;"
- 3D-zoom is the 3D volume rendering acquisition modality preferred, leading to higher temporal resolution and real-time visualization of the IAS

from different potential perspectives, together with simultaneous visualization of catheters/devices, and their different movements in relation to the IAS. The dimension of the sector should be as large as possible to include the entire IAS and surrounding structures/ landmarks (both venae cavae and AV), while the "depth" direction should be set to include only the left and the right sides of the septum, excluding right-sided surrounding structures that may cover the right aspect of the IAS [Figure 4].

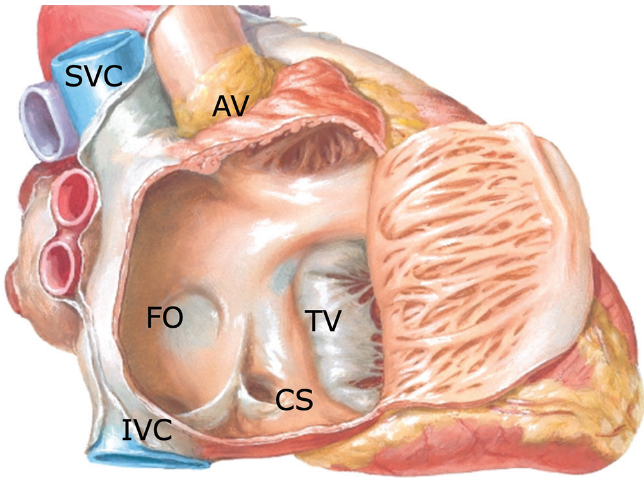

Figure 2: Illustration shows IAS anatomy, seen from the right atrium (RA). It is bounded posteriorly by a fold of pericardium between the left atrium (LA) and RA, superiorly by the superior vena cava, antero-superiorly by the noncoronary sinus (CS) of Valsalva in the aortic valve, anteriorly by the septal tricuspid valve annulus, antero-inferiorly by the CS ostium, and inferiorly by the IVC. Fossa ovalis is usually visualized as a depression on the septal aspect surrounded by a rim that is raised to varying degrees of prominence. However, in almost 20% of individuals, the rim is flat and blends into the fossa without clear distinction between the two structures. SVC: Superior vena cava, AV: Aortic valve, TV: Tricuspid valve, FO: Fossa ovalis, CS: Coronary sinus

Two-dimensional/Three-dimensional Transesophageal Imaging in Transseptal Puncture Setting

In the TSP setting, 2D and 3D imaging are complementary for the guidance of the procedural steps. According to the transcatheter procedure monitored, a specific position of the puncture site may be required.

2D ME Bi-caval view explores the superior and inferior aspects of IAS and is typically the primary working view used to follow the catheter approaching IAS and then FO.

After achieving FO, a 2D ME SAX-B view, displaying anterior and posterior aspects of FO, allows for antero-posterior adjustment of the sheath-Brockenbrough (BRK) needle apparatus. Any further manipulation/rotation of the BrockenBrough needle torque will place the tip in a different position on FO [Figure 5]:

- A superior position in the bi-caval view, toward the SVC, will make the puncture site gain height in relation to the MV plane and, in the meantime, less distant from the aortic root. A more inferior position, toward IVC, will place the puncture site at a lower height from the MV plane and more distant from the aortic root
- A posterior position in SAX-B view (corresponding to a clockwise rotation of the Brockenbrough needle torque), will place the puncture site distant from the aortic root allowing both for a safe puncture and for gaining more height from the MV plane. Conversely, any anterior orientation of the tip of the dilator (corresponding to Brockenbrough needle torque counterclockwise rotation),

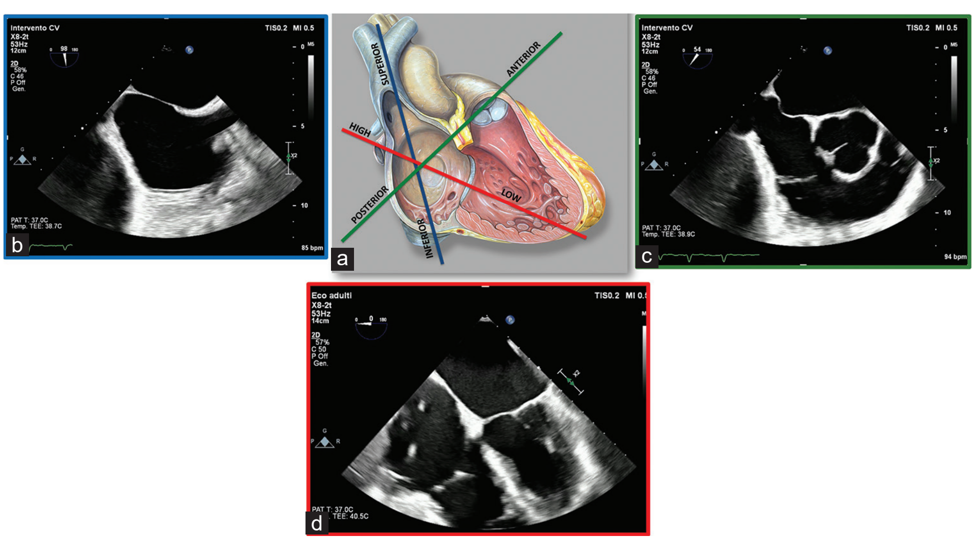

Figure 3: (a) Schematic representation of the 3 standard scan planes by which two-dimensional-transoesophageal echocardiography explores IAS. The blue line depicts Bi-caval view projection exploring the supero-inferior aspects of IAS (b). The green one provides the SAX at the base view, exploring the anterior-posterior aspects of IAS (c). The red plane represents the 4-chamber view, which allows for height definition, by the simultaneous visualization of the IAS (with tenting site) and mitral valve plane (d)

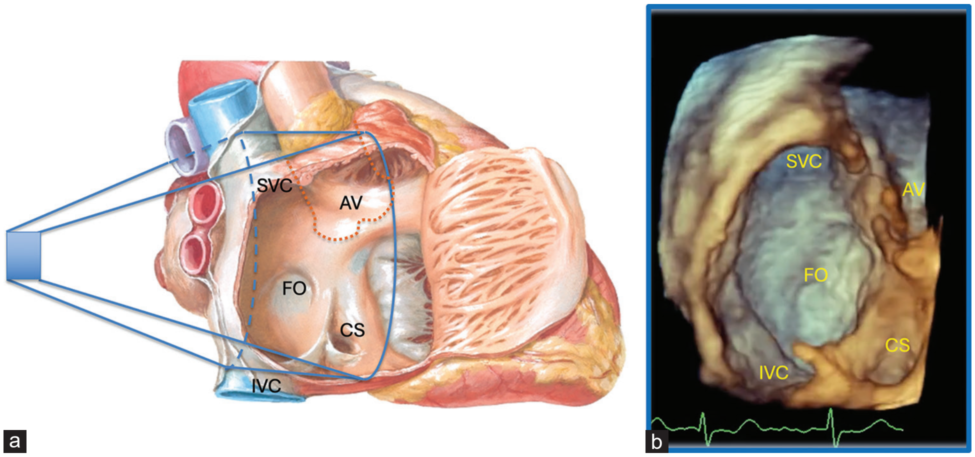

Figure 4: Once the three-dimensional zoom pyramidal dataset of IAS (a) has been acquired, any 90° up-down angulation and an alternatively 180° counterclockwise rotation will show the IAS in the most effective and familiar view desired. En-face perspective from right atrium (b) is characterized most of time, by the crater-like structure of the fossa ovalis with more or less prominence of its rims. RA: Right atrium, SVC: Superior vena cava, IVC: Inferior vena cava, AV: Aortic valve, CS: Coronary sinus

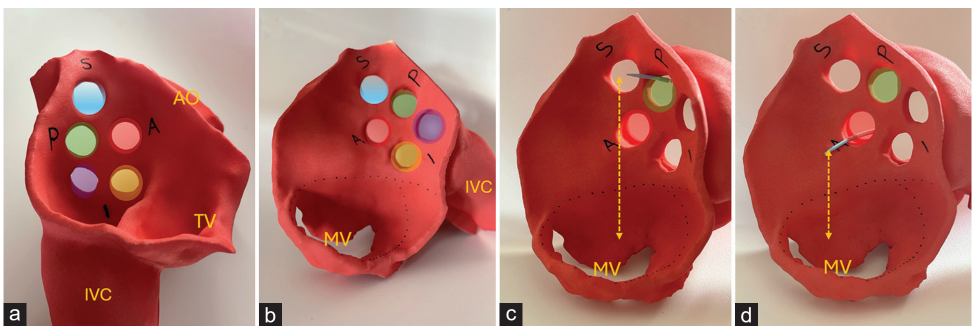

Figure 5: Three dimensional models showing the IAS from the right side (a) and the left side (b) and its relationship with the mitral valve (MV) plane. There are represented main transseptal puncture (TSP) sites: in posterior fossa (supero posterior in blue, mid posterior in green, infero posterior in violet); in anterior (red) and infero anterior (yellow) fossa. The same sites seen from left side makes easier to understand their implication in terms of height from MV. A clockwise rotation of the BrockenBrough needle (BRK) torque will place TSP site in posterior position (green) thus gaining more height (c); conversely a counterclockwise rotation will make the tip of BRK pointing more anterior, lowering the puncture site in relation with MV (d). IVC: Inferior vena cava, TV: Tricuspid valve, AO: Aorta

toward the aortic root/valve, will place the puncture site less distant from anterior–inferior aspect of FO, and so from the MV plane evaluable in 4Ch view. The anterior rim of an anteriorly situated FO may lie immediately behind the aortic root (septal aspect known as the aortic mound) and may represent a potential risk for aortic perforation. Moreover, few millimeters divide the anterior-superior margin of the FO from the RA wall, which overlies anteriorly the right and posteriorly the noncoronary aortic sinus. When large, the aortic root may about the right atrial cavity, creating a deformation of the RA and especially LA cavities

- 4Ch view allows for the evaluation of the height from the MV plane by the contemporary visualization of the tenting in FO and MV. When a candidate TSP site is decided, a modified 4Ch (0°–20°) or reverse 4Ch (160°–180°) view can be used to measure the anterior-posterior (AP) distance from the MV (or annulus) to the TSP site for various mitral procedures[6] [Figure 6].

However, multiple potential directions TSP catheter could achieve in a 3D space, thus it implies that following the intracardiac catheter and establishing its position relative to the FO may be difficult with 2D imaging and multiple views, and continuous adjustments/probe manipulation may be required. 3D imaging has the additional value to provide comprehensive images of the IAS and, according to the imaging needs of the specific procedural step, is possible to define two different but complementary perspective approach:

- If the structure-oriented approach is chosen, the 2D preview zoom sector should be placed and sized over the IAS, including part of RA, obtaining a 3D en-face visualization of FO from the RA/LA. This volume dataset can then be oriented in terms of lateral, oblique, and en-face perspective, to obtain/optimize the best view of the region of interest. This approach provides information on the localization/orientation of the sheath-BRK assembly in the RA, in relation to the IAS and surrounding structures [Figure 3]
- If the anatomic-oriented approach is chosen, the 2D preview zoom sector should be placed and sized over MV, including

IAS, LA, and AV. In this way, the volume dataset obtained provides a lateral perspective view of the IAS in relation to the other anatomical structures of LA and AV [Figure 7].

Transseptal Puncture Procedural Steps

In the TSP setting, 2D and 3D imaging are complementary for the guidance of the procedural steps.

Step 1: Advancement of the transseptal puncture catheter toward the fossa ovalis

The standard Bi-caval view allows for the visualization of the sheath-BRK apparatus approaching from SVC to FO, along the thick part of the septum. The sheath and needle assembly are retracted to the RA under clockwise rotation. Two characteristic "jumps" of the dilator tip are usually described: one as the tip passes under the aortic knob and one as the tip passes under the muscular septum into the fossa [Figure 8]. This step could be monitored also by a 3D zoom en-face view or lateral perspective view of IAS [Figure 9]. Once the tip of the dilator has reached the FO, then switching to 2D imaging is mandatory in order to have the best spatial resolution for assessing its fine position within FO and its proper distances from surrounding borders (posterior and anterior rims).

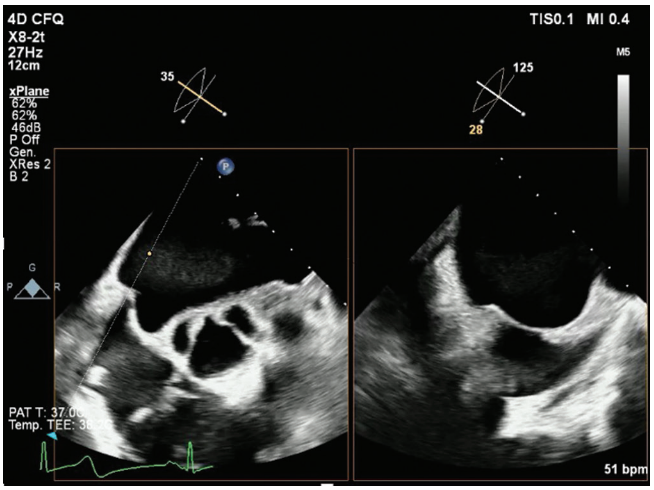

Figure 6: Tip and triks in cath lab. If the standard two-dimensional 4-chamber (4Ch) view for height measurement from mitral valve plane, is not available, then it is possible, in simultaneous biplane view, to achieve a reverse 4Ch view by increasing the angle of the derived elevation plane

Step 2: Achievement of the correct position and orientation of the tip of the dilator

In this phase, Bi-caval and SAX-B views, alternatively or by simultaneous biplane visualization [Figure 10] allow for fine evaluation of the position of the dilator on IAS:

- Its superior versus inferior position, according to the proximity to SVC or IVC, respectively (on Bi-caval view)
- As previously mentioned, the anterior position (near aortic root/valve) or posterior position (toward LA roof, far from aortic root/valve) of the puncture site (on SAX-B view); since clockwise torque is applied, the dilator tip moves from anterior to posterior, away from the aorta [Figure 11]
- To confirm the proper position within FO and exclude the curve of the sheath is anteriorly orientated, toward the aortic root (not perpendicular to the IAS, but approaching by an acute angle) (on SAX-B view)
- To confirm the catheter does not engage patent foramen ovale (PFO) [Figure 12], which may increase the risk of aortic perforation, directing the needle toward the aortic root, through the transverse pericardial space.

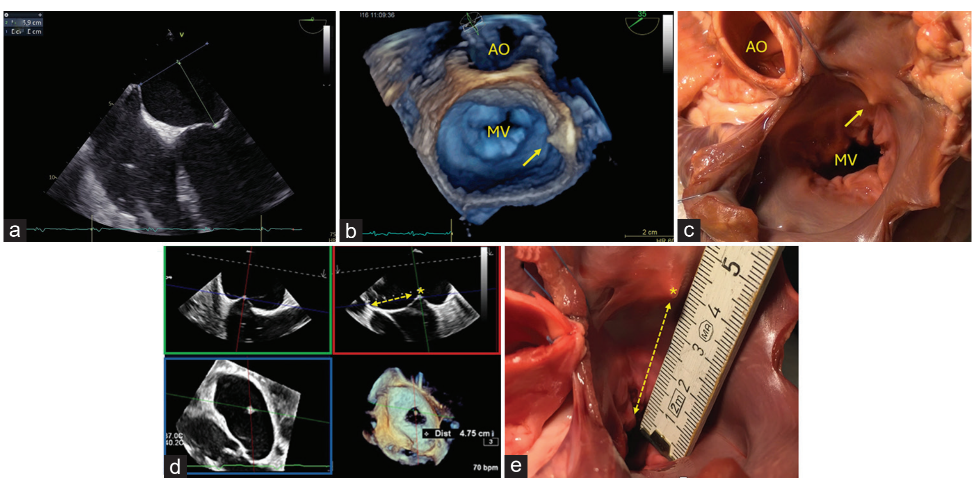

Figure 7: (a) 4 Chamber view allow for height of tenting site from mitral valve (MV) plane measurement. (b) Three dimensional (3D) zoom lateral perspective of IAS (b: corresponding to an anatomic overhead view of left atrium), showing both an adequate tenting (arrow) and the position of the tenting site in relation to the surrounding structures (MV, AV). (c) Corresponding suine heart spicemen "overhead view" with realistic representation of tenting (arrow). (d) Multiple plane reconstruction of 3D dataset can facilitate the fine detection of the tenting site. The green plane is oriented along the access route (venae cavae), producing a typical two dimensional Bi caval view, and the red plane is now counterclocked to cross the MV, which will now be displayed, allowing for height measurement. The cross hair is then used to follow the transseptal puncture (TSP) needle. The lower images display the 3D rendering and its corresponding projection (blue plane). The location of the TSP needle (asterisk) is at the intersection of the red and green planes at the middle and posterior aspect of the fossa ovalis. (e) Suine heart spicemen with realistic representation of tenting (asterisk) "height measurement". MV: Mitral valve, AO: Aorta, MPR: Multiple plane reconstruction

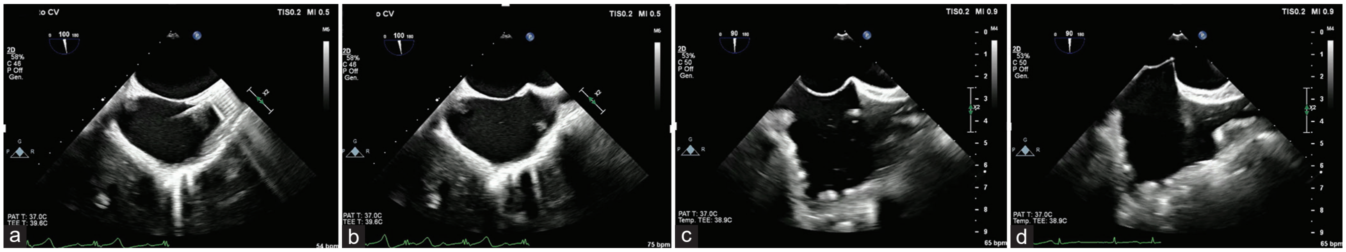

Figure 8: Two-dimensional mid-esophageal Bi-caval view shows in sequences the sheath-BRK assembly coursing along the superior vena cava (a), approaching the sptum secundum (b) and its edge with the septum primum (c) until it "jumps" in the middle of fossa ovalis (d). The discent of the sheath is accompained by the corresponding supero-inferior migration of the tenting. SCV: Superior vena cava

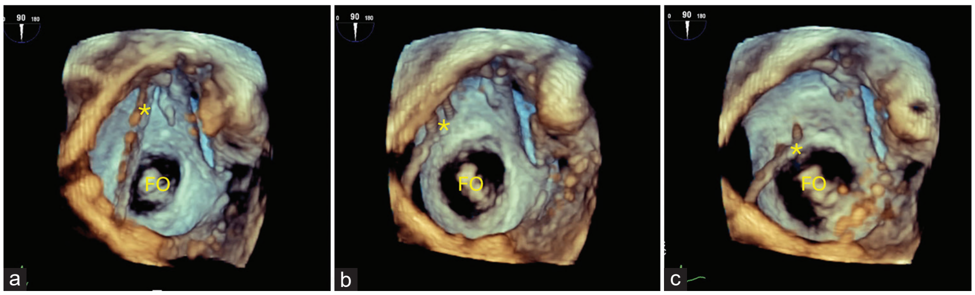

Figure 9: Three dimensional (3D) zoom en face perspective of IAS with the transseptal puncture (TSP) sheath (asterisk) approaching the fossa ovalis (FO) from superior vena cava (a-c). Because of its most usual thin tissue constitution and its spatial orientation in relation to the ultrasound beam, FO often presents "drop out" artefacts on 3D imaging. 3D imaging of IAS may be very useful in case of difficult two dimensional visualization of the TSP sheath descent toward the FO (i.e., too posterior position). SVC: Superior vena cava, FO: Fossa ovalis

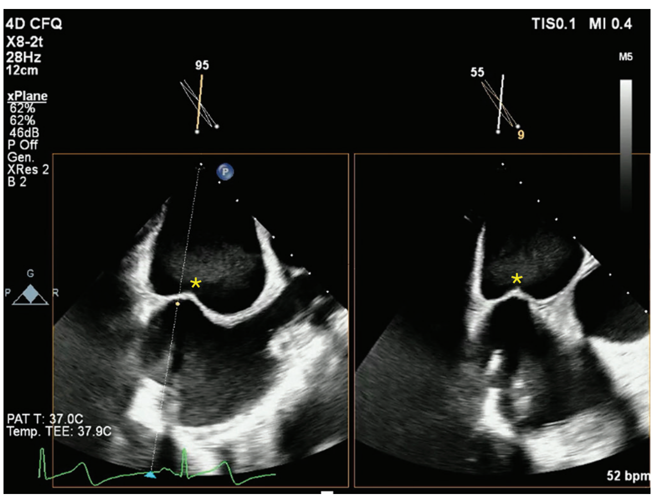

Figure 10: Simultaneous biplane view (Bi-caval on the left, SAX-B on the right) shows the transseptal puncture sheath-BRK assembly properly oriented against fossa ovalis floor, generating an adequate tenting and correctly positioned in relation with the aorta (asterisk). BRK: Brokenbrough needle, FO: Fossa ovalis

Step 3: Evaluation of tenting

The most appropriate site for the puncture is usually identified through recognition of 2D imaging typical "tenting" of the FO caused by the tip of dilator pressure. A not correct position and/or orientation of the tip of the dilator against the FO may not produce an adequate tenting [Figure 13], requiring a change in its position/orientation. Occasionally, the "tenting" can be missed using 2D imaging because it can be located deeper in relation to the 2D scan plane (i.e., too anterior or posterior with respect to the Bi-caval view or too superior or inferior with respect to the SAX view). This could be compensated for by clockwise or counterclockwise rotation of the probe. 3D-zoom imaging, in particular lateral perspective view (anatomic oriented approach), provides additional information about not only the quality of tenting but also the position of the puncture-site in relation to the other anatomical structures of LA. Moreover, live multiplane reconstruction may also help in fine evaluation of the dilator position and orientation, simultaneously in multiple planes [Figure 7].

In particular cases, an inadequate tenting could also be due to the presence of a thick septum (i.e., postsurgical patients), and not to an incorrect position of the catheter.

Step 1 and/or Step 2 must be repeated until a safe position along with adequate tenting, has been achieved.

Step 4: Septal puncture/crossing

Septal puncture/crossing is usually monitored on the SAX-B view or the simultaneous biplane view to make sure the position on the site selected is maintained during the puncture (either standard puncture or by use of radiofrequency [RF]). The needle is advanced while keeping the transseptal sheath in place. For additional safety, LA pressure should be confirmed before advancing the transseptal sheath. If the tenting is not clearly visualized or in any way in challenging scenarios, the LA position of the tip can be verified by aspirating oxygenated blood, measuring LA pressure, injecting contrast into the LA, or advancing a coronary wire into a PV.

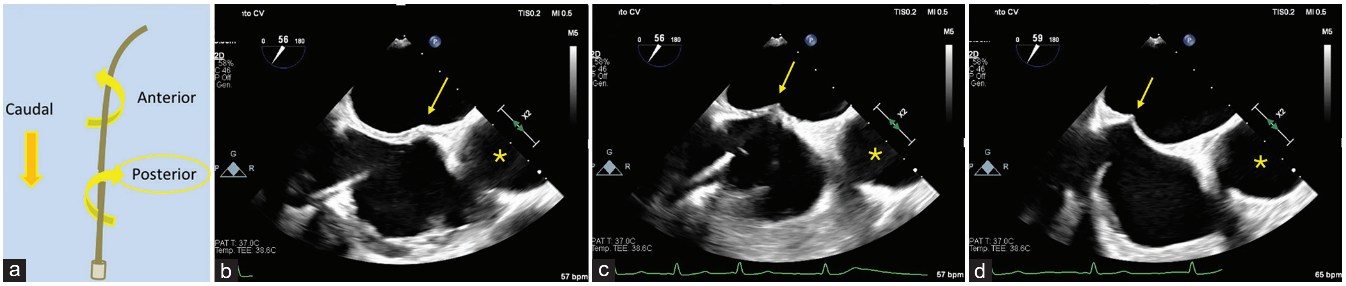

Figure 11: According to the rotation of the sheath-BRK assembly (a), the tenting site (arrow) on fossa ovalis will change in terms of anterior-posterior position. From the initial anterior position (b), near aortic root/valve (asterisk), by a clockwise torque, the tip of the dilator will move to a middle (c) and then to a more posterior position (d), far from aortic root/valve. Two-dimensional SAX-B view is mandatory for this procedural step monitoring

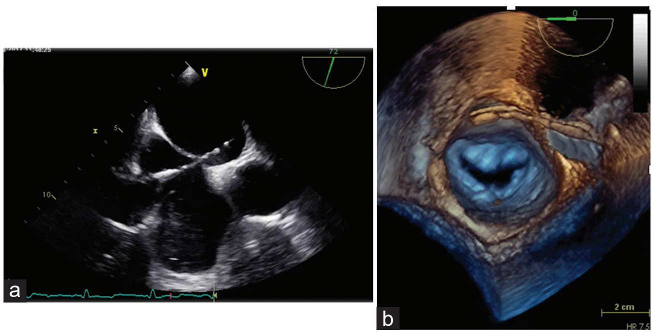

Figure 12: (a) SAX-B view showing the catheter engaging patent forame ovale (PFO). The PFO is never used as a crossing point of the septum because, given it its very anterior position, does not provide any advantage in terms of easing left side transcatheter interventions. A three-dimensional zoom left atrium overhead view provides immediate perception of too anterior route of the catheter (b). Moreover, a too anterior position increases the risk of aortic lesion, by directing the catheters toward the aortic root, potentially through the transverse pericardial space. PFO: Patent foramen ovale

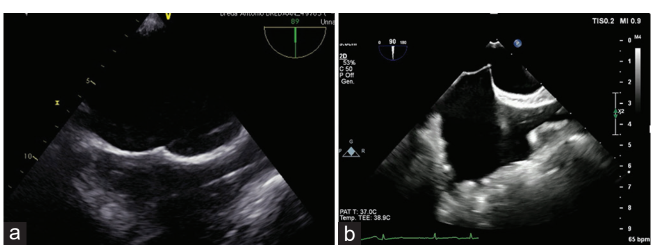

Figure 13: Two-dimensional Bi-caval view showing a different quality of tenting if the tip of the dilator approaches the fossa ovalis too tangentially oriented (a) versus more perpendiculary oriented (b). In a an effective tenting does not appear

Puncture of the fossa is usually followed by the release of the tenting [Figure 14]. The sheath and dilator assembly apparatus are then advanced over the needle into the LA. Because of the difference in diameter between the assembly and the needle and according to the thickness/resistance of the septum, another transient tenting effect could be present [Figure 15]. Any introduction of sheath/catheters with a larger diameter will obviously produce a new tenting of the tissues until the septum is effectively crossed. The complete crossing of the septum is then marked by the release of the tenting. The following steps (catheter insertion via the sheath, sheath exchange, IAS dilation, and so on) vary depending on the specific procedure being performed [Figure 16]. Finally, balloon septostomy may be needed to adequately predilate the FO,[7] especially in transseptal interventions that use large-bore sheaths (e.g., MV-in-valve).[8,9]

Site Specific Transseptal Puncture

TSP is usually the first step in complex percutaneous catheter-based procedures that normally require TEE guidance. The first aim is to avoid life-threatening complications related to inappropriate puncture sites such as atrial or aortic wall puncture and cardiac tamponade. Moreover, some of them, such as edge-to-edge (EtoE) MV repair devices and LA appendage (LAA) occlusion, necessitate a precise site-specific TSP.

Thus, according to the specific procedural guidance, we can distinguish a tailored TSP approach, where the puncture site is critical and should satisfy precise technical needs, from a not-tailored approach, in which the puncture site is less critical (i.e., paravalvular leak [PVL] closure, Valve in Valve/Ring) and TEE monitoring is mandatory mainly for safety control and early detection of complications. The latter procedures, because of their characteristics, do not require site-specific TSP, even if a sufficient height from the MV plane should be guaranteed.

Mitral valve intervention

Proper guiding catheter position is the most important initial step of the EtoE repair procedure. Tailored TSP, in posterior position, enables a suitable guide position and allows the device to smoothly reach the middle of the mitral orifice.[10] A suboptimal TSP site may result in inadequate treatment of mitral regurgitation (MR) or even to potential no treatment.[11] For central MR jets, a posterior and slightly superior TSP site should be achieved. Higher TSP heights are needed for more medial jets, while lower transseptal sites are more appropriate when lateral jets are targeted[11] [Figures 5 and 7].

The position of the TSP for mitral PVL closure requires similar forethoughts. For defects away from the IAS (lateral PVL), the location of the puncture is less critical. However, for medial

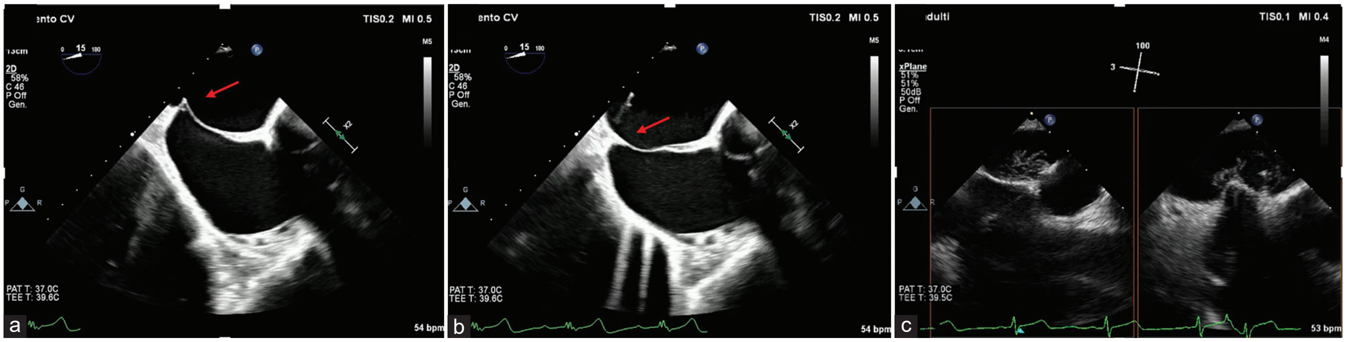

Figure 14: SAX B view showing the posterior position of tenting (a, Arrow) and its complete release (b, Arrow) along with the puncture of the septum in a "standrd puncture" scenario. (c) Simultaneous biplane view showing BRK needle crossing fossa ovalis after radiofrequency impulse delivery, with the evidence of transient microbubbles in left atrium. BRK: Brokenburg, RF: Radiofrequency, LA: Left atrium

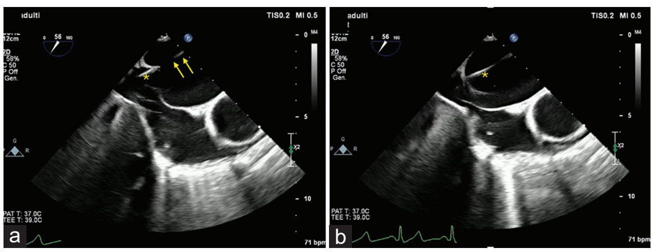

Figure 15: (a) Example of transseptal puncture with the needle passed into the left atrium (arrow) and the dilator-sheath assembly still in the right atrium (asterisk), leading to transient retention of residual tenting. This is due to the difference of diameter between the assembly and the needle and to the resistance of the septum. (b) The final crossing of the assembly (asterisk) is marked by the complete release of the tenting

defects, a posterior and slightly superior puncture provides the appropriate working height within the LA and allows readily access to the defect. If multiple PVL are present, in different locations, then different TSP could be performed, each one functional to ease engaging different defects [Figure 17].

In case of balloon valvuloplasty and transseptal MV-in-valve implantations, a mid-posterior puncture is usually adequate and provides a favorable working height in the LA and a coaxial plane with the MV.

Left atrial appendage closure

The long axis of the LAA is usually anteriorly oriented, and the plane of the ostium is perpendicular to that axis. Thus, successful coaxial device deployment depends on the ability to position the delivery sheath both coaxially with the LAA long axis and with sufficient depth into the appendage. This is best accomplished with a posterior-anterior trajectory of the sheath [Figure 18]. Therefore, an infero–posterior TSP [Figure 5] is recommended in the majority of percutaneous LAA closure procedures to obtain coaxial alignment between the delivery sheath and the LAA. On the contrary, an inferior but more central/anterior TSP should be recommended in case of a reverse chicken wing LAA or posterior bending of the proximal LAA, which occurs in 20%–25% of cases.[3,12]

There are little differences in the recommended TSP height related to the shapes of the transseptal sheaths used for different LAA occlusion technologies. For example, for the Watchman device (Atritech, Boston Scientific, Natick, MA, USA) and the Amplatzer Cardiac Plug (AGA, St. Jude Medical, Minneapolis, MN, USA), mid-posterior to slightly inferior TSP is ideal. A TSP that is too superior or too anterior can make it difficult to align the sheath with the long axis of the LAA and poses a challenge to device delivery, especially with retroverted LAAs.[13]

Intracardiac Echocardiography

In intracardiac echcocardiography (ICE)-guided procedures, the probe is advanced to the RA and manipulated to identify the initial "home" view. The exploration of the IAS is then performed: from the home view, a posterior tilt of the transducer and a clockwise rotation of the catheter usually allow for FO visualization (septal view). With the sheath and dilator apparatus engaged against the FO in the septal view, the height of the TSP could be then assessed. The AP location of the TSP can then be determined with an anterior (counterclockwise rotation) and posterior (clockwise rotation) of the transducer, allowing needle adjustment before performing the puncture.[12] This survey also allows screening for PFO and characterization of the IAS anatomy (i.e., thick septum, septal aneurysm, prior patch repair). After successful puncture of FO, it is possible to monitor the needle tip passing in LA and its relationship to the surrounding cardiac structures.[14]

ICE may increase the safety and the success rate of TSP in challenging/difficult cases, such as in patients with aneurysmal or thickened septum, patients with abnormally rotated hearts, and those with thickened or fibrotic IAS due to patch repair or prior TSPs.[15]

Fusion Imaging

Fusion of different imaging modalities has gained increasing popularity in structural heart disease interventions over the past decade. Currently, the combination of TEE and fluoroscopy (e.g., EchoNavigator, Philips, Amsterdam, the Netherlands) is the only modality that allows real-time image fusion of high-quality images during percutaneous interventions. The utility of the fusion technology to

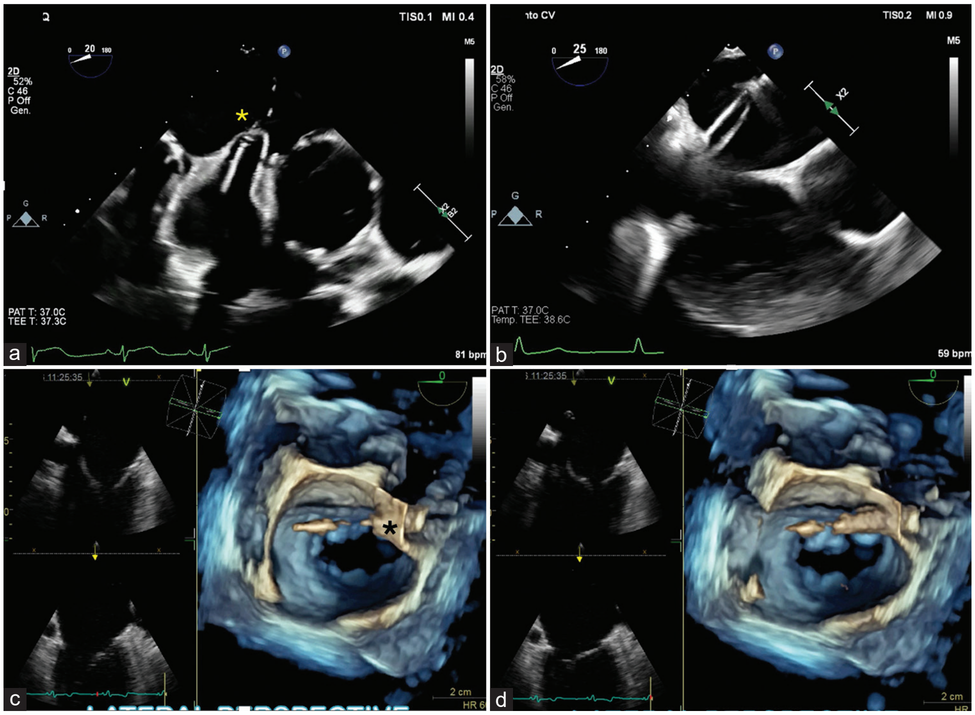

Figure 16: (a and b) Two dimensional (2D) SAX B view showing the passage of the sheath dilator assembly across the septum. In this step is critical the evaluation of residual tenting (a, asterisk) that may indicate a further resistance of the tissue to be crossed. Since the tenting is not realised, the sheath should be considered to be still on the right side of the septum (a), while the dilator is already passed in left atrium (LA). The sheath produces the typical duble binary artefact that ensure its recognition on 2D imaging (b). (c and d) Three-dimensional (3D) lateral perspective of IAS with the dilator crossing the septum (c, Asterisk). This 3D view allows to monitor the proper passage of the devices across the septum and their possible interference with the anatomical structure of LA

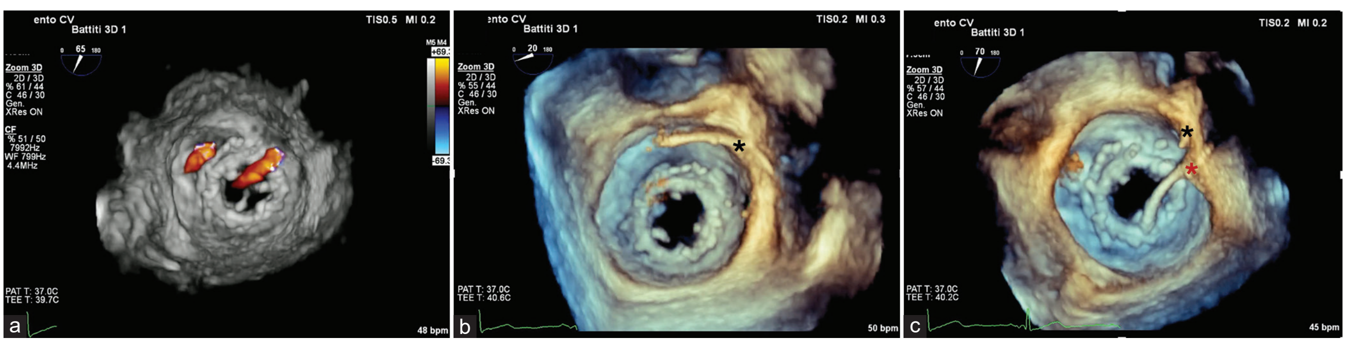

Figure 17: Example of different tailored transseptal puncture approach in the same procedure targeting two paravalvular leaks in antero lateral versus antero medial position (a): for more lateral defect a slightly anterior puncture site was selected (b, Black asterisk) versus a more middle/posterior position for the more medial defect (c, Red asterisk)

facilitate a targeted TSP has been demonstrated in several studies.[16,17] There are no standardized fusion imaging protocols for the TSP procedure. However, some 2D and 3D TEE views superimposed on fluoroscopic images can provide real additional value in some challenging cases. Moreover, also in undemanding situations, simultaneous visualization of 2D/3D images on fluoroscopic screen, may lead the imager and the interventionist to become more familiar with the technique.

All the 2D and 3D-TEE views of IAS have a corresponding fluoroscopic projection and can be superimposed to. It means that is possible to guide interventionists to move the C-arm in the patient-specific projection until the FO appears in the desired perspective (patient-tailored fluoroscopic view) [Figure 19]. According to the IAS anatomical position, right anterior oblique patient-tailored fluoroscopic view displays FO in an en-face fashion, corresponding to the 3D-zoom en-face view from the RA; AP projection displays FO in an oblique perspective fashion, corresponding to the 3D-zoom oblique perspective from RA; left anterior oblique projection allows for IAS side-on profile visualization, corresponding to both 3D-zoom lateral perspective or 2D ME Bi-caval view.

Fusion imaging could be very useful in case of challenging septum anatomy, such as a thick postcardiotomy septum, which prevents a clear visualization of the TSP catheter on the right side and the appearance of adequate tenting is not possible. Indeed, this technology overcomes these critical issues, enabling operator to visualize simultaneously the superimposed TSP catheter (by fluoroscopy) and the septum (by echocardiography) [Figure 20].

Challengin Scenarios

Severe kyphoscoliosis, abnormally rotated heart due to ventricular hypertrophy or prior surgery, enlarged left or RA, dilated ascending aorta, and excessive cardiac motion with respiration can pose significant technical and safety challenges during TSP.[18] Moreover, several IAS anatomies/morphologies can lead to difficulties in gaining access to the LA [Figure 21].

Many patients with atrial fibrillation or structural heart disease could have prior TSP or hypertrophied or fibrotic IAS. Repeat TSP can be more difficult and potentially associated with more complications compared with the first TSP, because of increased thickness of the FO due to local scarring.[19,20] Techniques to overcome these difficulties include the use of an RF transseptal needle or, if not available, brief application of RF energy using an electrocautery system connected to the proximal end of the transseptal needle.[21] The puncture by RF delivery is typically marked by the transient appearance of microbubble effect in LA. Adjunctive imaging with ICE has also been shown to facilitate crossing a scarred or highly resistant IAS.[15]

In cases of aneurysmal/floppy septum, there is a reduced distance between the apex of the tented FO and the opposite LA wall during TSP. There's therefore the need to avoid damaging of the LA wall from unanticipated and uncontrolled forward movement

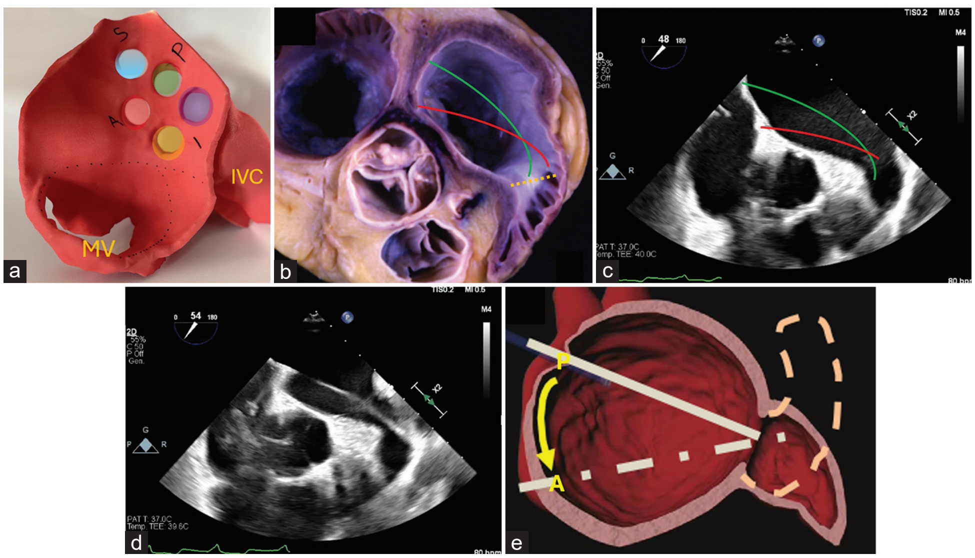

Figure 18: Left atrial appendage (LAA) is usually anteriorly oriented (b), and the plane of the ostium (dashed line) is perpendicular to that axis. Therefore, an infero posterior transseptal puncture (TSP) (a: violet circle) is recommended in the majority of percutaneous LAA closure, instead of an anterior puncture (red circle), because it allows for better coaxial alignment (green line) with long axis and sufficient depth into the appendage (b-d). Similarly, in case of reverse chicken wing LAA (e) an inferior but more central/anterior TSP should be selected to ensure proper coaxiality with the long axis of appendage

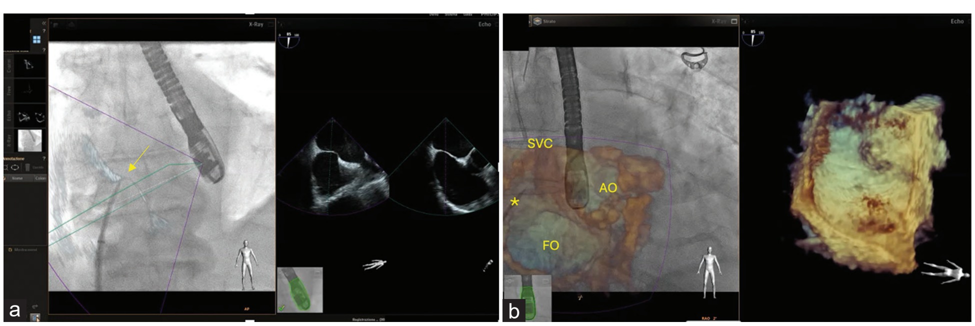

Figure 19: Two main displays of fusion imaging technology. (a) Patient tailored anterior posterior (AP) fluoroscopic view with the superimposition of two dimensional mid esophageal Bi caval view, clearly showing the transseptal puncture sheath BRK assembly pointing against the septum (ARROW). (b) Patient tailored AP fluoroscopic view with the superimposition of an en face three dimensional zoom of IAS from the right atrium, showing the dilator (asterisk) coursing from superior vena cava to fossa ovalis (FO). It is possible to appreciate the fine position of the dilator tip toward the superior posterior rim of the FO (visualized in its crater like fashion) and its distance from the aortic root (AO). SVC: Superior vena cava, FO: Fossa ovalis

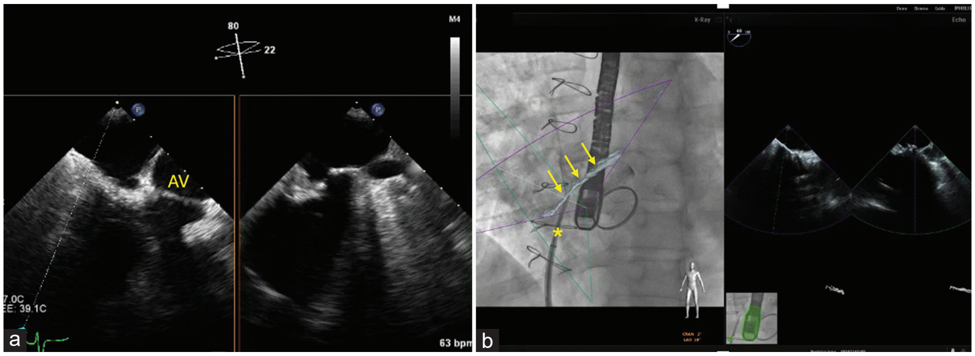

Figure 20: Transseptal puncture in a case of thick postcardiotomy septum: In simultaneous biplane view the sheath BRK assembly approaching IAS is not visible at all on the right side (a). (b) Fusion imaging technology could overcome this limit by the simultaneous combination of echocardiographic image of IAS (arrows) and fluoroscopic image of the sheath BRK apparatus (asterisk)

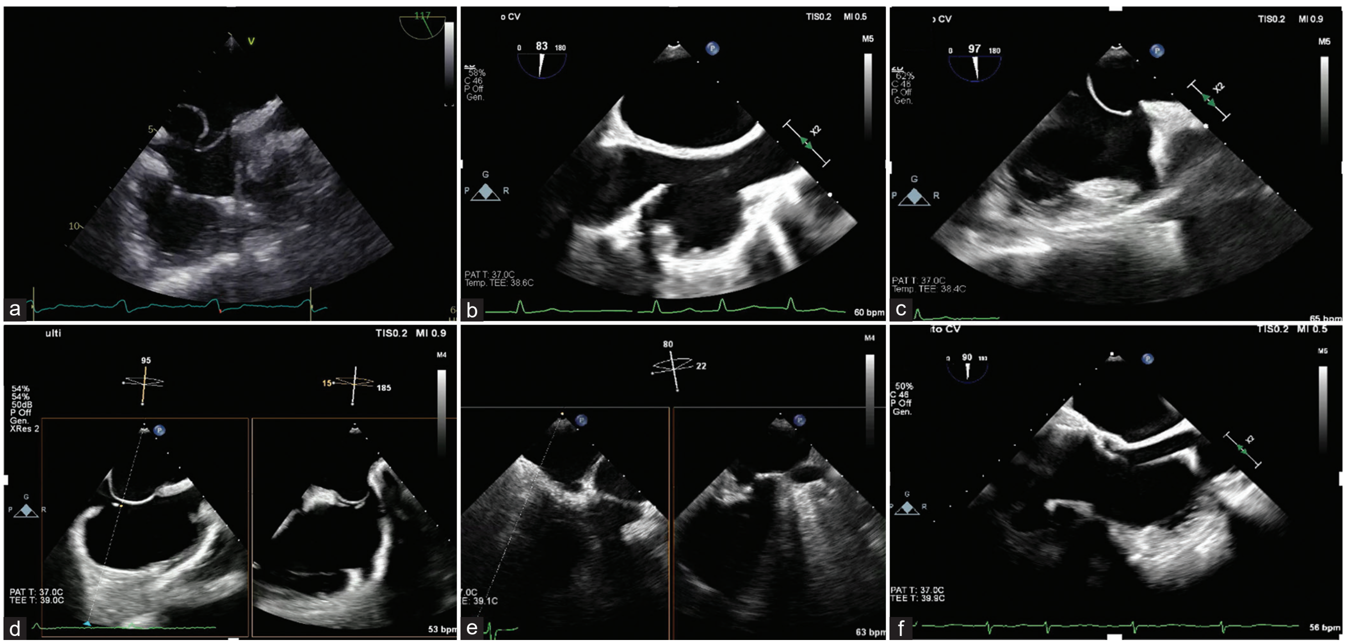

Figure 21: Different challenging anatomies of IAS. (a) A case of floppy septum. (b) A case of thick septum. (c) A case of aneurismatic, floppy septum with supero-anterior defect. (d) A case of aneurismatic septum with prominent Eustachian valve. (e) A case of thick, postsurgical septum, carachterized also by many artefacts. (f) Septum with a large septal defect occluder device

after the device passes through the FO. Again, a brief application of electrocautery or RF energy can be useful in this scenario.

In case of a prior septal occluder device implantation, transseptal access can be obtained in portions of the native IAS in the majority of cases. Direct trans-occluder puncture is rarely necessary but has been reported.[22,23]

In patients with surgically repaired IAS, puncture can be performed through neighboring native IAS tissue or through the patch itself in case of a pericardial or Dacron patch, but not in case of a Gore-Tex patch (W. L. Gore, Flagstaff, Arizona) because of its resistant texture.[24]

Complications

TSP is most often a safe procedure with a major complication rate of 1% to 2%. However, complications related to TSP could be life threatening, thus their prompt detection and management is of utmost importance. Cardiac tamponade during transseptal intracardiac procedures is usually the result of a perforation.[25] It may be caused by inadvertent advancement of the needle or the dilator or sheath into the free atrial wall or could be related to the intracardiac procedure itself. Patients with large atria are at a particularly high risk for perforation when a posterior TSP is performed. Since most of mitral procedures aim at posterior TSP, puncture of the border with the muscular septum may let the needle cross the pericardial space and cause pericardial effusion/tamponade. In case of too posterior TSP, early diagnosis can be difficult, because the sheath itself can lead to mechanical hemostasis. Thus, after catheter removal at the end of the procedure, it can potentially become clinically significant, usually causing delayed tamponade. In such cases of extremely posterior puncture, if not an early atrial hematoma appears, it is mandatory to continue TEE monitoring for some minutes after sheath removal at the end of the procedure.

Aorta puncture may occur in procedures where anterior puncture is required or due to difficult anatomy. Such a complication occurs in 0.05% of cases.[26] In case of unclear TEE images and difficult tenting visualization, a pressure line can be connected to the needle to confirm the needle position.

Air embolism and thrombus embolism are both uncommon. In some cases, if further heparin administration results are not sufficient, especially before crossing the septum, thrombus aspiration might be effective. If already in the left heart, cerebral protection placement should be considered. In some cases, air embolism may occur if large devices are placed across the septum and not properly de-aired. It is often a clinically silent event because of its transient nature and the procedural sedation. However, coronary ischemia, stroke, hypotension, and cardiac arrest have been reported.[27] It should be noted that transient ST-segment elevation during transseptal procedures is not always explained by coronary air embolism. A vasospastic neurally mediated mechanism, also known as Bezold-Jarisch-like reflex, could be implicated: the mechanical effects of the TSP on the IAS can activate the vagal network leading to coronary spasm and ST-segment elevation, usually located in the inferior leads, and is accompanied by vagal signs (hypotension, bradycardia, and diaphoresis).[28]

Iatrogenic septal defect is a common finding after large-bore sheath transseptal access. The strongest predictor for defect persistency is the size of the sheath or guiding catheter[9] while the role of LA pressure is still controversial. Hypoxemia resulting from large right-to-left shunt can occur after withdrawal of the transseptal sheath but is rare.[9] The clinical significance of persistent iatrogenic ASD is still debated, the most frequent indications for ASD closure are bidirectional or right-to-left shunt and large ASD (>8 mm).[29,30] Consequently, it is highly advisable after transcatheter MV implantation procedures, as very large bore sheaths and septal balloon dilatation are required. Systematic surveillance with serial echocardiography following large-bore TSP into the LA might be necessary.

Less common complications of TSP include vena cava perforation, coronary artery dissection, detachment of the tip of the transseptal sheath, and acute pericarditis.[31,32]

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Conflicts of interest

There are no conflicts of interest.

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