INNOVATIVE TECHNIQUES

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Site-specific Transseptal Cardiac Catheterization Guided by Intracardiac Echocardiography for Emerging Electrophysiology Applications

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ABSTRACT. Transseptal cardiac catheterization (TSC) has emerged as an increasingly important tool for catheter ablation of atrial fibrillation and other left-sided arrhythmias. Recent years have also seen an increase in the need for TSC for non-ablative electrophysiology applications such as percutaneous left atrial appendage (LAA) occlusion procedures. With this proliferation, there is increased interest in customizing the site of transseptal puncture (TSP) based on the particular clinical application. In this review, we highlight the role of intracardiac echocardiography (ICE) in performing site-specific TSP with the goal of optimizing procedural efficacy and safety. We also discuss approaches to site-specific TSP based on specific electrophysiology applications.

KEYWORDS. transseptal cardiac catheterization, intracardiac echocardiography, catheter ablation.

Introduction

Transseptal cardiac catheterization (TSC) for access to the left heart for hemodynamic assessment was initially described over six decades ago. Although TSC remained a mainstay in the assessment of various forms of acquired and congenital heart disease for many years, the advent of indirect measurements of left atrial pressure via right heart catheterization along with advances in non-invasive imaging, particularly echocardiography, led to a diminished role for TSC in routine clinical practice. However, the past decade has again seen a proliferation in TSC with the increased role of electrophysiology applications, including atrial fibrillation (AF) catheter ablation, ventricular tachycardia ablation, and interventions for structural heart disease. This growth in applications for TSC has renewed focus on TSC techniques. In this review, we provide a general overview of TSC techniques with a particular focus on the role of intracardiac echocardiography (ICE) to guide site-specific TSC for specific clinical applications.

Embryology of the interatrial septum

The primitive sinuatrium is separated into right and left atria by the downward growth of the septum primum from the roof of the sinuatrium toward the atrioventricular (AV) canal, thereby creating an inferior interatrial opening known as the ostium primum. Soon after, numerous perforations form in the anterior–superior portion of the septum primum, eventually coalescing to form the ostium secundum. The septum secundum begins to develop to the right of the septum primum and eventually leads to complete separation of the left and right atria with the exception of a small central opening, the fossa ovalis (FO). The area of fusion of the muscular septum secundum and the thinner portion of the septum primum is known as the limbus, which forms a raised margin around the superior aspect of the FO. The FO is covered by thin, fibrous tissue from the septum primum, forming the valve of the foramen ovale. The inferior portion of the atrial septum, the superior
portion of the ventricular septum, and the septal leaflets of both the mitral and tricuspid valves are formed from endocardial cushions and the integrity of the atrial septum depends on successful fusion of these structures² (Figure 1). The FO, usually located posteriorly at the junction of the mid- and lower third of the right atrium (RA),³ has traditionally been the targeted site for transseptal puncture (TSP) given the relatively thin tissue overlying this region which facilitates needle puncture and advancement of the transseptal dilator and sheath apparatus across the atrial septum.

Techniques for site-specific transseptal catheterization guided by ICE

ICE has emerged as a valuable tool for real-time imaging during complex cardiac procedures. The most commonly utilized contemporary imaging technology with ICE involves the use of a sector-based phased array transducer with a steerable catheter which is capable of providing Doppler and color flow imaging with adequate field of depth to image the interatrial septum (IAS) and far-field structures such as the left atrium (LA) and pulmonary veins (PVs) from the RA.⁴ In contrast to phased array technology, ICE catheters are also available using a radial transducer which provides cross-sectional imaging. Phased array ICE catheters have several advantages over radial transducers including better depth of view and steerability, which improves ease of use since the catheter can be positioned in the heart without need for a long sheath.⁴ For these reasons, phased array ICE is preferred in our laboratory and serves as the focus for this review.

Numerous techniques have been developed for successfully performing TSP without real-time echocardiography using only fluoroscopy, and these techniques can serve as important adjuncts even when using ICE. The placement of electrophysiology catheters in the coronary sinus and at the His position can demarcate important anatomic landmarks. The use of the His catheter is based on the premise that the location of the His bundle electrogram marks the most caudal aspect of the aorta. A pigtail catheter can also be introduced into the aortic root to directly identify the aorta, although this requires arterial access. Furthermore, upon withdrawing the

Figure 1: Embryologic development of the interatrial septum.

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transseptal sheath/dilator/needle assembly from the superior vena cava (SVC) into the RA, in the left anterior oblique (LAO) view, two distinct jumps of the assembly should be visible: the first marking passage of the sheath/dilator/needle from the SVC into the RA, and the second marking passage of the assembly over the muscular limbus and into the FO. The use of differently angled sheaths and transseptal needles can also facilitate safe TSP.  

Although TSP can be safely performed with the use of fluoroscopy only, the use of real-time echocardiography has the advantage of enhanced visualization of the IAS, FO, and surrounding structures, and we believe that it plays an integral role in performing safe, site-specific TSP.

Although direct comparisons are lacking, intraoperative echo may reduce the rate of cardiac perforation compared with TSP guided by fluoroscopy alone, particularly in cases with distorted anatomy such as aortic root dilation or tortuosity, atrial enlargement, or interatrial septal aneurysms. The use of intraoperative echo can also facilitate double TSP when the use of multiple sheaths in the LA is required. Although both transesophageal echocardiography (TEE) and ICE can accomplish these goals, ICE has the additional advantages of not requiring a second operator or general anesthesia.

To guide TSP, the ICE catheter is advanced from the femoral vein to the “home” view in the body of the RA.
facing the tricuspid valve (Figure 2a). From this position, a posterior tilt of the transducer and a clockwise rotation of the catheter brings the IAS and FO into view in the near field with the body of the LA visible in the far field (Figure 2b). Counterclockwise rotation of the catheter rotates the transducer anteriorly toward the anterior limbus of the IAS and then eventually brings the aortic root and aortic valve in long axis into view (Figure 2c). Clockwise rotation orients the transducer toward the posterior rim of the FO (Figure 2d). A full sweep of the IAS should be performed to assess the relationship of the FO to surrounding structures (Movie 1) with special attention paid to the location and thickness of the FO and the possible presence of a patent foramen ovale (PFO). A PFO may obviate the need for needle puncture of the IAS or may add an added level of complexity if the desired site for septal crossing is in a different location. In contrast, a particularly thick septum or a very aneurysmal septum may prompt the use of a radiofrequency (RF)-powered transseptal needle (Baylis Medical Company, Montreal, Canada) or RF energy from a standard electrosurgical cautery generator delivered through a standard transseptal needle to minimize the risk of trauma to adjacent structures.

Following an initial survey of the IAS anatomy, the ICE catheter can be used to guide site-specific TSP. As the
transseptal sheath and dilator apparatus is withdrawn from the SVC into the RA, ICE can be used to visualize the dilator engaging the FO by a “tenting” appearance (Figure 3a,b). With the dilator engaged against the FO in this view, another anterior–posterior sweep with the ICE catheter can be used to determine the exact location of the site of maximal tenting on the IAS with particular reference to the proximity of adjacent structures including the aortic root and the posterior wall of the LA. If the dilator has engaged the IAS too anteriorly, the aortic valve will be seen in close proximity to the site of maximal tenting with only a slight counterclockwise rotation of the ICE catheter. Attempted transseptal crossing in this position runs the risk of inadvertent injury to the aorta, and the needle/dilator apparatus should be repositioned. In this scenario, more posterior engagement of the FO can be accomplished by repositioning the transseptal needle in a more posterior orientation by clockwise rotation of the hub of the needle (i.e. from a “4 o’clock” to a “5 o’clock” position when the needle hub is viewed from the patient’s feet). In an analogous manner, if the dilator has engaged the IAS too far posteriorly, attempted crossing threatens injury to the

Figure 3: Transseptal puncture guided by intracardiac echocardiography (ICE). From the body of right atrium (RA), the ICE catheter is tilted posteriorly to bring the interatrial septum (IAS) and fossa ovalis (FO) into view in the near field and the body of the left atrium (LA) in the far field (a). As the transseptal needle and dilator are withdrawn from the superior vena cava, the appearance of “tenting” serves as confirmation that the FO has been engaged (Figure 2b). As the transseptal needle and dilator are advanced, the loss of tenting serves as an indicator of successful crossing into the LA (c). Finally, the transseptal sheath is visible in the LA (d).
posterior LA and should be avoided; counterclockwise rotation of the transseptal needle hub should be used to re-engage the FO. In addition to ICE imaging, the use of fluoroscopy in the right anterior oblique (RAO) projection can be used as an adjunct to determine the appropriateness of the transseptal crossing site along the anterior–posterior and superior–inferior axes.

Once the appropriateness of the anticipated transseptal crossing site has been determined, the transseptal needle can be advanced under real-time ICE visualization. Injection of a small amount of non-agitated saline through the needle can be used to confirm the presence of echo contrast in the LA by ICE, serving as a useful adjunct to other means of confirming crossing into the LA (pressure transduction, contrast injection, passage of a small-gauge guidewire into a pulmonary vein). After successful puncture of the IAS with the transseptal needle, further use of ICE can confirm the successful crossing of the dilator and then sheath into the LA. The successful crossing of the dilator and sheath into the LA can be

Movie 2: Transseptal puncture guided by intracardiac echocardiography (ICE). At the beginning of the clip, the transseptal needle and dilator can be seen engaging the fossa ovalis with the appearance of “tenting” of the interatrial septum. Advancing the needle and dilator into the left atrium (LA) is confirmed by the loss of tenting. Finally, the transseptal sheath is advanced into the LA under ICE visualization.
visualized by the loss of tenting of the septum (Figure 3c,d, Movie 2). In the setting of a fibrotic or scarred IAS, particularly during repeat procedures, or with an aneurysmal septum, ICE can be particularly useful in confirming safe passage of the dilator and sheath into the LA without inadvertent injury to the posterior LA.

Once passage into the LA has been confirmed, ICE can remain useful during the remainder of the procedure, particularly for monitoring for complications such as pericardial effusion/tamponade. From the home view in the body of the RA facing the tricuspid valve, ICE can be used to monitor for the presence of a pericardial effusion adjacent to the right ventricle and right atrium. In addition to monitoring for complications, ICE can be used for other purposes, depending on the specific clinical application. For instance, during AF ablation procedures, ICE has been used to identify the ostia of the PVs and to monitor lesion formation.7

**Electrophysiology applications for site-specific TSC**

**Catheter ablation of atrial fibrillation**

Circumferential electrical isolation of the PVs remains the mainstay of AF catheter ablation. Although RF catheter ablation has been the most commonly used modality for achieving PV isolation, the addition of cryoballoon ablation (Arctic Front, Medtronic, Minneapolis, MN) has emerged as an important complimentary technology. The use of site-specific TSC can play an important role in achieving success during AF ablation. The PVs are posterior structures in the LA and assuring adequate “reach” of the RF or cryoballoon catheter is particularly important, especially when addressing the right-sided veins. For the purpose of RF catheter ablation of AF, in our laboratory, a relatively anterior crossing of the IAS is

**Movie 3:** Anterior transseptal puncture guided by intracardiac echocardiography (ICE). The movie demonstrates preparation for a double transseptal puncture in anticipation of atrial fibrillation catheter ablation. At the beginning of the clip, the first transseptal sheath with a relatively more posterior crossing can be seen in the body of the left atrium. Counterclockwise torque of the ICE catheter brings the anterior portion of the interatrial septum (IAS) into view and further counterclockwise torque eventually brings the aortic valve into view in the long axis. From this position, clockwise torque again brings the anterior portion of the IAS into view at the end of the clip. The more anterior position along the IAS is targeted for the second transseptal crossing.

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preferred in order to allow adequate room for deflectable sheaths and catheters to freely reach around to the posterior wall and PVs. Others have suggested that a more posterior transseptal crossing can be favorable for RF ablation of AF by angling the catheters directly toward the PVs,7–9 but this may limit the ability to fully encircle the veins while controlling contact. For cryoballoon ablation, a more anterior crossing of the IAS has been recommended,9 and our experience also suggests that this provides the most favorable approach for accessing all PVS with the cryoballoon, particularly the right inferior vein. Regardless of the modality of ablation (RF or cryoballoon) or the operator’s preferred site of transseptal crossing (anterior or posterior), ICE provides a powerful tool for performing a safe site-specific TSP and improving the chances of a successful AF ablation procedure.

As discussed above, in our laboratory, a relatively more anterior crossing of the IAS is preferred for RF ablation of AF. Movie 3 shows an example of a double transseptal puncture guided by ICE in preparation for AF ablation. At the beginning of the clip, the first transseptal sheath can be visualized in the LA. Counterclockwise torque of the ICE catheter brings the anterior portion of the IAS into view, and further clockwise torque eventually brings the aortic valve into view in long axis. From this position, clockwise torque again brings the anterior portion of the IAS into view at the end of the clip. This more anterior position along the IAS is targeted for the second transseptal crossing. Figure 4 shows corresponding fluoroscopy views from the same case. In Figure 4a, the RAO projection shows the first transseptal sheath (with circular mapping catheter) positioned in the LA. The second transseptal needle/dilator can be seen engaging the FO in an anterior position in anticipation of the second TSP. The use of ICE in this setting allows a more anterior crossing of the IAS to be performed safely by monitoring proximity to the aortic root in real-time and ensuring that an adequate target for TSP exists along the anterior rim of the FO but with sufficient distance from the aorta.

Movie 4 shows another example of a relatively anterior TSP guided by ICE, this time in anticipation of cryoballoon ablation. At the beginning of the clip, the aortic valve is visualized in long axis confirming that the ICE catheter is projecting anteriorly. Slight clockwise torque shows the transseptal needle and dilator tenting the IAS in an anterior location, just posterior to the aortic root. An RF-powered needle is used to puncture the IAS and the appearance of bubbles in the LA and the loss of tenting confirm crossing of the IAS. Toward the end of the clip, further clockwise rotation of the ICE catheter brings the posterior rim of the FO into view and completes the anterior to posterior sweep of the IAS, thus confirming the relatively anterior position of the TSP. Figure 5 shows corresponding fluoroscopic views from this case with the relatively anterior site of transseptal crossing visible in the RAO projection (Figure 5a).
The use of ICE can also be particularly useful in guiding TSP for patients with percutaneous atrial septal defect (ASD) closure devices who are undergoing AF ablation. A case series of 39 patients with ASD closure devices suggested that ICE could be used to successfully guide double TSP in all patients. In 35 patients, the native IAS was targeted for TSP and in the remaining four patients, TSP was performed through the ASD closure device.

Transseptal access is often required for ablation of arrhythmias other than AF. Two frequently encountered scenarios include ablation of left-sided atrioventricular bypass tracts located along the mitral annulus and ablation of ventricular arrhythmias via the transseptal approach. In both circumstances, the TSP is performed with access to

Movie 4: Anterior transseptal puncture in anticipation of cryoballoon atrial fibrillation ablation. At the beginning of the clip, the aortic valve is visualized in long axis confirming that the intracardiac echocardiography (ICE) catheter is projecting anteriorly. Slight clockwise torque shows the transseptal needle and dilator tenting the interatrial septum (IAS) in an anterior location, just posterior to the aortic root. A radiofrequency (RF)-powered needle is used to puncture the IAS and the appearance of bubbles in the left atrium and the loss of tenting confirm crossing of the IAS. Toward the end of the clip, further clockwise rotation of the ICE catheter brings the posterior rim of the fossa ovalis into view and completes the anterior to posterior sweep of the IAS, thus confirming the relatively anterior position of the TSP.
relatively anterior structures in mind: either along the mitral annulus for bypass tracts or across the mitral annulus and into the left ventricle for ablation of ventricular tachycardia (VT). For ablation of bypass tracts, an anterior TSP can be particularly helpful by directing the transseptal sheath and ablation catheter directly toward the mitral annulus.\textsuperscript{8,11} In contrast, although some operators have also advocated an anterior TSP for transseptal ablation of VT, in our laboratory, a more posterior puncture is preferred. The site of septal crossing serves as a fulcrum point, allowing the deflectable transseptal sheath and ablation catheter to be directed anteriorly across the mitral valve. This approach also facilitates more complete ventricular mapping and access to target ablation sites.

**Figure 5:** Fluoroscopic projections of an anterior transseptal puncture for cryoballoon atrial fribillation ablation. The fluoroscopic views correspond to the same case as Movie 4. The relatively anterior site of transseptal crossing is visible in the right anterior oblique (RAO) projection (A). (B) The left anterior oblique (LAO) projection shows the cryoballoon positioned in the right superior pulmonary vein with adequate reach of the cryoballoon to the right sided veins facilitated by the anterior transseptal puncture.

**Figure 6:** Fluoroscopic views of a posterior transseptal puncture projection in anticipation of transseptal ventricular tachycardia ablation. (a) The posterior projection of the transseptal needle is suggested by the relatively vertical appearance of the needle and dilator, the proximity to the spine and the projection away from the coronary sinus catheter. Left anterior oblique (b) and right anterior oblique (c) projections show the transseptal sheath and ablation catheter directed across the mitral valve toward the superior-lateral left ventricle.
Figure 6a shows a RAO fluoroscopic projection in anticipation of a relatively posterior TSP for a VT ablation case. The posterior projection of the transseptal needle is suggested by the relatively vertical appearance of the needle and dilator, the proximity to the spine and the projection away from the coronary sinus catheter. Movie 5 shows transseptal puncture with the dilator and sheath being advanced into the LA in this posterior projection. The use of ICE in this circumstance is useful not only for identifying the posterior site of transseptal puncture (TSP) but also for monitoring the advancing needle, dilator and sheath in real-time to avoid inadvertent injury to the posterior LA.

Movie 5: Posterior transseptal puncture with dilator and sheath being advanced into the left atrium under real-time intracardiac echocardiography (ICE) monitoring. The movie clip corresponds to the same case as Figure 6. The use of ICE in this circumstance is useful not only for identifying the posterior site of transseptal puncture (TSP) but also for monitoring the advancing needle, dilator and sheath in real-time to avoid inadvertent injury to the posterior left atrium. The beginning of the clip shows the TSP being performed and then the dilator and sheath are advanced in to the left atrium (LA) while the posterior wall and body of the LA can be visualized continuously.

**Left atrial appendage occlusion**

An area of rapidly evolving interest in cardiac electrophysiology has been percutaneous occlusion of the left atrial appendage (LAA) for prevention of stroke in patients with AF and elevated CHADS2 scores. Several devices are at various stages of clinical testing for this application, including the WATCHMAN (Atritech Inc, Plymouth, MN), AMPLATZER Cardiac Plug (St. Jude Medical, St. Paul, MN), and the LARIAT (Sentreheart, Redwood City, CA). Although the technical aspects of device delivery differ between devices, in all three cases, a transseptal sheath is required to facilitate device delivery into or around the LAA. Intracardiac echocardiography...
Figure 7: Posterior and inferior transseptal puncture to facilitate delivery of a WATCHMAN left atrial appendage (LAA) occlusion device. In this case, the procedure is performed under transesophageal echocardiography (TEE) guidance. Right anterior oblique (RAO) fluoroscopic projection (a) shows the transseptal needle and sheath in a posterior orientation as suggested by the vertical projection of the transseptal apparatus overlying the spine. Transseptal puncture in this orientation allows the delivery sheath to be angled from posterior to anterior and aligns with the long axis of the LAA, which can be visualized during contrast injection through a pigtail catheter (b). The WATCHMAN device can be seen deployed in the LAA (c).

Figure 8: Transesophageal echocardiography to guide posterior transseptal puncture for left atrial appendage (LAA) occlusion procedure. The right atrium (RA), left atrium (LA), and aortic valve (AoV) in short axis are visible and the transseptal needle (arrow) can be seen just beginning to tent the posterior rim of the fossa ovalis. A posterior transseptal crossing facilitates device delivery into the anteriorly located LAA.
can be particularly useful in this setting.\textsuperscript{12,13} As a superior and anterior structure, our preference has been to perform the TSP in a slightly more superior location to align the transseptal sheath with the level of the LAA (when a Lariat device is to be deployed) or more inferiorly (when a Watchman or Amplatz Plug is used). These subtle differences are driven by the shapes of the transseptal sheathes used for the different technologies. The Watchman and Amplatz Plug require larger curved sheaths and require a more inferior fulcrum point to access the appendage safely. We also prefer a mid- to posterior crossing of the IAS to allow room for the transseptal sheath to be maneuvered from posterior to anterior and provide a coaxial approach along the long axis of the LAA. A more anterior crossing can make it difficult to align the transseptal sheath with the long axis of the LAA and poses a challenge to device delivery.

\textbf{Figure 7} shows examples of fluoroscopic images during implantation of a WATCHMAN LAA occlusion device, in this case being performed with TEE guidance under general anesthesia. In the RAO projection (\textbf{Figure 7a}), the transseptal needle and sheath can be seen with a posterior orientation suggested by the vertical projection of the transseptal apparatus overlying the spine. TSP in this orientation allows the delivery sheath to be angled from posterior to anterior and aligns with the long axis of the LAA, which can be visualized during contrast injection through a pigtail catheter in \textbf{Figure 7b}. The WATCHMAN device can be seen deployed in the LAA in \textbf{Figure 7c}. \textbf{Figure 8} shows a TEE image with the transseptal needle (arrow) beginning to tent the posterior rim of the FO.

\textbf{Conclusion}

The past decade has seen a rapid proliferation in the use of TSC for ablation of arrhythmias, in particularly AF, and non-ablative electrophysiology applications such as LAA occlusion. In these settings, choosing the optimal site of TSP can be particularly important in assuring procedural success and optimizing patient safety, and the use of real-time echocardiographic guidance to guide site-specific TSP can be particularly beneficial. ICE has the particular advantage of not requiring a second operator or general anesthesia and can be used with relative ease to guide site-specific TSP. Although controlled data validating the safety and efficacy of ICE compared with standard fluoroscopic techniques for TSP are lacking, as outlined in this review, we believe ICE serves as a valuable tool for maximizing the chances of a safe and optimally located transseptal crossing.

\textbf{References}