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STATE-OF-THE-ART REVIEW

Transseptal Techniques for Emerging Structural Heart Interventions

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ABSTRACT

The development of new transseptal transcatheter interventions for patients with structural heart disease is fueling increasing interest in transseptal puncture techniques. The authors review contemporary transseptal puncture indications and techniques and provide a step-by-step approach to challenging transseptal access and procedural complications. (J Am Coll Cardiol Intv 2016;9:2465–80) © 2016 by the American College of Cardiology Foundation.

The technique of transseptal puncture (TSP) was developed by Ross, Braunwald, and Morrow (1) in 1959 to allow direct measurement of left atrial (LA) pressure. Over the next several decades, with the growing acceptance of retrograde catheterization of the left ventricle, and the development and expanding use of echocardiography, experience with TSP declined. Substantial renewed application of the TSP technique ensued in the 1980s and 1990s because of the introduction of percutaneous balloon mitral valvuloplasty (PBMV) and catheter ablation of atrial fibrillation (AF) (2,3). In more recent years, the emerging percutaneous transcatheter therapies of valvular and congenital heart disorders have led to the widespread adoption and further modification of the TSP technique. In this paper we aim to: 1) provide an overview of the established and emerging indications for TSP; 2) describe the contemporary techniques of TSP, with an emphasis on the role of multimodality imaging and site-specific puncture; and 3) provide a systematic approach to aid in the management of challenging transseptal access and procedural complications (**Central Illustration**).

INDICATIONS FOR TSP

PERCUTANEOUS TREATMENT OF MITRAL VALVE DISEASE.

PBMV. In the 1980s, PBMV became the treatment of choice for rheumatic mitral stenosis with suitable anatomy (3). PBMV using a single-balloon technique (**Figure 1A**) became the most popular PBMV method and virtually replaced surgery in many areas of the world where rheumatic heart disease is prevalent (4).

Transcatheter mitral valve repair. Percutaneous edge-to-edge mitral valve repair (**Figure 1B**) using the MitraClip device (Abbott Vascular, Santa Clara, California) demonstrated superior safety and similar improvement in clinical outcomes compared with conventional surgery in patients with severe degenerative mitral regurgitation (MR) who are at high risk for surgery (5). The MitraClip device has been used in more than 30,000 patients worldwide for both functional and degenerative MR.

Transcatheter mitral valve-in-valve therapy. Initial results with transcatheter transseptal mitral valve-in-valve (**Figure 1C**) implantation are promising (6,7). If this therapy is proved durable, it would provide an excellent alternative to reoperation for patients with failed mitral bioprostheses.

Transcatheter mitral valve implantation. Several dedicated transcatheter mitral valve systems are in the early phase of development. The CardiAQ valve (CardiAQ, Irvine, California) (**Figure 1D**) is

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ABBREVIATIONS AND ACRONYMS

AF = atrial fibrillation

CB = cryoballoon

FO = fossa ovalis

IAS = intra-atrial septum

ICE = intracardiac echocardiography

IVC = inferior vena cava

LA = left atrial

LAA = left atrial appendage

MR = mitral regurgitation

PBMV = percutaneous balloon mitral valvuloplasty

PFO = patent foramen ovale

PV = pulmonary vein

PVL = paravalvular leak

RF = radiofrequency

SHD = structural heart disease

TEE = transesophageal echocardiography

TSP = transseptal puncture

currently the only transcatheter mitral valve with a transfemoral transseptal delivery system under testing (8).

Mitral paravalvular leak (PVL) repair. PVL occurs in 5% to 17% of patients after valve replacement surgery (9). Repeat surgery has been the traditional treatment for PVL, but it is associated with high operative mortality and variable results (10). Percutaneous repair of mitral PVL using a transseptal route (Figure 1E) is an effective alternative to surgery, with feasibility and efficacy demonstrated in multiple studies (11).

PULMONARY VEIN (PV) ISOLATION (PVI). The efficacy of PVI in treating drug-refractory AF has been established, with more than 15 years of clinical studies (Figure 1F). This indication has accounted for most of the growth in the use of TSP in the past 2 decades (12).

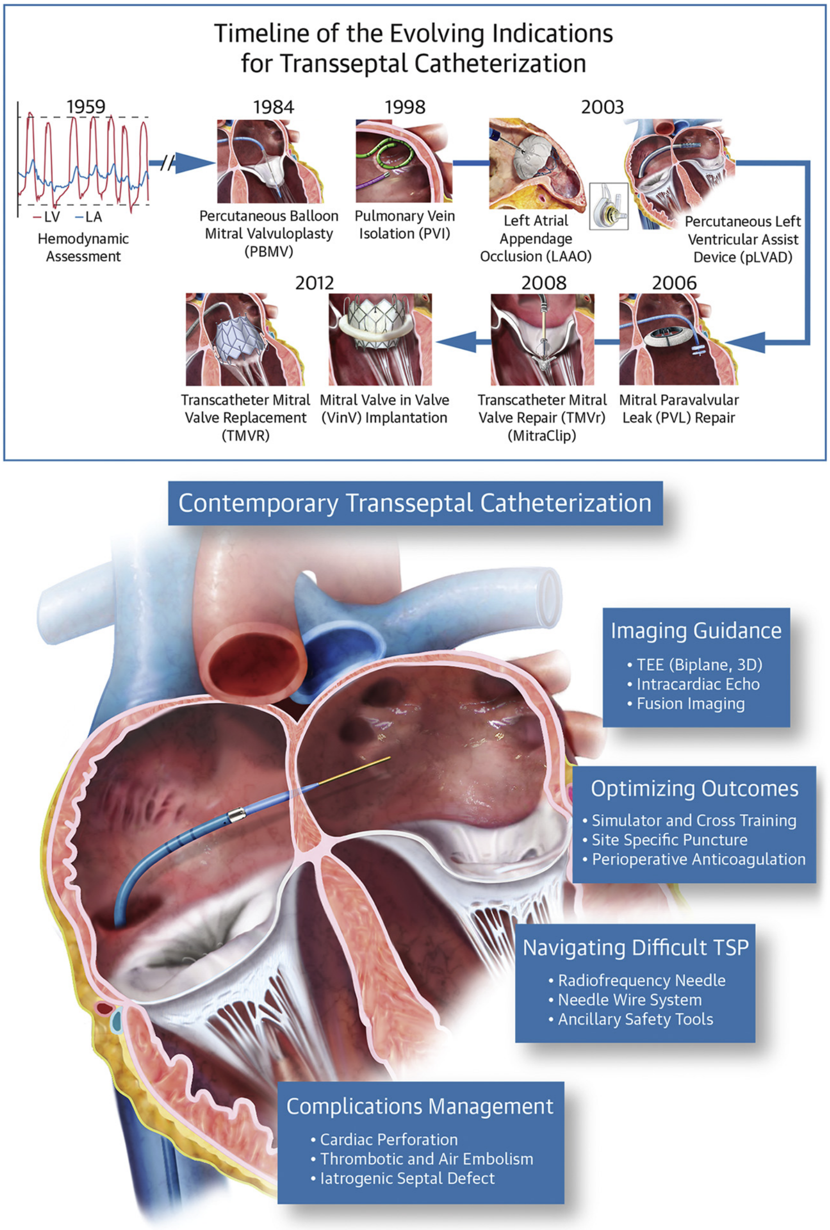
PERCUTANEOUS LEFT VENTRICULAR ASSIST DEVICES. Percutaneous left ventricular assist devices such as the TandemHeart (CardiacAssist, Pittsburgh, Pennsylvania) (Figure 1G) can be used to support patients in cardiogenic shock or as a temporary application during high-risk coronary intervention (13). Another form of percutaneous left ventricular assist device is transseptal extracorporeal membrane oxygenation. This technique is applied in patients with persistent pulmonary edema despite traditional venoarterial extracorporeal membrane oxygenation. In these cases, a "venting" cannula is placed in the left atrium through a TSP and is incorporated into the extracorporeal membrane oxygenation circuit using a Y connection (14).

LA APPENDAGE (LAA) CLOSURE. Percutaneous occlusion of the LAA is equivalent to warfarin in preventing stroke in patients with nonvalvular AF and is associated with a lower bleeding risk (15). Percutaneous LAA closure can be achieved with a transseptal approach with the Watchman device (Boston Scientific, Marlborough, Massachusetts) and the Amplatzer Cardiac Plug (St. Jude Medical, St. Paul, Minnesota) (Figure 1H), an epicardial approach with the Aegis system (Aegis Medical, Vancouver, British Columbia, Canada), or a hybrid approach with the LARIAT system (SentreHEART, Palo Alto, California). The Watchman device is the only LAA occluder to receive approval for the prevention of systemic thromboembolism in patients with nonvalvular AF in the United States. Several other devices are in CE-mark stages and are available outside of the United States.

ANTEGRADE TREATMENT OF LEFT VENTRICULAR AND AORTIC VALVE DISEASE. The initial transcatheter aortic valve replacement described by Cribier et al. (16) in 2002 was performed through an antegrade transseptal approach, but the procedural complexity led to its replacement with the transfemoral approach. However, in contemporary practice, the transseptal approach is still used on a limited basis for "no-access" patients (17). Similarly, the transseptal route has been used in balloon aortic valvuloplasty in patients with distal aortic occlusion and in patients who are undergoing concurrent mitral valvuloplasty (18,19). Ventricular septal defects are rare complications of aortic valve replacement. Percutaneous closure of these iatrogenic defects through a transfemoral retrograde approach is usually the treatment of choice but can be challenging if a mechanical prosthesis is present. In these cases, an antegrade transseptal approach can be used (20). Likewise, the transseptal approach can provide an excellent access option for percutaneous closure of iatrogenic left ventricular pseudoaneurysms (21).

OTHER INDICATIONS. Hemodynamic assessment of valvular heart disease is commonly achieved with indirect estimation of LA pressure using a Swan-Ganz catheter (1,22). Nevertheless, TSP remains essential in equivocal cases and to assess the transaortic gradient in patients with mechanical aortic prostheses (22). TSP has been used to aid in percutaneous closure of patent foramen ovale (PFO) with long tunnel. However, in contemporary practice, this has been abandoned in the light of excellent devices adapting to all anatomies of PFOs (23). TSP can be a valuable tool for facilitating carotid artery stenting in patients with acutely angulated arch-branch vessels and those with Takayasu arteritis (24) and transcatheter embolization of type I endoleak in the proximal aortic arch (25). In addition, an externalized transseptal guidewire has proved to be an important tool to aid thoracic stent graft passage in tortuous aortas and severely angulated arches (26,27). In rare occasions, transseptal access may provide an alternative route for coronary interventions in patients with no suitable peripheral access (28). Finally, balloon atrial septostomy is another indication for TSP in patients with severe pulmonary hypertension who do not respond to medical therapy or are awaiting lung transplantation (29).

The majority of the aforementioned procedures can also be performed using a transapical approach. However, because of the risks and the steeper learning curve with transapical access, the transseptal route is the preferred approach at most institutions (7,30).



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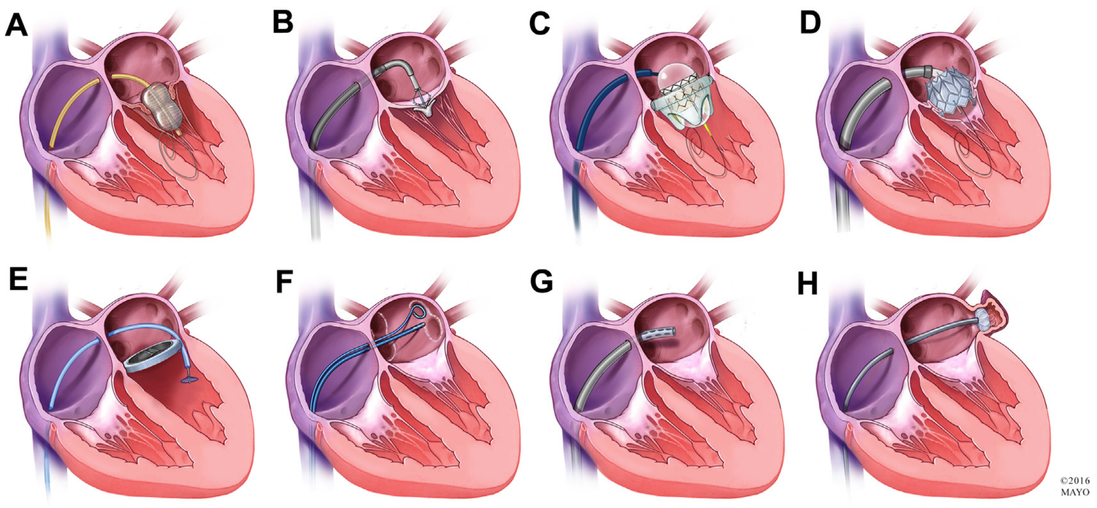
Historically, the goal of TSP was to safely traverse the intra-atrial septum (IAS), preferably through the fossa ovalis (FO) (Figure 2). Fluoroscopy-guided TSP is sufficient to achieve this goal in the majority of cases. However, the evolution of a variety of complex interventions that can be performed via the transseptal route has called attention to the importance of site-specific transseptal access. Therefore, transesophageal echocardiography (TEE) and intracardiac echocardiography (ICE) have become essential tools in many structural heart interventions by providing a greater degree of anatomic orientation. Figure 3 illustrates the various suggested locations for TSP for different transseptal procedures.



(A) Percutaneous mitral balloon valvuloplasty. (B) Transcatheter mitral valve repair (MitraClip). (C) Mitral valve-in-valve implantation. (D) Transcatheter mitral valve replacement. (E) Mitral paravalvular leak closure. (F) Pulmonary vein isolation. (G) Percutaneous left ventricular assist device placement. (H) Left atrial appendage closure.

Proper guiding catheter position is the most important initial step of the MitraClip procedure. Targeted TSP facilitates suitable guide position and allows the clip to reach the middle of the mitral orifice (31). A suboptimal TSP site may result in inadequate treatment of MR (32). For central MR jets, the operator aims for a posterior and slightly superior TSP. Higher TSP heights are needed for more medial jets, while lower transseptal sites are more appropriate when lateral jets are targeted (Figure 3) (32). The position of the TSP for mitral PVL closure requires similar forethoughts. For defects away from the IAS, the location of the puncture is less critical. However, for medial defects, a posterior and slightly superior puncture provides the appropriate working height within the left atrium and allows readily access to the defect. In PBMV and transseptal mitral valve-in-valve implantations, a midposterior puncture is usually adequate and provides a favorable working height in the left atrium and a coaxial plane with the mitral valve.

LAA CLOSURE. The long axis of the LAA is oriented anteriorly, and the plane of the LAA ostium is perpendicular to that axis. Successful coaxial device deployment depends on the ability to position the delivery sheath with sufficient depth into the LAA. This is best accomplished with a posterior-anterior trajectory of the sheath. Therefore, a posterior TSP provides the most favorable sheath orientation (33). There are subtle differences in the recommended TSP height related to the shapes of the transseptal sheathes used for different LAA occlusion technologies. For the Watchman device and the Amplatzer Cardiac Plug, midseptal to slightly inferior TSP is ideal. For the LARIAT device, a more superior location has been suggested (33). 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 (34).

PV INTERVENTIONS. The PVs are posterior structures in the left atrium. Ensuring adequate reach of the radiofrequency (RF) or cryoballoon (CB) catheter is essential to achieve successful ablation, especially when addressing right-sided veins (33). In RF ablation, some experts prefer a relatively anterior crossing of the IAS to allow adequate room for deflectable sheaths and catheters (33). Others suggest that a posterior TSP allows better angling of the ablation catheters toward the PVs (35). In CB ablation, the CB catheter uses the anterior balloon surface to push against the atrial tissue around the PV ostium. Therefore, a more anterior crossing of the IAS provides the most favorable approach for accessing all PVs with the CB, particularly the right inferior PV.

PERCUTANEOUS LEFT VENTRICULAR ASSIST. Mid-FO access for central transseptal catheter positioning allows more room in the left atrium and reduces the likelihood of device malfunction because of cannula–LA wall contact.

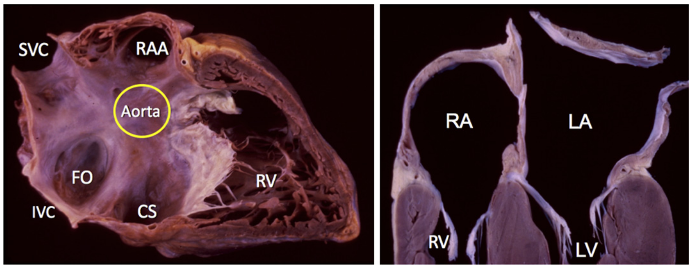
Using a PFO for LA access during left-sided structural heart interventions is generally discouraged. However, successful use of a PFO to facilitate LAA occlusion procedures has been reported (36).

TSP TECHNIQUES

IMAGING GUIDANCE FOR LOCALIZATION OF THE FO. Fluoroscopy has traditionally been the main imaging method for localization of the FO. A pigtail catheter is placed in the aortic root so that its tip marks the location of the aortic valve, while the cardiac silhouette identifies the lateral and posterior borders of the atria. Multiple angiographic projections can be used to puncture the septum safely (Figures 4 and 5). In difficult cases, right atrial angiography with delayed LA angiography can help visualize the septum (overlap area). A septal "staining" technique can also help visualize the FO by injecting 1 to 2 ml of contrast through the needle tip against the IAS (Figure 5). Although TSP performed with fluoroscopic guidance has been the standard since the early days of procedural performance, ultrasound-based imaging (TEE and ICE) has assumed increasing importance because it allows direct imaging of the soft tissue structures that are relevant to TSP and provides reassurance that the specific location of the puncture site is optimal. In addition, the use of TEE and/or ICE may increase the safety and the success rate of TSP in 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 TSP (37,38).

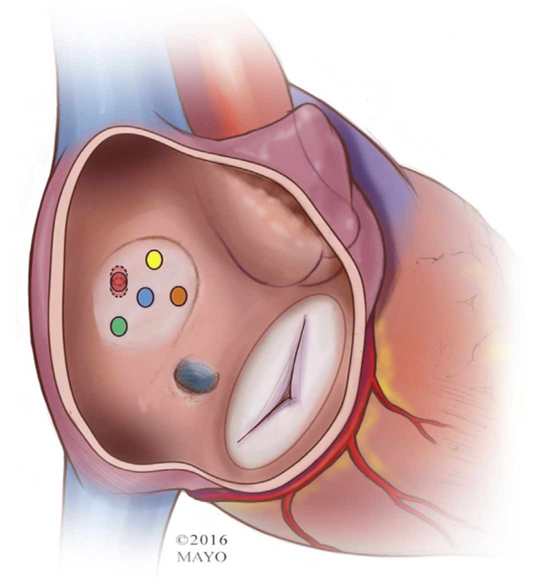
Both TEE and ICE are very useful in achieving site-specific TSP. ICE has the additional advantages of not requiring a second operator or general anesthesia, although TEE with conscious sedation is a common practice outside the United States. In contrast, ICE devices lack multiplanarity, and they may distract the operator, as 2 catheter systems must be handled separately, an additional venous puncture is necessary, and there is a possibility that the 2 catheter systems may get entangled (39).

Various transesophageal echocardiographic imaging maneuvers can display IAS anatomy in detail. Superior and inferior localization is seen best in the bicaval view (90), and anterior and posterior localization is seen best in the short-axis (30) and 4-chamber (0) views. An x-plane view that displays both the bicaval and the short-axis view is extremely helpful in puncturing the IAS at the desired location (Figure 6).

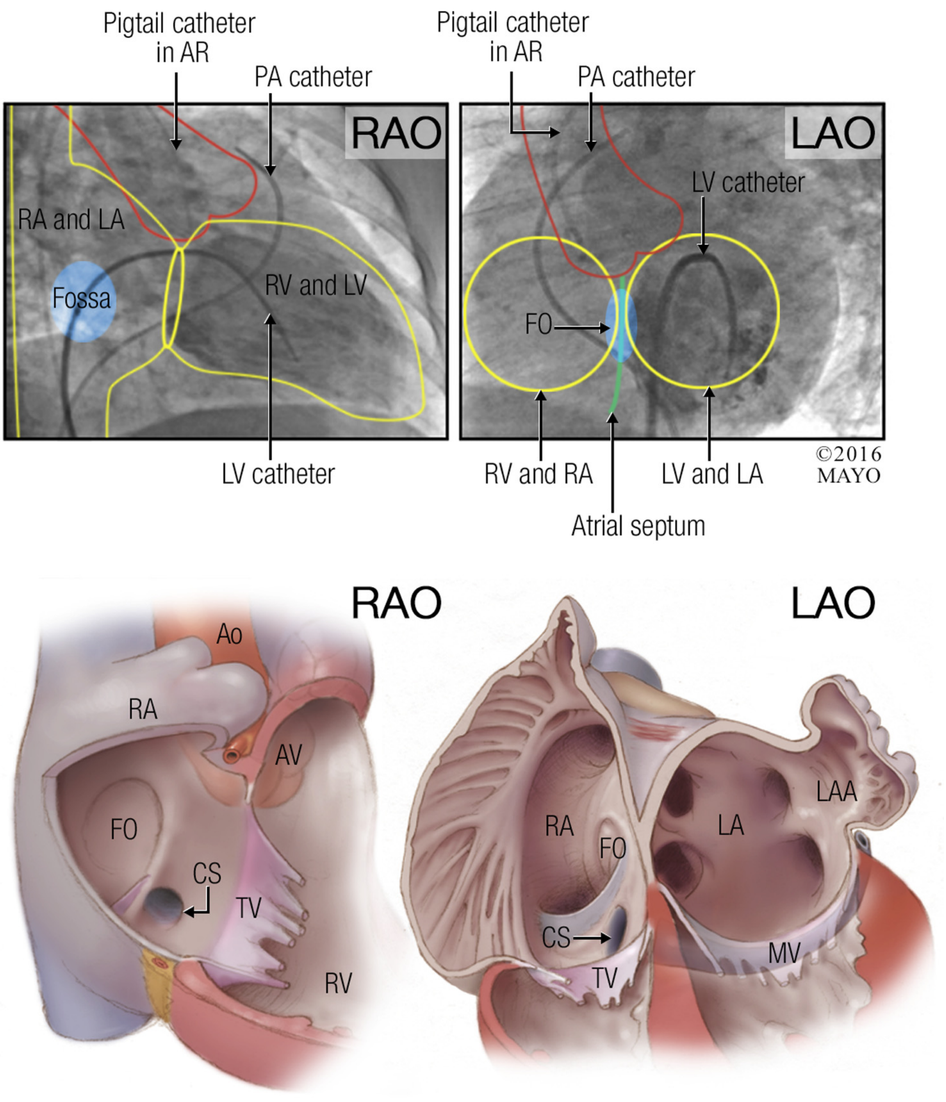


CS¼ coronary sinus; FO¼ fossa ovalis; IVC¼ inferior vena cava; LA ¼ left atrium; LV ¼ left ventricle; RA ¼ right atrium; RAA ¼ right atrial appendage; RV ¼ right ventricle; SVC ¼ superior vena cava.

In ICE-guided procedures, a phased-array intracardiac echocardiographic catheter (AcuNav, Siemens, Malvern, Pennsylvania; or ViewFlex, St. Jude Medical) is advanced to the right atrium and manipulated to identify the "home" view (Figure 7). The initial survey of the IAS is then performed; from the home view, a posterior tilt of the transducer and a



Red: MitraClip, paravalvular leak closure (a higher crossing site is recommended for medial leaks, and a lower crossing site is recommended for lateral leaks; dashed red circles). Yellow: transseptal patent foramen ovale closure. Blue: percutaneous left ventricular assist device placement, hemodynamic studies. Green: left atrial appendage closure. Orange: pulmonary vein interventions.



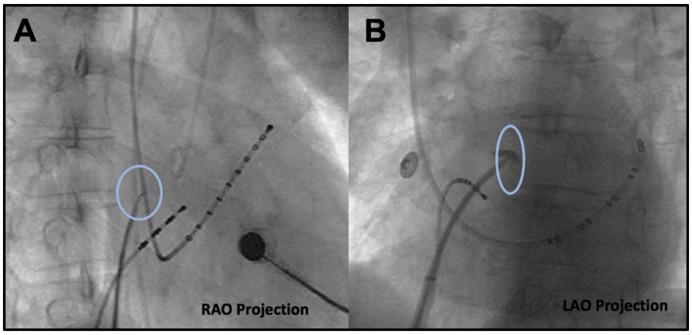
Ao ¼ aorta; AR ¼ aortic root; AV ¼ aortic valve; CS ¼ coronary sinus; LAA ¼ left atrial appendage; LAO ¼ left anterior oblique; PA ¼ pulmonary artery; RAO ¼ right anterior oblique; TV ¼ tricuspid valve; other abbreviations as in Figure 2.

clockwise rotation of the catheter bring the IAS and FO into view (septal view) (Figure 7). With the sheath and dilator apparatus engaged against the FO in the septal view, the height of the TSP can be readily assessed. The anterior-posterior location of the TSP can then be determined with an anterior (counterclockwise rotation) and posterior (clockwise rotation) of the transducer, allowing needle adjustment before puncturing the FO (33). This survey also allows screening for PFO and characterization of the IAS properties (thick septum, septal aneurysm, prior patch repair, and so on). After successful TSP, ICE allows direct visualization of the needle tip and its relationship to the surrounding cardiac structures (39).

Fusion of different imaging modalities has gained increasing popularity in structural heart disease (SHD) 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 during SHD interventions. The utility of the EchoNavigator system to facilitate a targeted TSP has been demonstrated in several studies (37,40). Newer imaging techniques are emerging as useful guiding tools for TSP, but their additional value to the current imaging modalities remains to be fully evaluated. These modalities include 3-dimensional echocardiography, computed tomography–derived 3-dimensional augmented fluoroscopy (CARTO3, Biosense Webster, Diamond Bar, California), real-time magnetic resonance imaging, and rotational angiography (41–43).

TSP TOOLBOX. The basic TSP kit consists of a transseptal sheath, an introducer, and the transseptal needle. Novel ancillary tools have been added to the TSP toolbox and served to increase the safety and success of the TSP procedure (Figure 8).

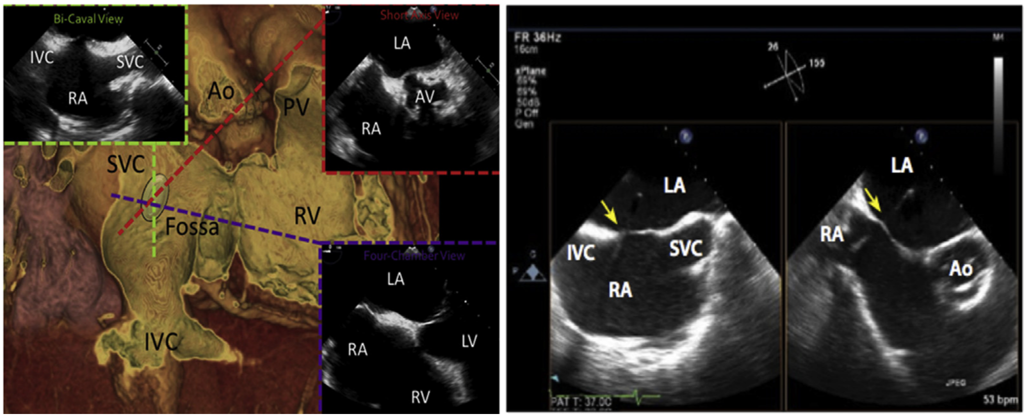
Transseptal sheaths. Transseptal sheaths are generally categorized in 2 broad groups: fixed-curve sheaths and steerable sheaths. Traditionally, fixed-curve sheaths of various shapes and sizes have been used in the majority of transseptal procedures. However, the wide adoption of PVI techniques for AF ablation led to the development of steerable sheaths to improve LA access, maneuverability, and tissue contact (44,45). Steerable sheaths may be associated with superior clinical outcomes in PVI procedures, but are 4 to 5 times more expensive than traditional fixed-curve sheaths (45,46). A brief description of the available transseptal sheaths and their characteristics is shown in Online Table 1.



Engaging the fossa ovalis in the right anterior oblique (RAO) (A) and left anterior oblique (LAO) (B) projections. The blue circle/oval shapes indicate the fossa ovalis. Note the staining of the fossa ovalis in the LAO view. A pigtail is present in the RAO projection to mark the anterior location of the aorta.

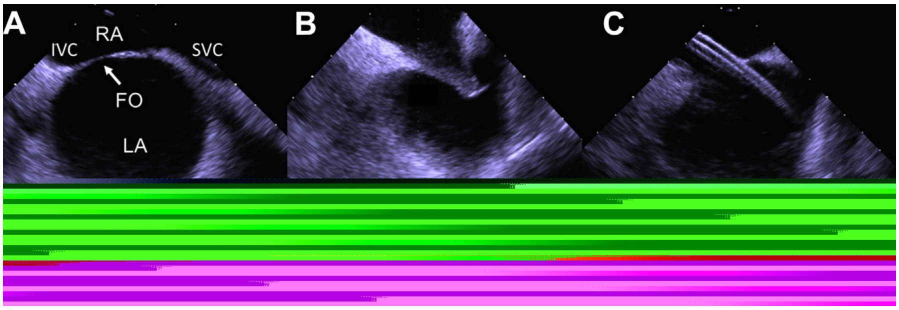
Transseptal needles. Historically, the stainless steel Brockenbrough needle (Medtronic, Minneapolis, Minnesota) has been the standard needle used to mechanically puncture the FO. The BRK series of transseptal needles (St. Jude Medical) are similar to the Brockenbrough needle but are available in multiple lengths and curves. The NRG RF transseptal needle (Baylis, Montreal, Quebec, Canada) uses RF energy and allows the operator to cross the IAS in a controlled manner without using excessive force (Figure 9B). The use of RF needles has been shown to improve the safety and efficacy of TSP for AF ablation compared with conventional transseptal needles (47). The commercially available transseptal needle systems are listed in Online Table 2.

Ancillary devices. Needle-wire system. The SafeSept wire (Pressure Products, San Pedro, California) is a 120-cm nitinol guidewire with 0.014-inch diameter that has a sharp and floppy "J tip" that assumes a



AV = aortic valve; PV = pulmonary vein; SVC = superior vena cava; other abbreviations as in Figure 2. Reprinted with permission from Singh et al. (32).

FIGURE 7 Intracardiac Echocardiography for Transseptal Puncture



(A) The fossa ovalis (FO) as seen in the "septal" view. (B) Tenting of the FO with the transseptal needle. (C) The transseptal sheath across the FO in the left atrium (LA). Abbreviations as in Figures 2 and 6.

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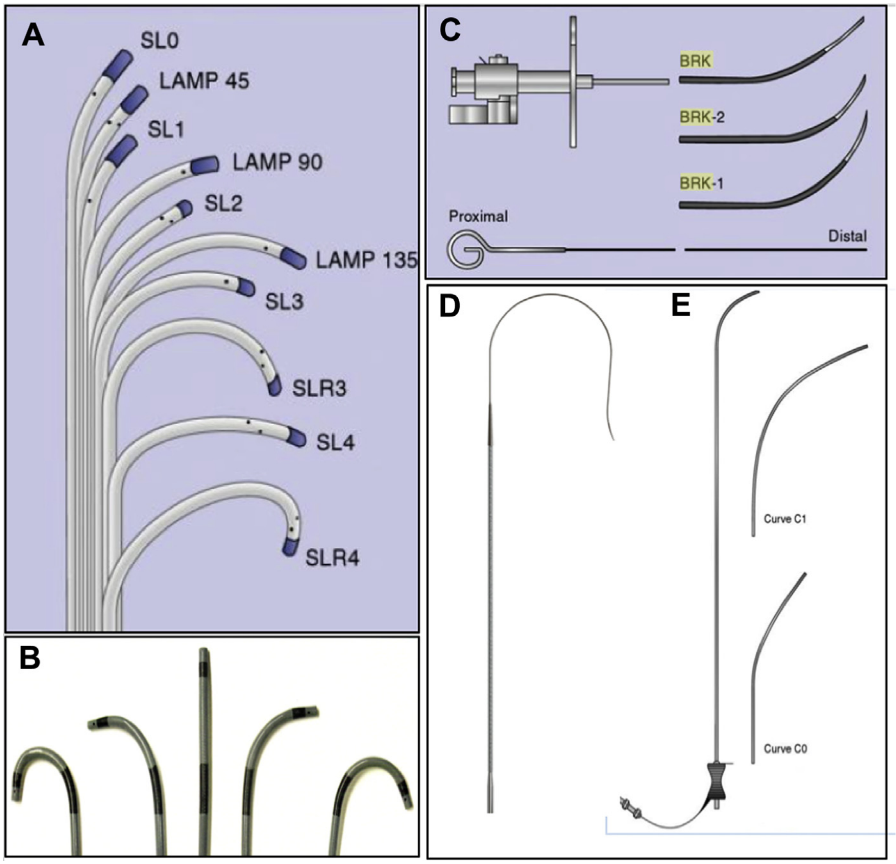

(A) Fixed-curve sheath. (B) Steerable sheath (Agillis). (C) BRK (Brockenbrough) transseptal needle. (D) SafeSept wire. (E) NRG radiofrequency needle.