

STATE-OF-THE-ART REVIEW

STRUCTURAL

Anatomic Approach to Transseptal Puncture for Structural Heart Interventions



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ABSTRACT

The use of transseptal puncture continues to rise given the increase in left atrial cardiac interventions. The authors review an anatomic approach to transseptal puncture incorporating multimodality imaging both pre- and intraprocedurally with stepwise escalation algorithms to ensure safe and efficacious large-bore transseptal puncture.

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Transseptal puncture (TSP), first described in 1959 for left atrial (LA) pressure measurement (1), has experienced a resurgence attributable to the growth of LA-based cardiac interventions (2). Although TSP for diagnostic purposes requires simply crossing the fossa ovalis, TSP for structural heart disease (SHD) and electrophysiologic interventions necessitates site-specific punctures to optimize anatomic positioning, the details of which we have previously reviewed (2).

The goals of TSP in SHD interventions are to: 1) achieve LA access in a manner allowing safe passage of large-bore catheters at a height and position that enables the necessary manipulation and positioning for the intended procedure; 2) avoid inadvertent trauma to adjacent structures; and 3) provide a safe exit from the left atrium, avoiding tears in the interatrial septum (IAS) that could result in a larger than intended orifice with significant intracardiac shunting.

Achieving these goals requires knowledge of cardiac anatomy and characteristic anatomic perturbations induced by specific and common pathologies (2). The incorporation of multimodality imaging affords a far more refined anatomic approach to TSP than fluoroscopy alone, enabling safe and efficacious TSP in increasingly complex anatomies. Simultaneously, a detailed understanding of fluoroscopic markers, both cardiac and noncardiac, can provide anatomic information, enabling maximum utility of this planar imaging technique. In this review we discuss a systematic method of planning and executing TSP for SHD interventions (**Central Illustration**).

ANATOMIC APPROACH TO TSP

Thorough pre-procedural planning is crucial and includes careful study of available chest radiographs, transthoracic echocardiography, and transesophageal

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ABBREVIATIONS AND ACRONYMS

3D = 3-dimensional
CT = computed tomography
IAS = interatrial septum
IASD = iatrogenic atrial septal defect
ICE = intracardiac echocardiogram
LA = left atrial
RF = radiofrequency
SHD = structural heart disease
TEE = transesophageal echocardiography
TSP = transseptal puncture

echocardiography (TEE). Cardiac computed tomography (CT) yields further insights into patient-specific anatomy, allowing more detailed anatomic assessments for TSP, including pre-planning of fluoroscopic landmarks, chamber locations and sizes, IAS characteristics, and adjacent structure positions (**Central Illustration**) (3).

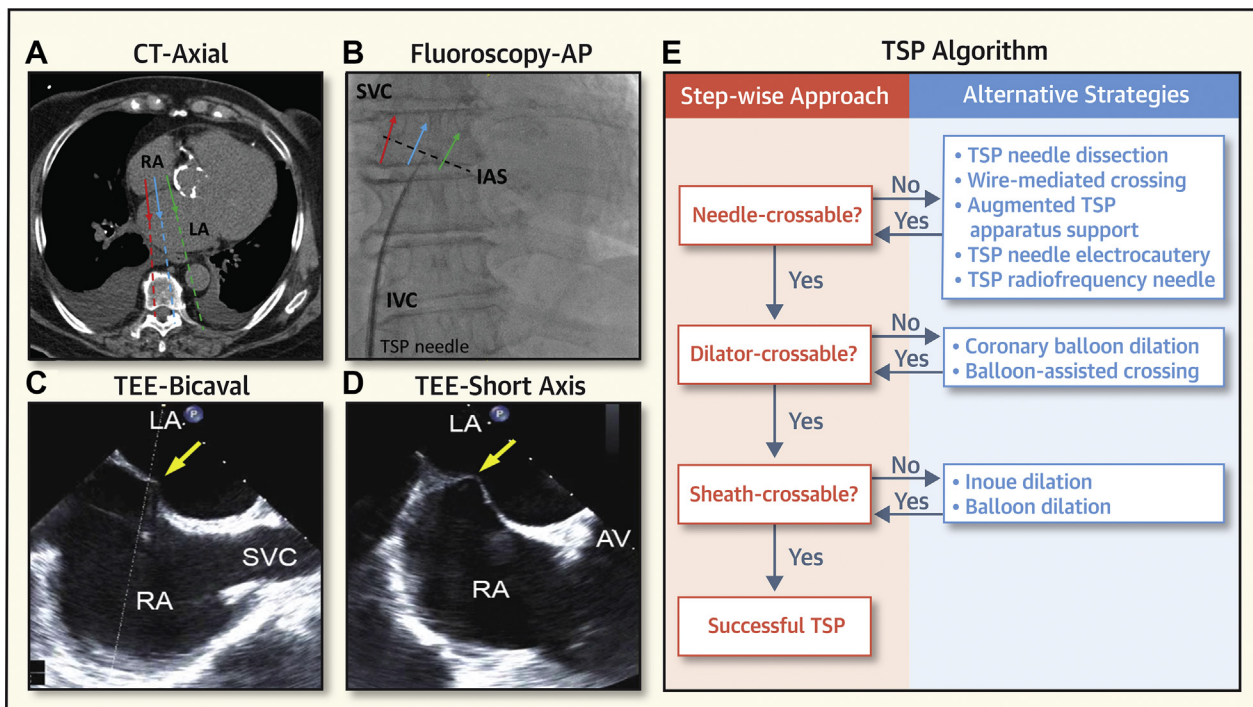
A key observation is the anterior-posterior relationship between any point in the right atrium and the left atrium. In patients with advanced SHD and associated LA enlargement, a transseptal needle pointed toward the spine (spinous process to left spinal border) will invariably encounter the left atrium, which is the most posterior structure of the heart. Posteriorly directed TSP will avoid trauma to the aorta and avoid perforation in the vast majority (exceptions exist) of patients undergoing TSP for SHD interventions. To achieve this, one

HIGHLIGHTS

- Site-specific TSP continues to rise with ever-increasing LA interventions for SHD.
- The anatomic approach to TSP incorporates pre- and intra-procedural multi-modality imaging.
- Stepwise escalation of alternative techniques in challenging cases is crucial for safe TSP.
- Rising LA intervention rates will require dedicated efforts to preserve the IAS and develop novel LA access strategies.

must use fundamental maneuvers to achieve specific needle positioning, including clockwise rotation for posterior and counterclockwise rotation for anterior rotation. Should the needle fall inferior to the desired

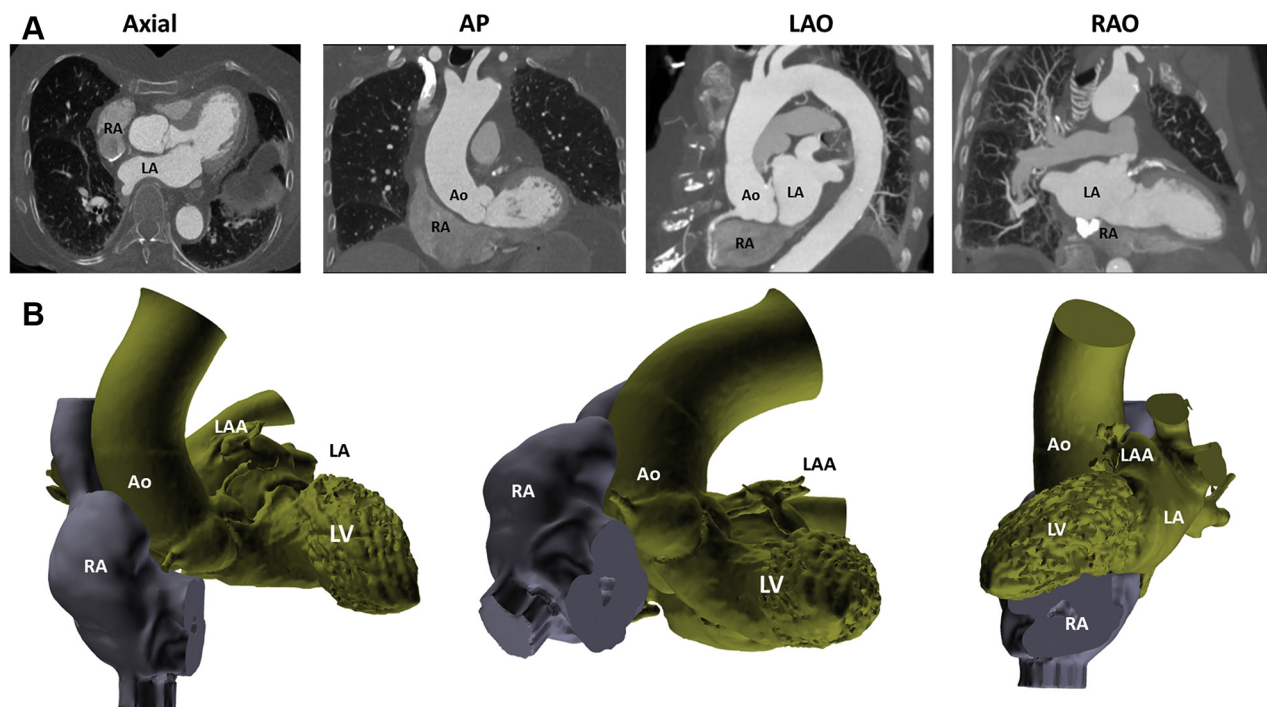
CENTRAL ILLUSTRATION Stepwise Anatomic Approach to Transseptal Puncture



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(A) Computed tomographic scan in axial plane demonstrating relationship of cardiac chambers in anteroposterior projection with anterior right atrium and posterior left atrium. (B) Fluoroscopy in anteroposterior projection. Arrows indicate differing transseptal puncture (TSP) needle trajectories across the interatrial septum (IAS), with colored dashed lines indicating positioning relative to the spinous process for differing TSP locations (red, posterior IAS; blue, mid IAS; green, anterior IAS). Black dashed line delineates IAS position. Standard transesophageal echocardiographic views for TSP, including bicaval (C) and short axis (D). (E) Standardized escalation algorithm for achieving successful TSP. AP = anteroposterior; AV = aortic valve; CT = computed tomography; IAS = interatrial septum; IVC = inferior vena cava; LA = left atrial; RA = right atrium; TEE = transesophageal echocardiography.

FIGURE 1 Computed Tomography and 3D Reconstruction in Challenging Cardiac Anatomy



(A) Computed tomography (CT) in multiple projections demonstrating marked pectus excavatum resulting in compression of the cardiac structures posteriorly with diminutive interatrial septum and challenging left atrial appendage (LAA) anatomy for consideration of closure. **(B)** Three-dimensional (3D) reconstructions on the basis of CT, which enable thorough understanding of the anatomy, and 3D printing to facilitate detailed pre-procedural anatomic assessment. Ao = aorta; AP = anteroposterior; LA = left atrium; LAO = left anterior oblique; LV = left ventricle; RA = right atrium; RAO = right anterior oblique.

location, the wire should be readvanced into the superior vena cava and the approach repeated.

Advances in cardiac imaging have revolutionized SHD intervention, with continued innovations forthcoming (4,5), including 3-dimensional (3D) modeling, 3D printing, and CT-derived 3D fluoroscopy, enabling refined assessment of complex TSP anatomy (Figure 1) (6). Although CT is not a prerequisite for TSP, often patients presenting for SHD interventions have undergone previous cardiac CT; if not, even non-dedicated chest CT can often provide considerable insights into general cardiac anatomy. Methodical analysis of all available pre-procedural imaging can improve the safety and efficacy of TSP.

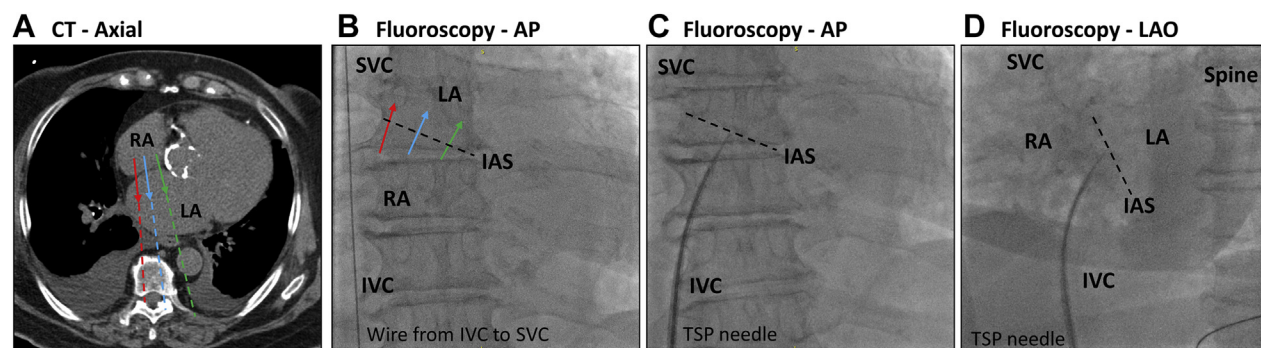
Taken together, the anatomic approach to TSP involves complete integration of all available imaging modalities coupled with one fundamental concept: that the left atrium is a posterior structure with variable extension to the patient's right and left. Knowledge that the left atrium can extend to the right of the spine can facilitate successful TSP in patients in whom it otherwise may be impossible or unsafe. Review of axial CT images provides insights into the

medial or lateral deviation required, and coronal imaging (akin to anteroposterior fluoroscopy) enables superior or inferior localization relative to the spine. Careful observation reveals that when a TSP needle is located within the right atrium, orienting the TSP needle posteriorly toward the spine (spinous process to left border) will invariably result in successful LA puncture (Central Illustration, Figure 2).

INTRAPROCEDURAL TEE, INTRACARDIAC ECHOCARDIOGRAPHY, AND FLUOROSCOPY

Typically, TSP is guided using TEE. Although CT provides an important pre-procedural roadmap for safe and successful TSP, biplane or 3D TEE remains important intraprocedurally for precise localization of the puncture site to avoid iatrogenic trauma, to help ensure coaxial alignment of devices and catheters, and to ensure adequate space to maneuver within the left atrium for various structural heart procedures. We typically use the bicaval view (100° to 120°) as the primary working view, which provides visualization of the superior-inferior axis of the atrial septum

FIGURE 2 Anatomic Approach to TSP

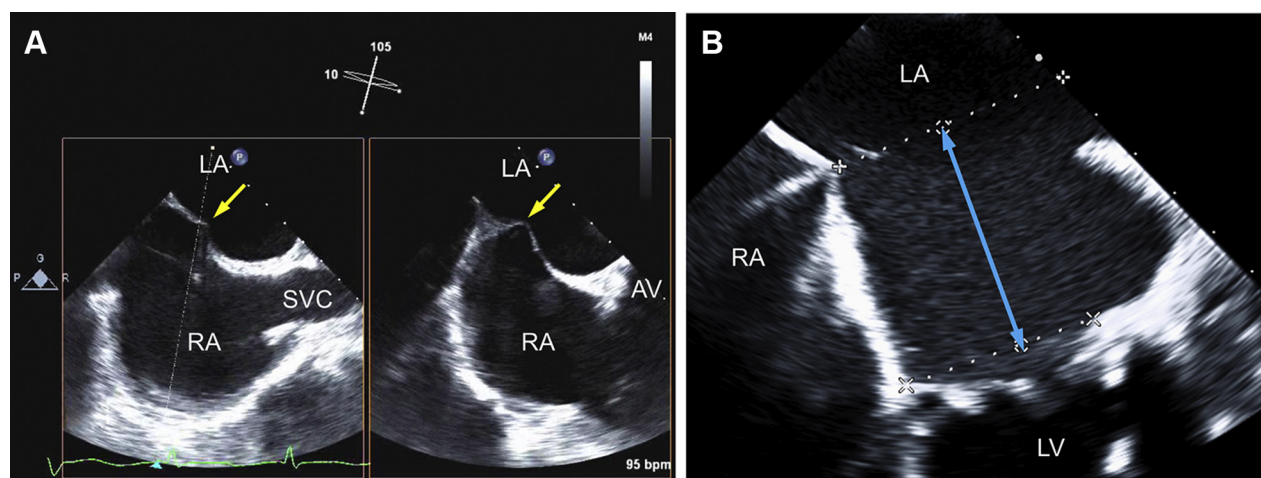


(A) CT in axial plane demonstrating relationship of cardiac chambers in AP projection, with RA being anterior and LA being posterior and slightly leftward relative to the RA and spine. Fluoroscopy in AP angulation demonstrating (B) 0.032-inch wire traversing from the inferior vena cava (IVC) to the superior vena cava (SVC) and (C) the transseptal puncture (TSP) needle against the interatrial septum (IAS), while (D) demonstrates the LAO angulation of the same. Arrows in (A) and (B) indicate differing TSP needle trajectories across the IAS, with colored dashed lines indicating positioning relative to the spinous process for differing TSP locations (red, posterior IAS; blue, mid IAS; green, anterior IAS). Black dashed line delineates IAS position. Abbreviations as in Figure 1.

(Figure 3). Biplane TEE is used to provide simultaneous visualization of the orthogonal short-axis view (secondary view; 10° to 30°), which allows visualization of the anterior-posterior axis of the atrial septum (Figure 3). Using this work flow, some echocardiographic imaging platforms require that the orthogonal short-axis view (secondary view; 10° to 30°) be

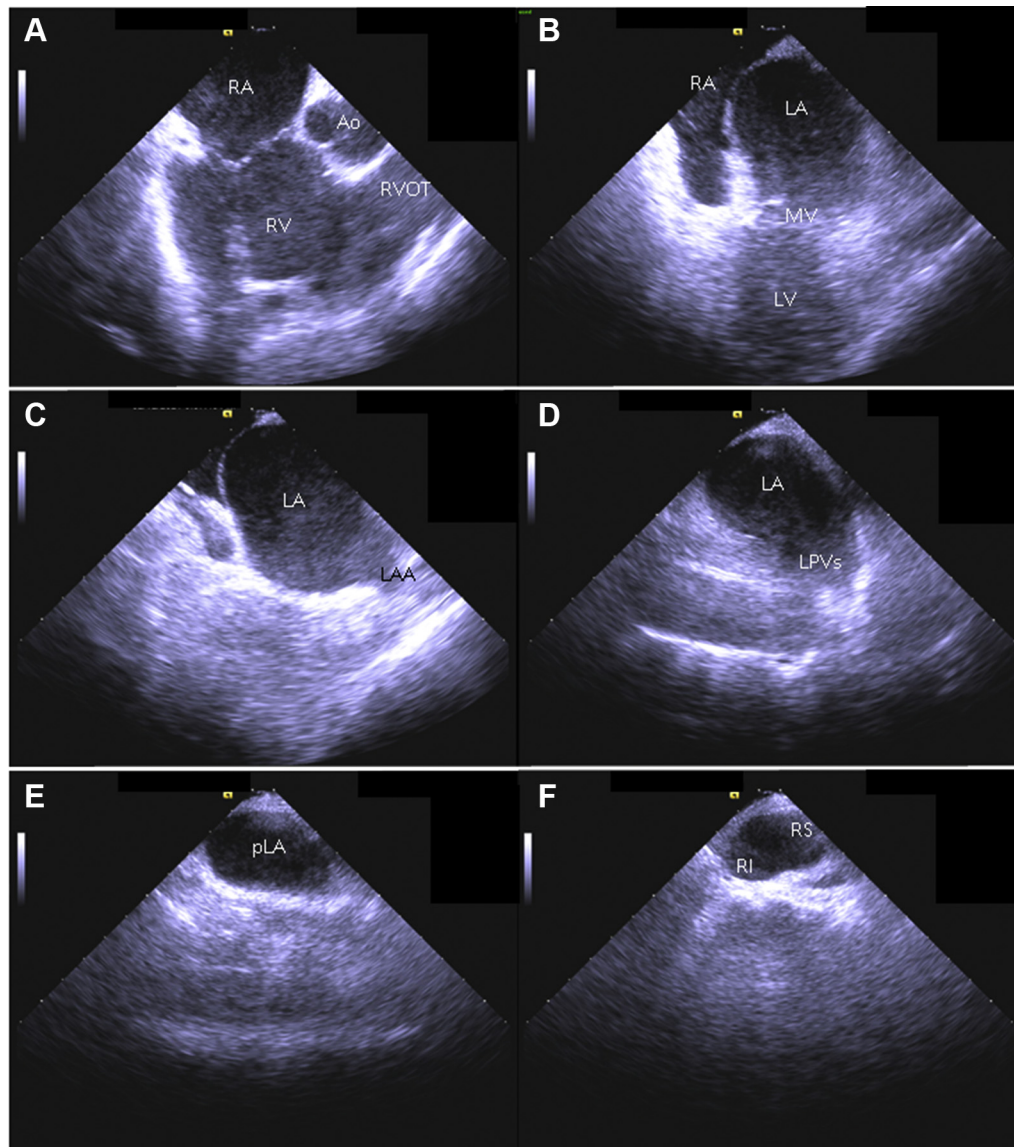
mirrored or “flipped” for the orientation to match typical fluoroscopic biplane views. When a candidate TSP site is decided, a modified 4-chamber (0° to 20°) or reverse 4-chamber (160° to 180°) view can be used to measure the anterior-posterior distance from the mitral valve (or annulus) to the TSP site for various mitral procedures (2). The use of TEE to guide TSP

FIGURE 3 Intraprocedural Transesophageal Echocardiographic Imaging for TSP



(A) A typical biplane transesophageal echocardiographic image for TSP using a primary bicaval view (left) and a secondary short-axis view (right), with tenting of atrial septum from the transseptal needle seen in 2 orthogonal views (yellow arrows). Note that the bicaval view (left) shows the superior-inferior axis with superior to the right (toward the SVC) and inferior to the left (away from the SVC); the short-axis view (right image) shows the anterior-posterior dimension with anterior to the right (toward the aortic valve [AV]) and posterior to the left (away from the AV). (B) “Height” above the mitral annulus for various mitral valve procedures is typically measured in a 4-chamber (shown) or modified 4-chamber view as the anterior-posterior distance from the level of the TSP to the mitral annulus or mitral leaflets (blue arrow). Abbreviations as in Figures 1 and 2.

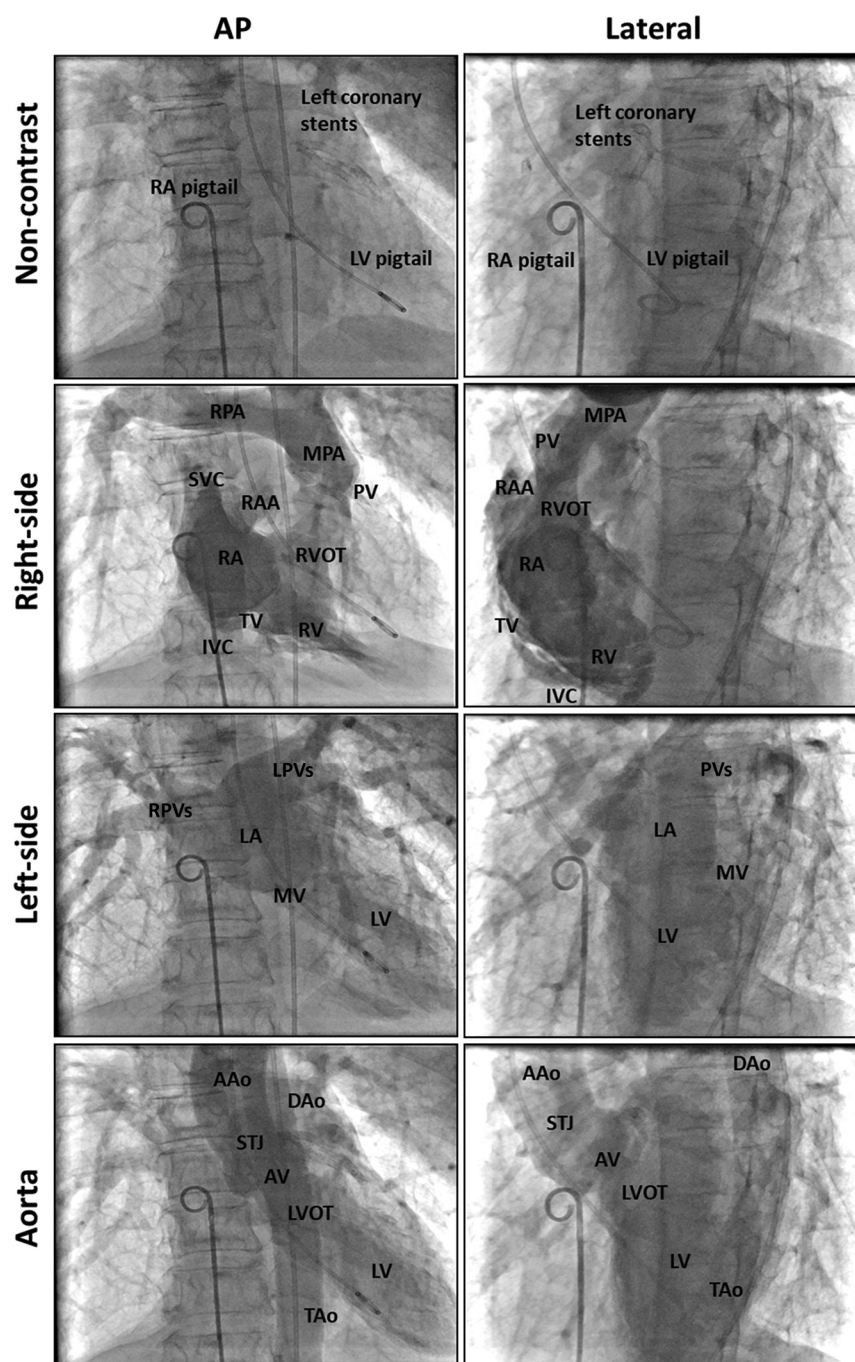
FIGURE 4 Intraprocedural Intracardiac Echocardiographic Imaging for Transseptal Puncture



Relevant anatomic landmarks demonstrated. **(A)** “Home view” demonstrating the RA, right ventricle (RV), and Ao off axis. The right ventricular outflow tract (RVOT) is the most anterior structure. **(B to F)** As the intracardiac echocardiographic catheter is rotated in clockwise fashion, structures that are gradually more posterior are demonstrated. Notably, the mitral valve (MV), LAA, left pulmonary veins (LPVs), posterior LA (pLA), and finally the right pulmonary veins (right inferior [RI] and right superior [RS]). See [Video 1](#) for corresponding ICE manipulation through the noted structures. Abbreviations as in [Figures 1 and 2](#).

highlights the need for a synergistic team relationship between the operator and imager, ensuring continual communication with a common language to optimize procedural success. Although not currently used routinely in clinical practice, 3D TEE also has the potential to offer a more precise understanding of the TSP needle position in relation to adjacent vital cardiac structures in cases in which the anatomy is more

complex (7). However, TEE has important inherent limitations as a tomographic technique. The ability to visualize the full extent of the IAS in 1 to 2 imaging planes is limited, particularly among patients with severe LA dilation. Moreover, the spatial resolution of transesophageal echocardiographic images is dependent upon adequate contact with esophageal mucosa in a supine patient.

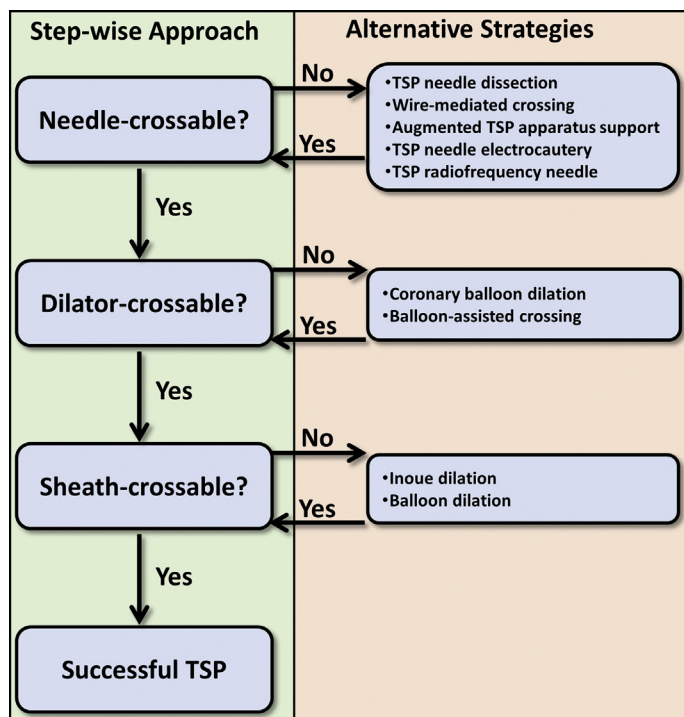
FIGURE 5 Fluoroscopic Assessment of Chamber Anatomy

Challenging transseptal anatomy with straight-back syndrome leading to vertical cardiac orientation and superior left atrial positioning. Selective angiography of cardiac chambers simultaneously in both AP and lateral projections completed from pigtail placed within the RA with left ventricular pigtail providing landmarking on baseline imaging. Angiography demonstrating right-sided structures including SVC, IVC, RA, RA appendage (RAA), RV, RVOT, pulmonic valve (PV), main pulmonary artery (MPA), and right pulmonary artery (RPA) visible. Next, contrast passes through the lung microcirculation and emerges to opacify the left-sided structures, including pulmonary veins (PVs), LA, MV, and LV. Finally, contrast passes into the aorta with demonstration of the left ventricular outflow tract (LVOT), AV, sinotubular junction (STJ), ascending aorta (AAo), descending aorta (DAo), and thoracic aorta (TAo). See [Videos 2 and 3](#) for corresponding cineangiography. Abbreviations as in [Figures 1, 2, and 4](#).

Intracardiac echocardiography (ICE) has become an integral part of many interventional procedures, reducing radiation exposure while also facilitating rapid detection of potential complications (8). Although it is routinely used for TSP in electrophysiological procedures, it is gaining popularity within interventional cardiology procedures. With knowledge of cardiac anatomy, ICE can help determine the plane of TSP with minimal, or even no, radiation. For example, positioning in the anterior-posterior plane can be ascertained by rotating the probe clockwise from the “home view” to sequentially visualize the aortic valve and root, mitral valve, LA appendage, left pulmonary veins, posterior LA wall, and right pulmonary veins. Yet the impact of catheter position relative to the septum can render some views difficult because of a form of parallax between the transeptal sheath and needle, intracardiac echocardiographic catheter, and adjacent structures. Posterior tilt of the catheter may be useful in these situations. Positioning in the superior-inferior plane can be determined by direct visualization of the fossa and determining its relationship relative to the superior and inferior limbus (Figure 4, Video 1). Successful TSP into the left atrium can be verified using various techniques that are aided by ICE. This includes directly visualizing the transeptal needle passing through the fossa into the left atrium, demonstration of bubbles flowing from the transeptal needle and out into the left atrium, or passing a wire (eg, SafeSept, Pressure Products, San Pedro, California; TORAYGUIDE Guidewire, Toray, Tokyo, Japan), wire via the transeptal puncture into the left atrium. Use of ICE has several advantages over TEE. First, it does not require a dedicated team for TEE, as it can be operated by the primary proceduralist. Furthermore, it can be used independent of anesthesia and potential requirement for endotracheal intubation. This may shorten procedural time compared with using transesophageal echocardiographic guidance. ICE provides excellent visualization of structures at short distance from the probe. Furthermore, its small caliber (8- to 10-F) minimizes interference with fluoroscopic views. Downsides of ICE include the need for additional vascular access and inferior 3D imaging compared with TEE, though this remains the focus of ongoing innovation in ICE.

In some cases (hemodynamic assessment, septal ablation, mitral valvuloplasty, etc.), TSP may be guided solely by fluoroscopy. This approach requires incorporation of aortic root delineation with a pigtail, biplane fluoroscopy, and hemodynamic monitoring to achieve safe TSP, with studies supporting this as a resource-effective strategy (9). Intraprocedural imaging with fluoroscopy can supplement TEE and ICE and

FIGURE 6 TSP Algorithm



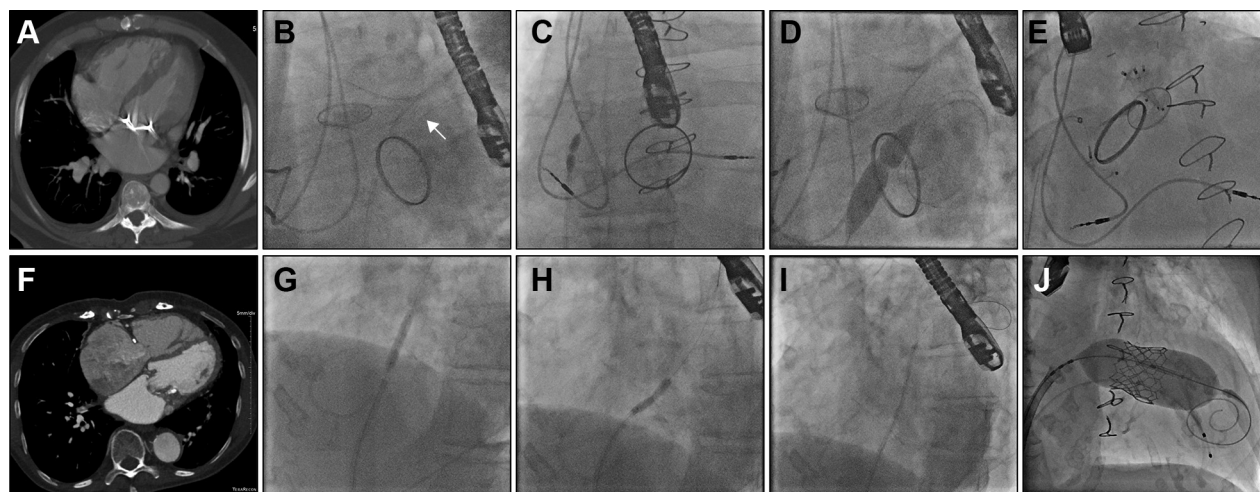
Stepwise escalation approach for transeptal puncture (TSP) with corresponding alternative access strategies.

guide TSP relative to adjacent structures coupled with pre-procedural imaging (8,10). For example, with severe LA dilatation, the carina of the trachea and left main stem bronchus often delineate the superior border of the left atrium. Characteristic calcifications of the mitral annulus, aortic valve, aortic annulus, and coronary arteries should be recognized and integrated in mind as TSP is being performed. In particularly challenging anatomies, angiography of the cardiac chambers can be completed via injection of the right atrium to enable direct visualization of the relevant cardiac structures within the fluoroscopic planes as the contrast moves sequentially through the relevant structures (Figure 5, Videos 2 and 3). Although pre- and intraprocedural imaging enables identification of challenging IAS anatomy and optimization of the TSP orientation, physically crossing the IAS also requires a methodical stepwise approach.

STEPWISE ALGORITHM FOR CROSSING THE IAS

TSP is achieved with a transeptal sheath, dilator, and needle, with a broad range of devices commercially

FIGURE 7 Balloon-Mediated Crossing of the IAS



(A) Cardiac CT demonstrating thickened IAS. (B) Needle crossing achieved by SafeSept followed by platinum coronary wire placement within the left atrium. (C) Dilation with coronary balloon with notable waist. (D) Serial dilation with Mustang balloon with progressive enlargement despite persistent waist at the interatrial septum. (E) Successful perivalvular leak closure using multiple Amplatzer vascular plugs. (F) Cardiac CT demonstrating directly posterior location of the TSP vector. (G) Balloon dilation of the IAS with a coronary balloon. (H) Balloon-assisted crossing with inflation of coronary balloon followed by multipurpose catheter. (I) Successful crossing of the IAS with the multipurpose catheter enabling left atrial access. (J) Successful transcatheter mitral valve-in-valve replacement. Abbreviations as in Figures 1 and 2.

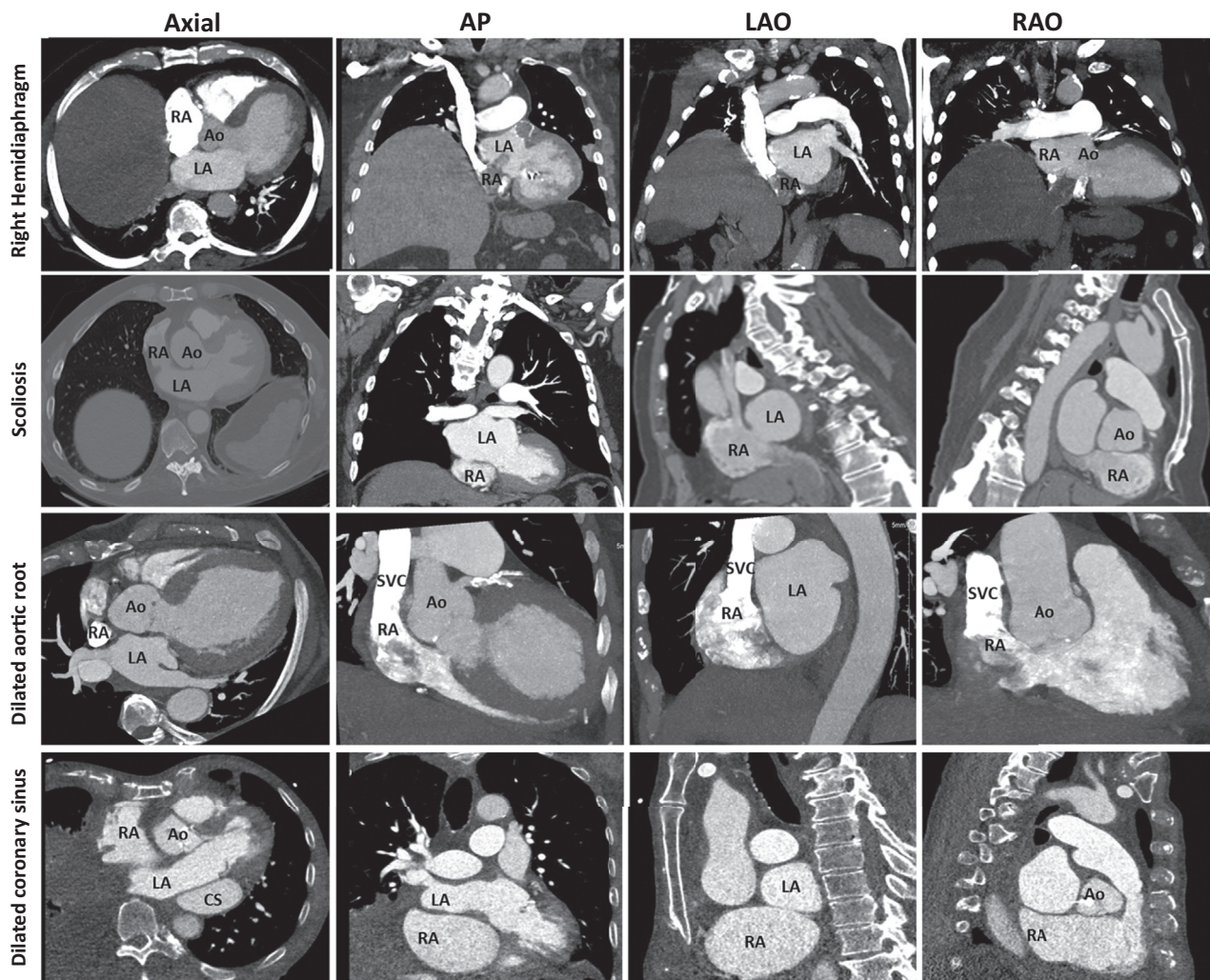
available to facilitate access (2). Division of TSP into its individual components provides a stepwise approach, with the IAS needing to be needle-crossable, dilator-crossable, and sheath-crossable to achieve successful TSP. Each step has its own escalation strategies (Figure 6). First, for a needle-uncrossable IAS, one may consider needle dissection, whereby after confirming tenting of the IAS, purposeful to-and-fro rotational motion of the TSP needle against the septum gradually facilitates needle crossing. Occasionally a careful and small contrast injection through the transseptal needle during needle forward contact with a resistant septum will result in enhanced dissection and allow IAS crossing. Confirmation of successful LA access can be achieved via LA pressure transduction through the needle and/or aspiration of arterial blood. Alternatively, needle crossing can be achieved by tenting the septum while using a wire to cross the IAS. Wires can include any 0.014-inch caliber wires, including the TSP needle stylet, SafeSept wire or the back end of a workhorse coronary wire. After crossing, the wire can be positioned in the pulmonary vein (ideally the left superior pulmonary vein), over which the needle and sheath are then advanced.

Often, patients with SHD have significant biatrial enlargement such that the usual curve may not

reach the IAS adequately, requiring an additional 1 to 2 cm of reach. This can be achieved by selection of a larger needle curve or by gently manually bending the TSP needle in plane with the existing curve, while taking care not to kink the lumen, to provide the added reach (2). Next, fortifying the TSP apparatus support via modification of the sheath or dilator stiffness, length, or curve or modifying the TSP needle type, curve, or sharpness grade can also enable crossing. Failing this, electrocauterization of the existing apparatus can be performed using a standard surgical cautery by very briefly touching the proximal part of the needle. Radiofrequency (RF) ablation using the NRG Baylis needle (11) or Versa-Cross combined system (12) (Baylis Medical, Montreal, Quebec, Canada) is used in some laboratories and can be helpful, although at an added cost. Although RF ablation offers an alternative strategy when required, the outlined stepwise escalation strategy typically enables uncomplicated TSP in the vast majority of cases.

Following successful TSP needle crossing, the dilator is next to be advanced. If the dilator encounters resistance and is unable to pass through the IAS, then modification of the atriotomy site should be pursued. An 0.014-inch coronary wire can be placed across the IAS through the TSP needle. Over this a

FIGURE 8 Extrinsic Factors Affecting Transseptal Anatomy

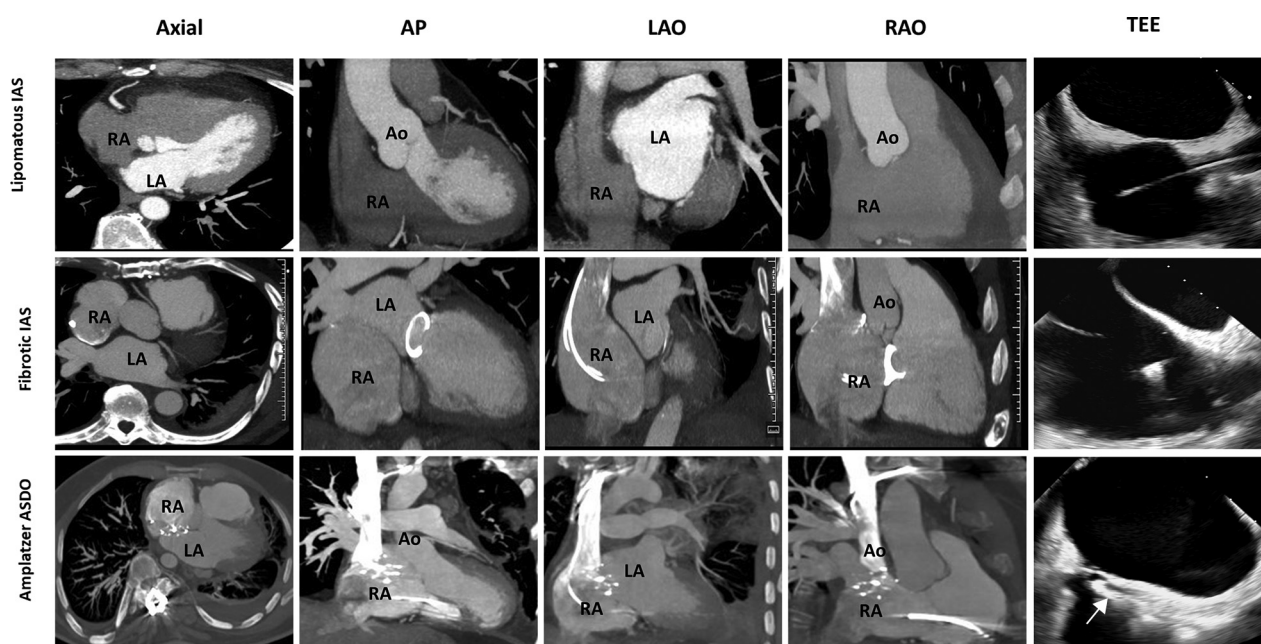


Multiplanar computed tomographic images in multiple projections. Right hemidiaphragm elevation demonstrated marked compression of RA and leftward shift of cardiac structures. Thoracic spinal scoliosis leading to horizontal IAS and small RA with dilated LA. Dilated aortic root leading to prominent posterior and rightward projection of aortic wall into typical IAS space. Dilated coronary sinus leading to compression of the LA. CS = coronary sinus; other abbreviations as in [Figures 1 and 2](#).

coronary dilation balloon may be passed and used to sequentially dilate the IAS and even used to track the dilator into the left atrium ([Figure 7](#)). This is only rarely required. This strategy will enable dilator passage, establishing LA access and leaving only the sheath to pass through the IAS. Care must be taken not to push the IAS over the needle/dilator assembly, thereby losing LA access. Sheath-uncrossable cases should be managed similarly via additional dilation of the IAS. Wire access to the left atrium should first be stabilized through the dilator with either an 0.032-inch stiff wire or an 0.025-inch TORAYGUIDE Guide-wire (Toray), while considering that most TSP dilators

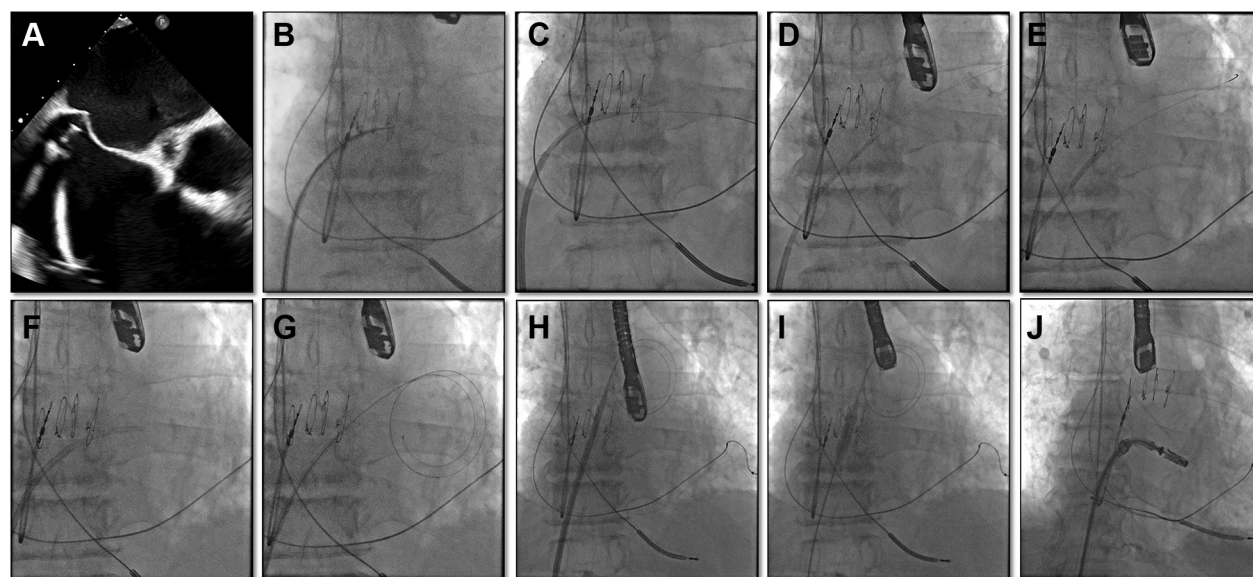
will only accommodate up to an 0.032-inch-caliber wire ([2](#)). Once LA access is stabilized, dilation can then be performed in 2 ways. First, a 14-F Inoue dilator can be passed over the LA wire from the femoral access site through the atriotomy multiple times. This is the approach we favor. Alternatively, a larger caliber balloon can be advanced over the LA wire and used to dilate the IAS to enable advancement of the TSP sheath or proceed directly to the dedicated procedural sheath planned. Operators should be familiar with anticoagulation and TSP-related complications and their management, which we have previously reviewed ([2](#)). Taken together,

FIGURE 9 Intrinsic Factors Affecting Transseptal Anatomy



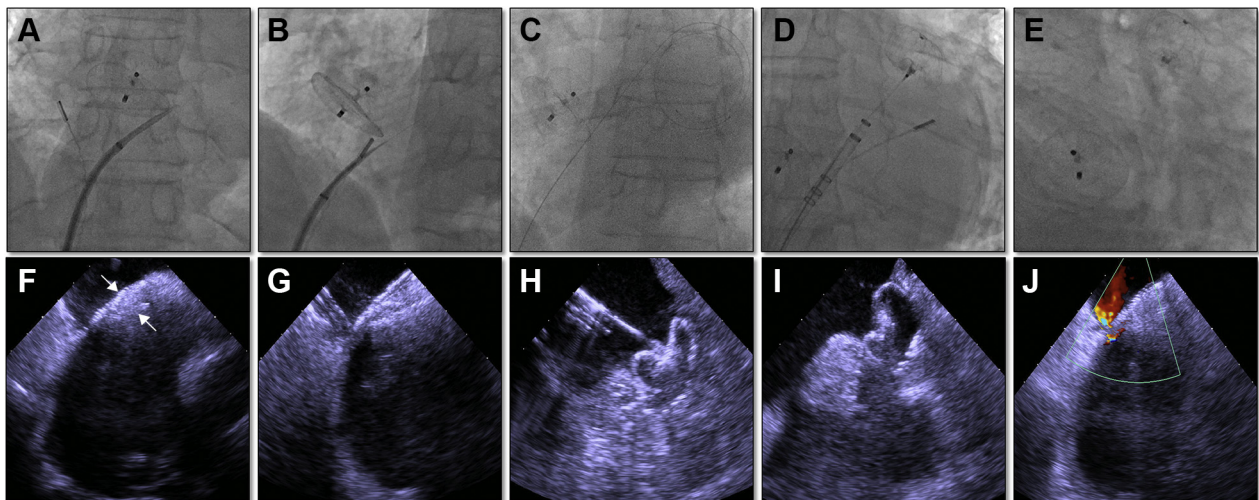
Multiplanar computed tomographic images in multiple projections. Lipomatous IAS with aneurysmal mid segment protruding into left atrial space. Fibrotic IAS with thickened IAS appreciable between RA and LA. Presence of an Amplatzer atrial septal defect occluder (ASDO) noted as **bright white spots** within the IAS. TEE = transesophageal echocardiography; other abbreviations as in [Figures 1 and 2](#).

FIGURE 10 Challenging Large-Bore Transseptal Crossing



(A) Successful tenting of a fibrotic IAS by an 8-F Mullins/BRK needle on TEE. (B) Inability to cross IAS despite forward pressure and needle dissection technique. (C) Successful IAS crossing with the 0.014-inch SafeSept wire, though unable to cross with the needle despite electrocautery application. (D) SafeSept wire maintained in pulmonary vein while TSP needle removed and a 1.5-mm coronary balloon used for IAS dilation, followed by 3.0-mm balloon (E). This enabled successful advancement of the needle and Mullins dilator into the LA (F). (G) TORAYGUIDE Guidewire (Toray), advanced through the Mullins dilator to establish left atrial access. Additional IAS dilation with 14-F Inoue dilator (H) followed by an 8-mm Mustang balloon (I) over the TORAYGUIDE Guidewire, (J) Successful passage of a MitraClip delivery sheath across the IAS into LA. Abbreviations as in [Figures 1, 2, and 9](#).

FIGURE 11 LAA Closure in the Setting of a Prior Septal Closure Device



(A) Transseptal apparatus positioned inferior and posterior to the pre-existing 35-mm Amplatzer patent foramen ovale (PFO) occluder device with intracardiac echocardiographic (ICE) catheter positioned within the RA for guidance. (B) TSP performed with SafeSept wire placed within the left superior pulmonary vein followed by passage of the TSP apparatus and (C) subsequent placement of an TORAYGUIDE Guidewire (Toray), to establish left atrial access. (D) Successful placement of both the 14-F Watchman LAA occlusion sheath and the 10-F ICE catheter through the septal defect into the LA with subsequent advancement of 27-mm Watchman FLX device within the LAA. (E) Withdrawal of delivery apparatus and ICE catheter leaving the LAA device in place with an intact and undisturbed PFO occluder device in place. Sequential ICE images demonstrating (F) PFO closure device (arrows denote RA and LA discs of device), (G) TSP apparatus positioned inferiorly to the PFO closure device, (H) placement of Watchman FLX device within the LAA, and (I) subsequent release. (J) Color flow demonstrating left-to-right shunting inferior to the existing PFO closure device from the septostomy performed. Abbreviations as in [Figures 1 and 2](#).

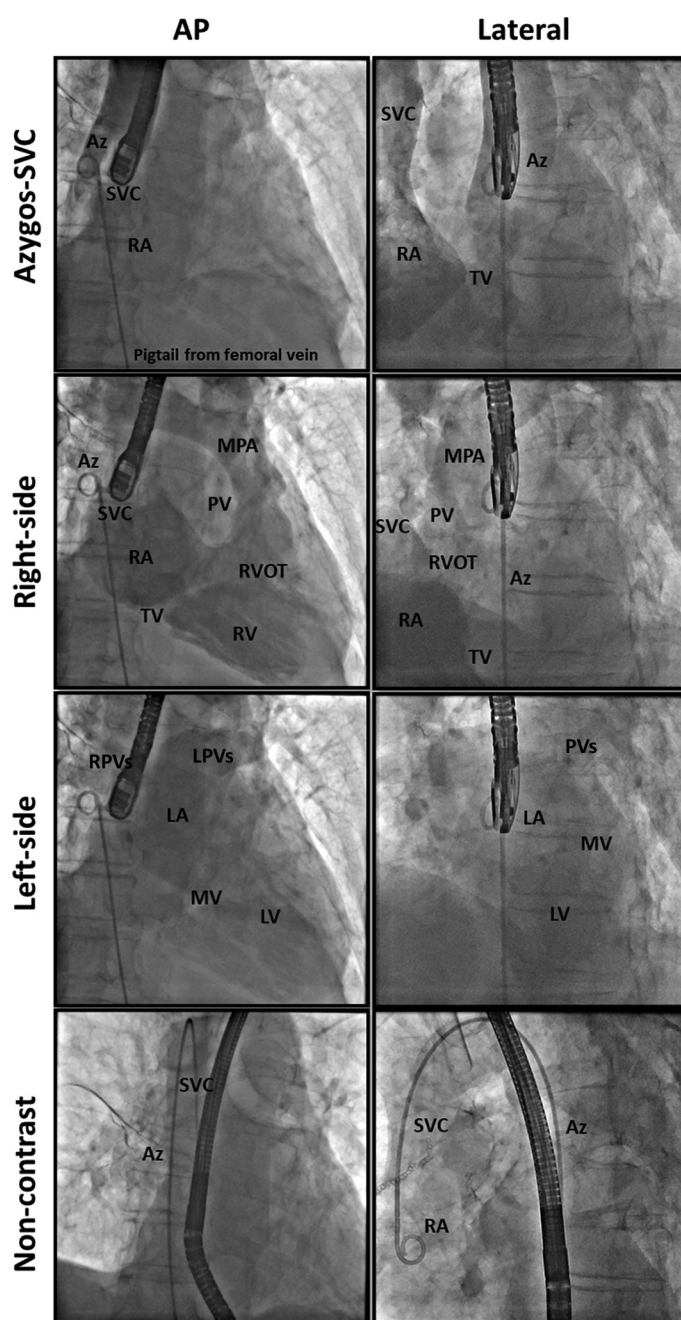
these sequential strategies, coupled with an anatomic approach to TSP, will enable safe and reproducible TSP in even the most complex anatomies.

CHALLENGING TRANSSEPTAL SCENARIOS

Characteristic anatomic variations affecting TSP can be divided into intrinsic and extrinsic factors. Extrinsic factors alter the typical alignment and relation between the cardiac structures ([Figure 8](#)). Noncardiovascular extrinsic factors include obstructive lung disease, diaphragmatic elevation ([Figure 8](#)), and sternal deviation, and musculoskeletal abnormalities such as pectus excavatum ([Figure 1](#)), straight-back syndrome ([Figure 5](#)), and severe kyphosis or scoliosis ([Figure 8](#)) may all markedly displace the position of the cardiac chambers. Clinically, one most often encounters abdominal obesity, leading to a more superior and leftward rotation of the cardiac apex; obstructive lung disease, yielding a more vertical cardiac orientation with relatively narrow LA space; and skeletal abnormalities, which can induce a wide array of structural variants. Similarly, extrinsic factors potentially affecting TSP include

cardiovascular sources spanning variations in the cardiac chambers, aorta, superior vena cava or inferior vena cava, and coronary sinus, among others ([Figure 8](#)). Extremes in LA or right atrial size distort the IAS position, while coronary sinus dilation can compress the left atrium ([Figure 8](#)). A very commonly encountered anatomic variant is dilation and counterclockwise (as seen from above) rotation of the aortic root and ascending aorta, often with a horizontal attitude. This can be commonly seen with chronic hypertension (type III arch) and is an exaggeration of normal age-related anatomic changes. Extreme care to avoid anterior positioning of the TSP needle is required in such cases. Indeed, a leftward-directed needle may encounter the aorta without anterior deflection ([Figure 5](#)). Chronic mitral valve disease leading to significant LA dilation or chronic aortic valve disease resulting in aortic root dilation and a horizontal ascending aorta necessitates specific precautions with anterior-posterior TSP needle positioning to avoid inadvertent puncture. Chronic obstructive pulmonary disease and disorders of the spine such as severe kyphoscoliosis ([Figure 8](#)) or straight-back syndrome can further complicate

FIGURE 12 Fluoroscopic Assessment of Anomalous Venous Anatomy



Patient with congenital absence of the IVC with prominent azygos vein (Az) continuation into the SVC. Selective angiography of the cardiac chambers simultaneously in both AP and lateral projections completed with pigtail advanced from the femoral vein and positioned within the azygos continuation. Contrast injection delineates the azygos venous communication to the SVC. Subsequent opacification of the right-sided structures including the RA, tricuspid valve (TV), RV, RVOT, pulmonary valve (PV), and MPA. Next, contrast passes through the lung microcirculation and returns to opacify the left-sided structures, including pulmonary veins (PVs), LA, MV, and LV. Noncontrast panels demonstrate pigtail advanced from femoral vein through the azygos and down the SVC with the tip located within the RA, demonstrating the anomalous course on both projections. Abbreviations as in [Figures 1, 2, 4, and 5](#).

successful TSP and increase the risk for complications ([Figure 5](#)).

Intrinsic factors include differences in the thickness, fibrosis, mobility, and orientation of the fossa ovalis, while also considering previous instrumentation and device closure of the IAS ([Figure 9](#)). Clinically, one will most often contend with an aneurysmal or fibrotic IAS. Aneurysmal IAS necessitate cautious forward pressure while avoiding excessive LA tenting, which can lead to inadvertent puncture of the contralateral LA wall on crossing. Use of a SafeSept wire in these scenarios is often helpful to cross the IAS while not excessively tenting the IAS to the opposing LA wall pending the LA size. A severely fibrous IAS can be encountered in the native state, following chest wall radiation or following iatrogenic instrumentation of the IAS, requiring similar precautions with wire-mediated IAS crossing or RF ablation if significant resistance is encountered ([Figure 10](#)).

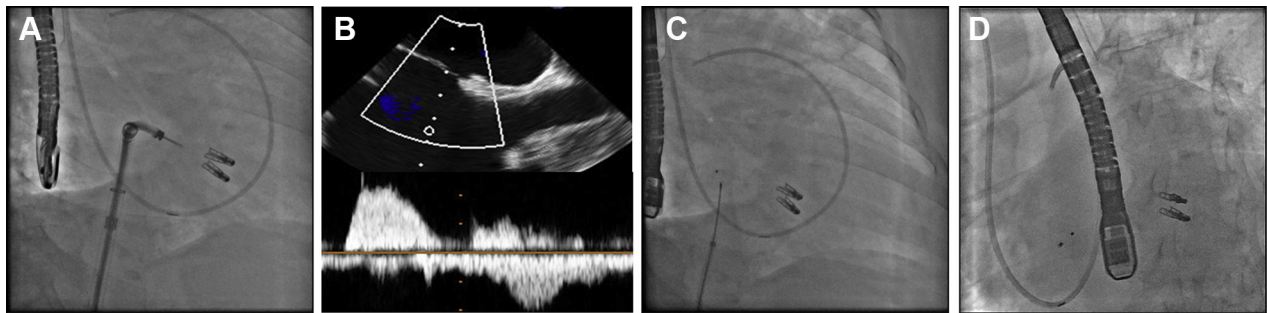
Although rarely encountered, the presence of a closure device in the IAS presents a unique challenge. Cross-sectional imaging provides insights into the device margins and remaining fossa space to accommodate TSP through the tissue. In the absence of a suitable peridevice TSP location (which is typically located posterior to the device rim) ([Figure 11](#)), commercially available IAS closure devices are amenable to TSP through the devices, with device-specific considerations for both the Gore (Gore Medical) and Amplatzer (Abbott) devices ([13](#)). If traversing the device, care must be taken to escalate the TSP methodology appropriately while also considering reclosure post-procedure ([2](#)). Hence, both intrinsic and extrinsic factors can cause significant variations in TSP anatomy, which can be readily identified and adjusted for when incorporating all available imaging modalities.

Operators should not hesitate to perform contrast injections (30 mL-40 mL is usually sufficient) into the right atrium with close observation of levophase. All 4 cardiac chambers can be readily visualized and the anatomic relationships between them clearly identified ([Figure 5](#), [Videos 2 and 3](#)). Using this approach, we have encountered venous anomalies such as a congenitally absent inferior vena cava with a large azygos vein continuation to the superior vena cava ([Figure 12](#)).

INDICATIONS FOR IAS CLOSURE FOLLOWING TSP

The continued evolution of left-sided SHD interventions has also generated progressive increases in the caliber of sheaths traversing the IAS and the

FIGURE 13 ASD Closure Following Transcatheter Edge-to-Edge Repair



(A) Successful transcatheter edge-to-edge repair with 2 MitraClip devices. (B) Following MitraClip sheath removal, note made of significant residual interatrial shunt with bidirectional shunting across iatrogenic atrial septal defect (ASD), prompting closure. (C) 8-mm Amplatzer ASD occluder attached to delivery line across the ASD. (D) Released ASD occluder device in stable position.

resultant iatrogenic atrial septal defects (IASDs) created. Although the majority of IASDs spontaneously close over time, some persist, with increasing sheath size predicting late patency (14,15). Early observational studies suggested up to 50% IASD patency rates with large-bore SHD interventions, with controversial concern of adverse clinical outcomes in those that persist (16,17). However, recent randomized data on empirical IASD closure after large-bore LA access suggest no difference in clinical outcomes compared with those managed conservatively (18). Interestingly, IASDs are also being investigated as LA decompression therapy for symptomatic heart failure (19), extending benefits initially observed in subjects with Lutembacher syndrome (20). Taken together, the IAS represents an important anatomic region with numerous aspects to consider for potential closure post-TSP.

Generally, we consider IASD closure when there is significant IAS tearing, bidirectional or right-to-left shunting with hypoxemia, severe tricuspid regurgitation, or significant concern for paradoxical embolization (Figure 13) (15). However, IASD closure is not without a downside. The continued development of left-sided cardiac procedures will translate to patients' undergoing multiple TSPs for varied procedures over their lifetimes. As discussed, although possible, TSP in the presence of a septal occluding device is more complex, making preservation of the

IAS an important consideration. Accordingly, alternative strategies such as percutaneous atriotomy, which provides LA access through the coronary sinus rather than the IAS, may prove beneficial to diversify the toolbox for operators requiring alternative large-bore LA access strategies (21).

CONCLUSIONS

Pre-procedural multimodality imaging enables operators to use a patient-specific anatomic approach to TSP. Integrating echocardiography and intra-procedural fluoroscopy with angiography can facilitate successful TSP in challenging situations. Moreover, consistent stepwise escalation of TSP techniques and devices while considering patient-specific anatomy is crucial to ensuring safe, reproducible, and efficacious TSP.

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APPENDIX For supplemental videos, please see the online version of this paper.