Revista Colombiana de
Cardiología
Órgano oficial de la Asociación Sociedad Colombiana de Cardiología & Cirugía Cardiovascular

PERMANYER

Check for updates

REVIEW ARTICLE

How to perform a transseptal puncture safely and effectively

Cómo realizar una punción transeptal de manera segura y exitosa

Juan C. Díaz[1], César D. Niño[2], Oriana Bastidas[1], Julián M. Aristizábal[3], Jorge E. Marín[4], Juan M. Martínez[4], and Mauricio Duque[3]*

[1]Electrophysiology and Cardiac Arrhythmia Service, Clínica Las Vegas Grupo Quirón Salud, Universidad CES, Medellín; [2]Electrophysiology and Cardiac Arrhythmia Service, Clínica SOMER, Universidad CES, Rionegro; [3]Electrophysiology and Cardiac Arrhythmia Service, Hospital Universitario San Vicente Fundación, Universidad CES, Rionegro; [4]Electrophysiology and Cardiac Arrhythmia Service, Clínica Las Américas, Universidad CES, Medellín. Colombia

Abstract

Initially described in 1959 as a technique to measure left atrial pressures, and later used during balloon mitral valvuloplasty, transseptal puncture (TSP) is frequently the access route for procedures involving the left heart chambers. Currently, it is mostly used in electrophysiology laboratories for arrhythmia ablation and during left atrial appendage occlusion procedures. However, with the ongoing development of percutaneous mitral valve interventions, it is expected that a greater number of interventional cardiologists will be using this technique in the near future. In this article, we review the technique for performing TSP safely, and we provide recommendations and different strategies to deal with difficult TSPs.

Keywords: *Transseptal puncture. Arrhythmia ablation. Structural cardiology. Complications.*

Resumen

Introducida inicialmente en la década de los cincuenta para la evaluación de las presiones de la aurícula izquierda y posteriormente para la realización de valvuloplastia mitral, la punción transeptal es, con frecuencia, la vía de acceso para efectuar procedimientos que involucren las cavidades izquierdas. En la actualidad, se usa comúnmente en los laboratorios de electrofisiología, tanto para la ablación de arritmias en cavidades izquierdas, como para los procedimientos de cierre percutáneo de orejuela. No obstante, con la llegada de diversas técnicas para el manejo percutáneo de la válvula mitral, se espera un aumento progresivo de su uso por parte de cardiólogos intervencionistas. En este artículo, se revisa la técnica para hacer una punción transeptal segura y se dan recomendaciones y estrategias para el manejo de la punción transeptal difícil.

Palabra clave: *Punción transeptal. Ablación de arritmias. Cardiología estructural. Complicaciones.*

***Correspondence:**
Juan C. Díaz
E-mail: jcdiaz1234@hotmail.com

Date of reception: 24-12-2022
Date of acceptance: 13-06-2023
DOI: 10.24875/RCCARE.M23000070

Available online: 01-02-2024
Rev Colomb Cardiol. 2023;30(6):359-368
www.rccardiologia.com

Introduction

Transseptal puncture (TSP) was originally introduced in 1959 for measuring left atrial pressures[1,2], and rapidly evolved as an access route for managing mitral valve disease. However, the development of techniques to indirectly measure left atrial pressure using balloon catheters, together with a decreased prevalence of rheumatic valve disease, led to the technique rapidly disappearing from interventional cardiology laboratories. Toward the end of the 80s, the technique was infrequently used, and interventional cardiology training programs no longer had a large enough volume to provide adequate training for their fellows, significantly increasing the rate of complications[3]. With the advent of atrial fibrillation ablation at the end of the 90s[4], the technique experienced a resurgence: in only five years, the number of TSPs grew 60 times[5] and it is a common procedure in electrophysiology labs today. This experience has been harnessed in atrial appendage occlusion interventions[6] and, more recently, in percutaneous mitral valve interventions[7,8]. However, TSP continues to be a high-risk procedure which must be performed by highly trained personnel. In an analysis of the causes of pericardial effusion during atrial appendage occlusion procedures, up to 9% of the effusions occurred during TSP[9,10], showing the importance of proper technique during this procedure.

This article provides a step-by-step review of the technique for performing TSP safely using different imaging aids, as well as the management of difficult approaches and complications.

Operator training and experience

It is important for training programs to include both theoretical and practical aspects of TSP. A review of anatomy, possible risks and complications, as well as the use of simulators in the company of an experienced operator can help improve the skill of fellows-in-training in performing these procedures. As the operator's experience increases (measured by the number of TSPs performed per year), the rate of complications decreases significantly. It has been determined that an operator must perform at least 50 TSPs to have an "acceptable" level[11], while performing more than 45 TSPs per year is considered a high volume which, in turn, results in a significant reduction in the time required to obtain transseptal access and in the rate of complications[12]. Therefore, it is recommended that procedures involving TSP be performed by high-volume operators.

Before transseptal puncture: the importance of anticoagulation

Although, in the initial years, the use of anticoagulants was considered to be an absolute contraindication for TSP, today it is recommended that procedures involving TSP be performed without interrupting anticoagulation[13]. This also applies for patients treated with direct oral anticoagulants (DOACs), in whom, although the evidence establishes that their uninterrupted use could be just as safe or even safer than uninterrupted warfarin use[14], most electrophysiologists (63%) omit at least one dose before the procedure[13]. Although there is a fear that anticoagulant use prior to the procedure could increase mortality and the length and amount of bleeding if cardiac tamponade should occur, the available evidence indicates the opposite[15].

In addition to a prior anticoagulant, heparin is recommended before performing TSP, as both the guidewires and transseptal sheaths are highly thrombogenic. In our practice, 10,000 units of unfractionated heparin are infused prior to femoral puncture (in order to avoid thrombus formation on the femoral guidewires and introducers), with another 3,000 units after TSP to maintain the ACT > 300 seconds. Administering heparin only after performing TSP does not reduce the risk of bleeding, but does significantly increase the risk of thrombogenesis in the left atrium and should therefore be avoided.

Tools for performing transseptal puncture

There are various transseptal introducers which may be useful, depending on the procedure being performed. For ablations, deflectable introducers (Agilis, Abbot; Vizigo, Biosense Webster) are preferred, as they make it easier to manipulate the catheters in the left atrium. For procedures involving introducer exchange (for example, percutaneous atrial appendage occlusions), SL0 (Abbot) introducers are preferred, as their curvature (50°) facilitates left superior pulmonary vein cannulation and allows a high-support guidewire to be installed at this point. When using different introducers, it is important to consider their varying lengths in order to select an appropriately sized transseptal puncture needle (that is, not using a long needle in a short introducer, as it can easily inadvertently puncture other vascular structures).

There are additional tools which are not currently available in Colombia, like the SafeSept (Pressure Products) and Versacross (Baliss) guidewires. Both reduce the risk of complications and time required to obtain transseptal access[12] and therefore, if available, could be considered.

Fluoroscopy-guided transseptal puncture

Fluoroscopy is the most basic form of TSP guidance. Although the fossa ovalis (FO) is not directly visible on fluoroscopy, the use of other anatomical landmarks and appropriate placement of reference catheters can help locate it in a simple way. The anatomical landmarks which help locate the FO are:

- The coronary sinus, which can be located by inserting an electrophysiology catheter in it.
- The noncoronary aortic cusp, which can be located with a catheter through a retroaortic artery.
- The left main bronchus, which marks the position of the roof of the left atrium.
- The conduction system, which is easily located with an electrophysiology catheter and is directly related to the position of the aorta (making a catheter in the aorta unnecessary).
- The thoracic vertebrae.

Technique for performing fluoroscopy-guided TSP (Fig. 1)

- Step 1: locate the orientation of the interatrial septum, introducing an electrophysiology catheter toward the right ventricle. The fluoroscopy unit is angulated to the left to allow the catheter located in the bundle of His to be seen straight on; this angulation places the fluoroscopy ray parallel to the interatrial septum. Most of the procedure will be done in the left oblique plane.
- Step 2: advance the transseptal sheath to the superior vena cava, using a guidewire. Then withdraw the guidewire and advance the TSP needle. When inserting the needle, it is important to use the internal guidewire, as this keeps plastic fragments from being dragged along and potentially embolized. Although it is a common practice, we suggest not to manually modify the curvature of the guidewire, as an excessive curvature may make it difficult to advance the needle within the introducer (and even cause perforation). The tip of the needle should be located 1 cm from the tip of the transseptal dilator, aligning the curvature of the sheath and the needle (Fig. 2) and orienting them toward the 4 or 5 o'clock position.
- Step 3: in the left oblique position, slowly pull back the sheath, watching the falls (which are seen as jumps toward the right of the screen). The first fall corresponds to the entry to the right atrium (it is very subtle and not always visible), and it is followed by a larger fall which corresponds to the entry to the FO. While this would seem to be the appropriate site, at this point, the sheath should be pulled back slightly, watching for a third fall. This corresponds to the lower part of the FO.
- Step 4: evaluate the position of the tip of the dilator in the right oblique view. The angulation needed for this is determined by a perpendicular position to the left oblique obtained in the septum evaluation: if the septum was found at 40° from the left oblique, the perpendicular is 50° to the right. This allows the interatrial septum to be viewed perpendicularly in its full extension. In this projection, ensure that the tip of the dilator is not pointing toward the aorta, nor toward the vertebrae.
- Step 5: return to the left oblique and pull the needle back 2 cm. This leaves the tip of the dilator without support. Push the sheath softly with the dilator, watching the behavior of the tip and the curvature: when it is in the FO, the tip tends to remain fixed (in the vertical axis) and the sheath curvature tends to rise up, increasing the curve. If the tip rises and falls freely, it is probably on a smooth wall (for example, toward the torus aorticus or toward the posterior wall) and should be repositioned. Injecting contrast at this point helps detect septal tenting; in some cases, a tattoo even remains (Fig. 3). If there is a catheter in the coronary sinus, the 3 o'clock position in the sinus will correspond approximately to the location of the FO (as long as the catheter has been advanced to the cardiac border).
- Step 6: advance the needle until it is out of the dilator in the left oblique. The interatrial septal puncture will feel like a sudden loss of resistance; if there is too much tenting, the dilator can "jump" to the other side uncontrollably, and therefore it is not advisable to create a lot of tenting on entering. Before advancing the dilator, contrast should be injected to confirm the location of the needle in the left atrium, determine the position of the atrial wall and establish how far the sheath and dilator can be advanced.

However, as much as possible, puncture guided solely by fluoroscopy should be avoided, as it significantly increases the risk of complications compared with TSP performed under echocardiographic guidance[12].

Echocardiography-guided transseptal puncture

In addition to increasing the safety of the procedure, the use of echocardiography (either transesophageal or intracardiac) to guide TSP has several benefits:

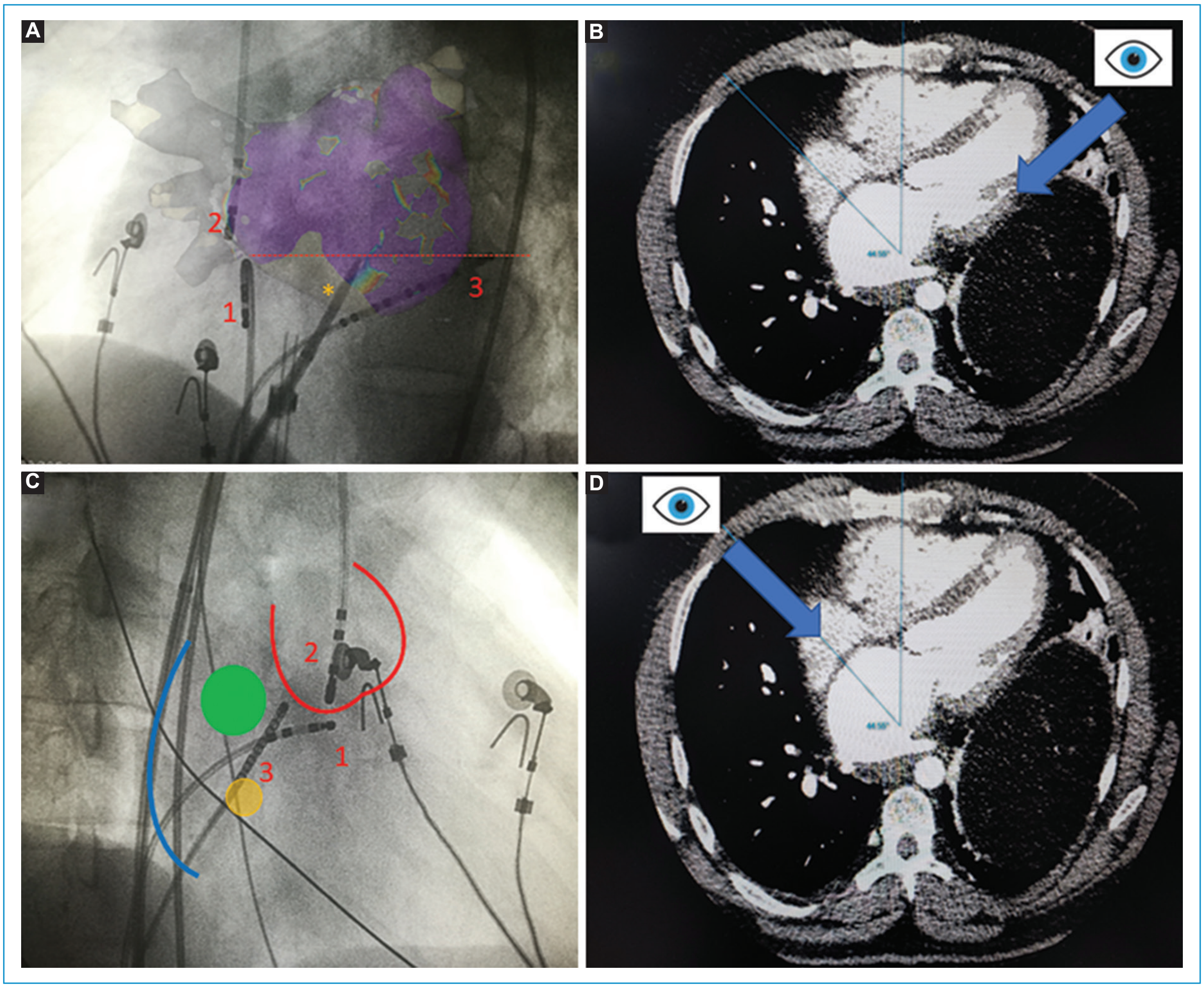

Figure 1. Location of the fluoroscopic anatomical landmarks for TSP. **A:** left anterior oblique image showing the fluoroscopic landmarks and their relationship to the left atrium (superimposed slide). A catheter in the right ventricle (1), a catheter in the aorta (2), a catheter in the coronary sinus (3) and the transseptal introducer can be seen. The relationship between the tip of the coronary sinus catheter and the puncture site (dotted red line) can be seen. **B:** locating the right ventricular catheter pointing directly toward the operator achieves a parallel position to the atrial septum. **C:** right anterior oblique view showing the fluoroscopic landmarks; note the close relationship between the catheter at the bundle of His (1) and the aortic catheter (2); therefore, a catheter does not need to be placed in the aorta (red silhouette) if one can be placed in the bundle of His. The FO (green circle) is located above the coronary sinus ostium (yellow circle), which is marked by a catheter (3). The atrial border (blue border) is in line with the vertebrae. When performing the puncture, the introducer should not be pointing toward the aorta or the vertebrae. **D:** a position at a 90° angle to the left oblique will be perpendicular to the atrial septum, allowing its length to be clearly seen.

- It helps detect anatomical variants of the interatrial septum that modify its fluoroscopic configuration, including marked heart rotation[16,17].
- It helps immediately detect previously formed thrombi or those that may form during the procedure[18].
- It facilitates the manipulation and proper placement of the transseptal introducer in the desired site within the FO.
- It detects cardiac tamponade early, as it allows real-time monitoring of the pericardial space.

Transesophageal vs. intracardiac echocardiography: Which is better?

In general, the choice is based on the operator's experience with one modality or the other, rather than on their availability (both are widely available in the country). Most of the time, electrophysiologists prefer to use intracardiac echocardiography (ICE), while interventional cardiologists prefer transesophageal echocardiography (TEE). For atrial appendage occlusion

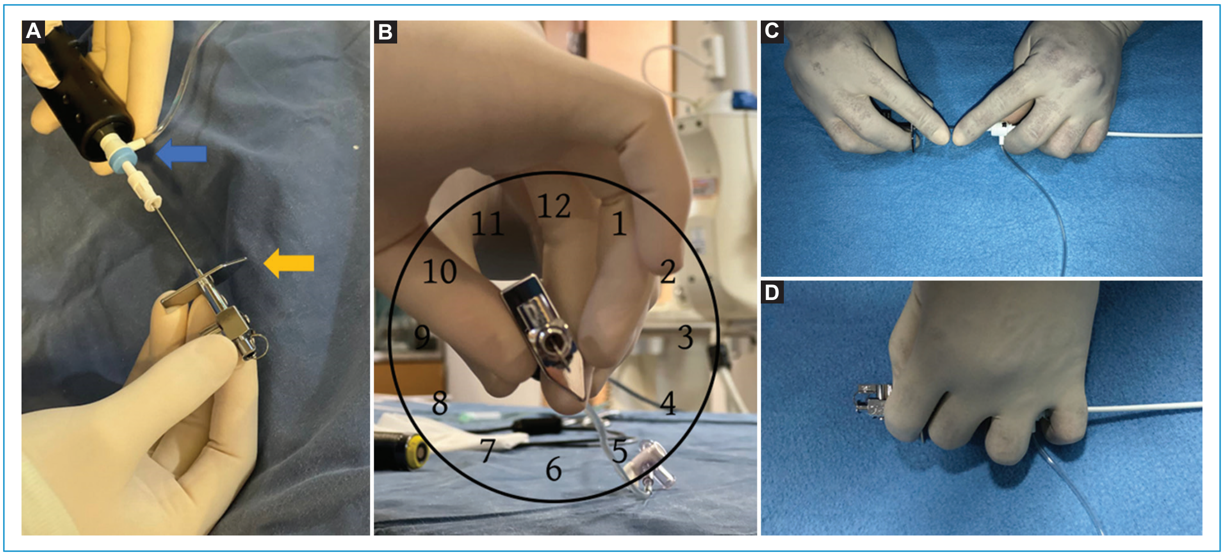

Figure 2. **A:** it is important to align the introducer and needle before starting to drop from the SVC toward the FO. To do this, the sheath irrigation port (blue arrow) should be aligned with the needle tip marker (yellow arrow). **B:** once the sheath and needle are aligned, they are positioned clockwise pointing toward 4 or 5 o'clock. **C:** hand position to ensure needle alignment with the introducer: using both hands, the transseptal sheath irrigation port is aligned with the needle marker. Keeping the index fingers together keeps the needle from accidentally protruding. **D:** when a single operator performs the TSP while handling the ICE probe, the right hand handles the probe while the left hand simultaneously manipulates the sheath (placing the port between the 4th and 5th fingers) and the needle (placing the marker between the 1st and 2nd fingers).

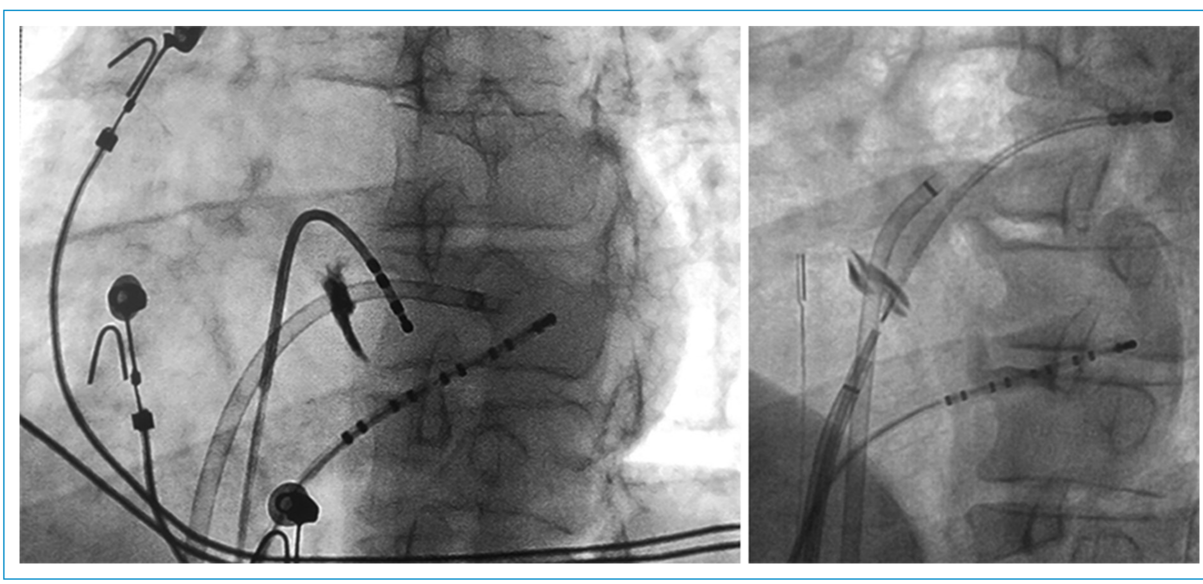

Figure 3. Examples of tattoos made in the FO, marking an appropriate puncture site. Note that, in the image on the left, the right ventricular catheter is not directly aimed at the observer, which indicates that the position is not parallel to the atrial septum. In this case, greater left angulation would be needed to be parallel.

procedures, most (both electrophysiologists as well as interventionists) use TEE, and few groups use ICE exclusively. Although there are reports of transcatheter aortic valve replacement and atrial septal defect closures using ICE[19,20], it is infrequently used worldwide.

For TSP, we believe that ICE is the better option. Compared with TEE, ICE offers images with the same

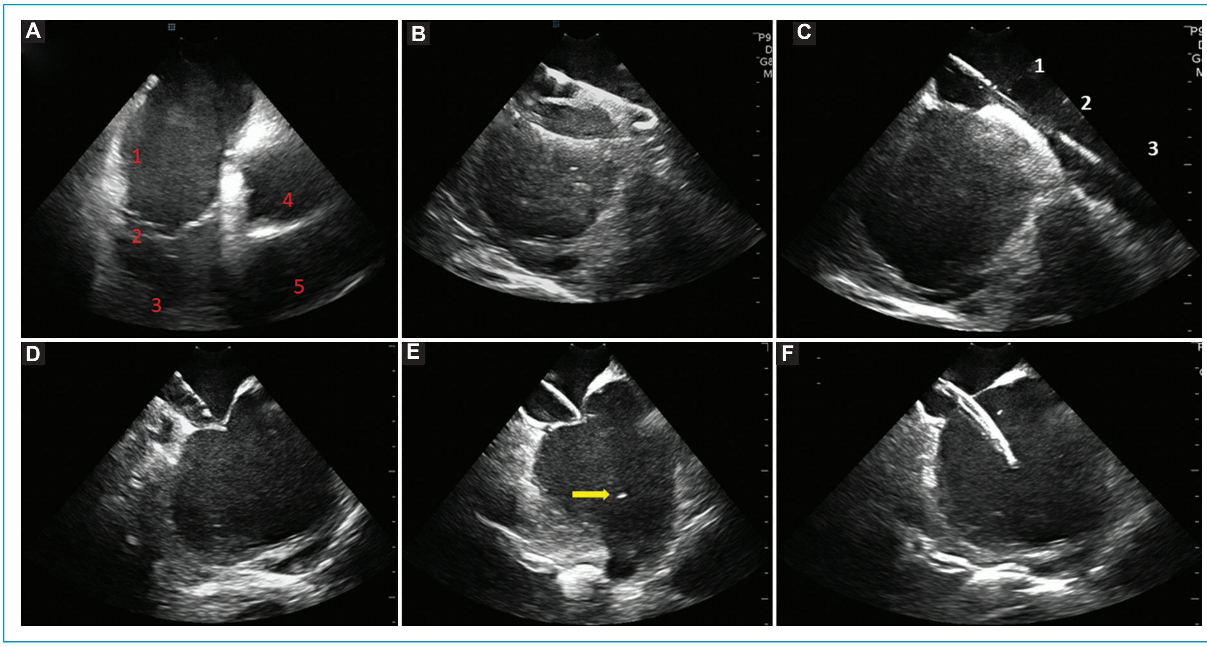

Figure 4. Sequence of images during ICE-guided transseptal puncture. **A:** right home view. The right atrium (1), tricuspid valve (2), right ventricular inflow tract (3), aorta (4) and right ventricular outflow tract (5) can be seen. **B:** image of the SVC with the guidewire inside it. **C:** advancement of the sheath (3) and dilator (2) over the guidewire (1) toward the SVC. **D:** picture of tenting over the interatrial septum. **E:** pasing the needle toward the left atrium, which is visible as a bright white point. **F:** passing the sheath through the septum.

or even better quality[21], does not require general anesthesia (which, in turn, reduces the patient's costs and risks), and decreases the number of people needed in the operating room. This last point is especially important, as its handling by the operator him/herself avoids the need for three or more people (an anesthesiologist, anesthesia assistant and echocardiographer) in the operating room. Having fewer people in the operating room is associated with a lower risk of infection[22] and fewer people exposed to ionizing radiation (which is especially high for the echocardiographer, due to the position he/she must occupy in relation to the source of radiation, and the need to have his/her hands within the radiation field).

Transseptal puncture guided by ICE and without fluoroscopy (Fig. 4)

By 2011, 50% of electrophysiologists were routinely using ICE in atrial fibrillation ablation procedures[23], accumulating extensive experience in handling this equipment over the years. Significantly, all the steps used to guide TSP with ICE can be performed without fluoroscopy[24], which has led to highly experienced laboratories conducting "fluoroless" TSP. However, the steps described below can be combined with reference fluoroscopy to facilitate TSP until enough confidence is gained with the sequence guided exclusively by ICE:

– Step 1: locate the ICE probe in the middle of the right atrium (RA), oriented toward the tricuspid valve. This is known as the "right home view" (to differentiate it from the "left home view," used in atrial appendage occlusion procedures with ICE); from this position, rotate the probe clockwise until the pulmonary veins are within the visual field.
– Step 2: using the probe handle, tilt it posteriorly until the superior vena cava (SVC) is visible. In some cases, it must be tilted a bit to the right to visualize the full length of the SVC. In this position, guidewire and transseptal sheath advancement toward the SVC can be easily seen.
– Step 3: slowly withdraw the sheath, watching how it slides from the VC toward the RA. As it nears the FO, the probe's right and posterior tilting is slowly removed. The anterior or posterior puncture site can be evaluated by rotating the probe clockwise or counterclockwise, respectively. For arrhythmia ablation procedures and atrial appendage occlusions, inferior punctures are preferred, but toward the center (in an anteroposterior direction) of the FO.
– Step 4: once in position, perform the puncture (the needle's position within the left atrium can be verified

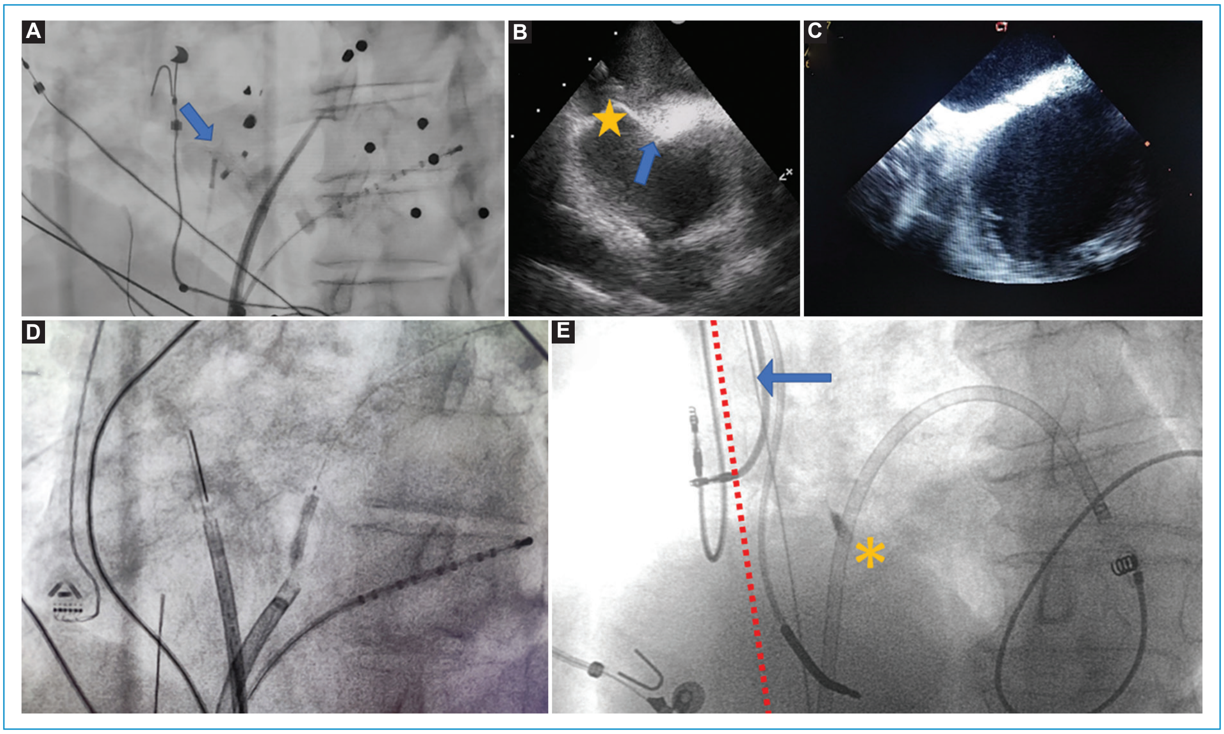

Figure 5. Special situations which entail method changes during TSP. **A:** in patients with atrial septal defect closure devices (blue arrow), a more inferior and posterior TSP is preferred. Although the puncture could also be done through the device, this risks trapping the catheter. **B:** in some patients, the distance between the inferior vena cava and the FO makes it difficult to tent at the desired site (yellow star), as when the sheath is pushed, it slides upward (blue arrow) instead of tenting. **C:** an example of a thickened interatrial septum. These septa may require the use of radiofrequency to facilitate needle passage. **D:** in patients with rigid/thick septa which do not allow the transseptal sheath to be passed, the hole may need to be dilated with (6 mm) peripheral angioplasty balloons; after this, the transseptal sheath is easily advanced. **E:** an example of the proper location of the guidewire in a patient with stimulation cables. The guidewire (blue arrow) should pass between the electrode path (marked in this case by the dotted line) and the interatrial septum, to keep the sheath from dislodging the cable when it falls into the FO. Note the tattoo at the FO from a previous puncture (yellow asterisk).

by injecting saline solution) and advance the entire system as already described.

Difficult scenarios and how to resolve them (Fig. 5)

Superior vena cava thromboses

In patients with SVC thromboses, the traditional technique of dragging the TSP system from the superior cava to where it falls into the FO is not possible. In this situation, it is preferable to use a "down-up" technique: using an electrophysiology catheter as a guide, the TSP sheath is advanced to the desired point in the FO. Once it is situated, the catheter is withdrawn and the dilator and (unexposed) puncture needle are advanced, without losing the sheath position in the FO. Great care must be taken when advancing the dilator outside of the sheath, so as not to lose the position. Once the tip of the dilator is in position over the FO, TSP is performed using the conventional technique.

The presence of atrial septal defect closure devices (Fig. 5A)

In patients with atrial septal defect closure devices there are two options: to puncture through the device or puncture below the device. As much as possible, puncturing through the device should be avoided, as there is a risk of the catheters being trapped[25], and punctures posterior and inferior to the device should be preferred. If the puncture is made through the device, the access should be sufficiently dilated (using balloons) to facilitate the movement of sheaths and catheters.

Difficulty in achieving proper tenting

In patients with severe RA dilation, the distance between the inferior vena cava and the atrial septum increases, making tenting difficult; when pushed, the sheath slides up without exerting enough pressure on the FO (Fig. 5B). In these cases, once the tip of the dilator is successfully positioned in an adequate puncture area, the needle is pushed before tenting. This allows the needle to act as an anchor and keep the sheath from sliding upward. If tenting is still not achieved, a 0.014” guidewire can be advanced by its rigid end to puncture the septum and function as an anchor before pushing the sheath to achieve tenting.

Elastic or rigid/thick septa

Patients with elastic septa have a higher risk of inadvertent atrial perforation, as the septum can move up to the posterior or lateral left atrial wall during tenting. In these cases, it is recommended that the puncture be done pointing toward the left veins (in order to have more room to move the septum) and always with ICE visualization. If the puncture cannot be accomplished with that maneuver, it is suggested that radiofrequency be applied to the needle (using an electrosurgical unit) to facilitate its passage.

In patients with stiff/thick septa, an electrosurgical unit can also be used to facilitate needle passage (Fig. 5C). Alternatively, a 0.014” guidewire can be advanced by its rigid end to facilitate septal puncture. Advancing sheaths in patients with this type of septum (especially deflectable sheaths that have a larger caliber compared with the dilator) may be difficult. In these cases, changing to a nondeflectable sheath may facilitate the transeptal passage. If this is not possible, the operator should be prepared to dilate the entry through the interatrial septum with a 6 mm peripheral angioplasty balloon (Fig. 5D).

The presence of cardiac stimulation device cables

Patients with cardiac stimulation device (CSD) cables, especially those implanted within the last year, have a higher risk of cable dislocation during TSP, as the sheath can become tangled with the cable as it slides down from the cava. This occurs more often with atrial devices, as they generally flow from the SVC toward the right appendage with a loop which is most often located at the FO. In these patients, it is important to ensure that the guidewire passes between the cable loop and the FO (Fig. 5E) to keep it from pulling on the loop and dislocating the cable when it falls toward the FO.

Transseptal puncture complications

Several factors increase the risk of complications during TSP, including the operator’s experience (< 45 TSPs per year), older patients, performing TSP without echocardiographic guidance, and failing the first TSP attempt[12]. Transseptal puncture complications can be fatal, and therefore should be detected and treated promptly.

Cardiac tamponade

Cardiac tamponade is the most feared complication during TSP, with a global incidence of 1.6%[12]. However, with echocardiographic guidance, this incidence reduces significantly, to as low as 0.2%[26]. In the event of tamponade, heparin reversal with protamine is recommended, along with percutaneous drainage. This is generally enough to stop most bleeds. If necessary, anticoagulant reversal with four-factor prothrombin complex concentrate (for patients on Xa inhibitors or warfarin; 50 IU/kg dose)[27] or idarucizumab (for patients on dabigatran)[28] can be considered. In most cases, this treatment may be enough to stop the bleeding without the need for surgical treatment[29], especially if the effusion was only caused by the transseptal needle.

Thrombus formation

It is easier to *prevent* thrombus formation than to treat a formed thrombus. When the heparin dose is delayed until after TSP, up to 10% of patients can have visible thrombi on the transseptal guidewires and sheaths[30-32]. Connecting the sheaths to a continuous flow of heparinized saline solution may also be useful, as it prevents thrombi from forming within the sheath lumen. In cases where a thrombus has already formed, vigorous aspiration through the sheath is recommended, attempting to capture the thrombus.

Inadvertent puncture of other structures

Puncture of the posterior right atrial wall is generally not serious as long as the dilator and sheath have not been advanced, as this is a low-pressure chamber. The procedure can usually be continued without complications, constantly monitoring the pericardial space. If the dilator and sheath have been advanced, they should not be withdrawn until pericardial drainage has been established and everything is ready for an emergency thoracotomy. If the puncture is done too anteriorly, there is a risk of puncturing the aorta. Most of these punctures connect the RA with the noncoronary cusp of the aorta or the sinotubular junction, and rarely with the ascending aorta[33]. The first two cases do not usually carry the risk of tamponade, while puncturing the ascending aorta does (as this implies passing through the pericardial space). If this occurs, whatever has been introduced into the aorta (needle, dilator or sheath) should not be withdrawn. An aortogram should be performed to determine the exact site of aortic penetration, the cardiovascular surgeon should be alerted, and the patient should be prepared for emergency pericardial drainage. Cusp or sinotubular junction punctures tend to heal completely with no intervention during follow up, even if the dilator was advanced. Although some cases have been described in which the defect in the ascending aorta was closed using ductus occlusion devices[34-36], this should only be attempted once the support of a cardiovascular surgeon has been obtained. It is worth noting that, in the largest series of inadvertent aorta puncture cases, echocardiographic guidance was not used for the punctures and the authors recognize that this complication could have been avoided by using it.

Conclusion

Transseptal puncture is a technique which has been increasingly used with the advances in complex arrhythmia ablation and the percutaneous management of cardiac conditions. Despite having considerable risks, these can be significantly reduced by using a proper technique, employing echocardiographic guidance and having an experienced operator. Mastery of intracardiac echocardiography makes this approach much easier and even allows procedures to be performed without fluoroscopy.

Funding

The authors declare that they have received no funding.

Conflicts of interest

The authors declare no conflicts of interest.

Ethical disclosures

Human and animal protection. The authors declare that no experiments were conducted on humans or animals for this study.

Data confidentiality. The authors declare that no patient data appear in this article.

Right to privacy and informed consent. The authors declare that no patient data appear in this article.

References

1. Cope C. Technique for transseptal catheterization of the left atrium; preliminary report. J Thorac Surg. 1959;37(4):482-6.
2. Ross J, Jr., Braunwald E, Morrow AG. Transseptal left atrial puncture; new technique for the measurement of left atrial pressure in man. Am J Cardiol. 1959;3(5):653-5.
3. Schoonmaker FW, Vijay NK, Jantz RD. Left atrial and ventricular transseptal catheterization review: losing skills? Cathet Cardiovasc Diagn. 1987;13(4):233-8.
4. Haïssaguerre M, Jaïs P, Shah DC, Takahashi A, Hocini M, Quiniou G, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med. 1998;339(10):659-66.
5. De Ponti R, Cappato R, Curnis A, Della Bella P, Padeletti L, Raviele A, et al. Trans-septal catheterization in the electrophysiology laboratory: data from a multicenter survey spanning 12 years. J Am Coll Cardiol. 2006;47(5):1037-42.
6. Holmes DR, Reddy VY, Turi ZG, Doshi SK, Sievert H, Buchbinder M, et al. Percutaneous closure of the left atrial appendage versus warfarin therapy for prevention of stroke in patients with atrial fibrillation: a randomised non-inferiority trial. Lancet. 2009;374(9689):534-42.
7. Herrmann HC, Rohatgi S, Wasserman HS, Block P, Gray W, Hamilton A, et al. Mitral valve hemodynamic effects of percutaneous edge-to-edge repair with the MitraClip device for mitral regurgitation. Catheter Cardiovasc Interv. 2006;68(6):821-8.
8. Coylewright M, Cabalka AK, Malouf JA, Geske JB, Pollak PM, Suri RM, et al. Percutaneous mitral valve replacement using a transvenous, transseptal approach: transvenous mitral valve replacement. JACC Cardiovasc Interv. 2015;8(6):850-7.
9. Reddy VY, Holmes D, Doshi SK, Neuzil P, Kar S. Safety of percutaneous left atrial appendage closure: results from the Watchman Left Atrial Appendage System for Embolic Protection in Patients with AF (PROTECT AF) clinical trial and the Continued Access Registry. Circulation. 2011;123(4):417-24.
10. Price MJ, Valderrábano M, Zimmerman S, Friedman DJ, Kar S, Curtis JP, et al. Periprocedural pericardial effusion complicating transcatheter left atrial appendage occlusion: a report from the NCDR LAAO Registry. Circ Cardiovasc Interv. 2022;15(5):e011718.
11. Quinn RW, Vesely MR, Dawood M, Benitez M, Holmes SD, Gammie JS. Transseptal puncture learning curve for transcatheter edge-to-edge mitral valve repair. Innovations (Phila). 2021;16(3):288-92.
12. Maclean E, Mahtani K, Roelas M, Vyas R, Butcher C, Ahluwalia N, et al. Transseptal puncture for left atrial ablation: Risk factors for cardiac tamponade and a proposed causative classification system. J Cardiovasc Electrophysiol. 2022;33(8):1747-55.
13. Calkins H, Hindricks G, Cappato R, Kim YH, Saad EB, Aguinaga L, et al. 2017 HRS/EHRA/ECAS/APHRS/SOLAECE expert consensus statement on catheter and surgical ablation of atrial fibrillation. Heart Rhythm. 2017; 14(10):e275-e444.
14. Romero J, Cerrud-Rodriguez RC, Diaz JC, Michaud GF, Taveras J, Alviz I, et al. Uninterrupted direct oral anticoagulants vs. uninterrupted vitamin K antagonists during catheter ablation of non-valvular atrial fibrillation: a systematic review and meta-analysis of randomized controlled trials. Europace. 2018;20(10):1612-20.
15. Latchamsetty R, Gautam S, Bhakta D, Chugh A, John RM, Epstein LM, et al. Management and outcomes of cardiac tamponade during atrial fibrillation ablation in the presence of therapeutic anticoagulation with warfarin. Heart Rhythm. 2011;8(6):805-8.
16. Rigatelli G, Dell'Avvocata F, Giordan M, Viceconte N, Osanna RA, Braggion G, et al. Usefulness of intracardiac echocardiography with a mechanical probe for catheter-based interventions: a 10-year prospective registry. Journal of Clinical Ultrasound: JCU. 2014;42(9): 534-43.
17. Fender EA, Sibley CT, Nazarian S, Cheng A, Spragg DD, Marine JE, et al. Atrial septal angulation varies widely in patients undergoing pulmonary vein isolation. J Invasive Cardiol. 2014;26(3):128-31.

18. Baran J, Sikorska A, Piotrowski R, Krynski T. Intracardiac echocardiography for immediate detection of intracardiac thrombus formation. Blood Coagul Fibrinolysis. 2015;26(8):959-60.
19. Bartel T, Bonaros N, Müller L, Friedrich G, Grimm M, Velik-Salchner C, et al. Intracardiac echocardiography: a new guiding tool for transcatheter aortic valve replacement. JASE. 2011;24(9):966-75.
20. Alqahtani F, Bhirud A, Aljohani S, Mills J, Kawsara A, Runkana A, et al. Intracardiac versus transesophageal echocardiography to guide transcatheter closure of interatrial communications: Nationwide trend and comparative analysis. Journal of Interventional Cardiology. 2017;30(3):234-41.
21. Anter E, Silverstein J, Tschabrunn CM, Shvilkin A, Haffajee CI, Zimetbaum PJ, et al. Comparison of intracardiac echocardiography and transesophageal echocardiography for imaging of the right and left atrial appendages. Heart Rhythm. 2014;11(11):1890-7.
22. Birgand G, Saliou P, Lucet JC. Influence of staff behavior on infectious risk in operating rooms: what is the evidence? Infection Control and Hospital Epidemiology. 2015;36(1):93-106.
23. Calkins H, Kuck KH, Cappato R, Brugada J, Camm AJ, Chen SA, et al. 2012 HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for patient selection, procedural techniques, patient management and follow-up, definitions, endpoints, and research trial design: a report of the Heart Rhythm Society (HRS) Task Force on Catheter and Surgical Ablation of Atrial Fibrillation. Developed in partnership with the European Heart Rhythm Association (EHRA), a registered branch of the European Society of Cardiology (ESC) and the European Cardiac Arrhythmia Society (ECAS); and in collaboration with the American College of Cardiology (ACC), American Heart Association (AHA), the Asia Pacific Heart Rhythm Society (APHRS), and the Society of Thoracic Surgeons (STS). Endorsed by the governing bodies of the American College of Cardiology Foundation, the American Heart Association, the European Cardiac Arrhythmia Society, the European Heart Rhythm Association, the Society of Thoracic Surgeons, the Asia Pacific Heart Rhythm Society, and the Heart Rhythm Society. Heart Rhythm. 2012;9(4):632-96.e21.
24. Razminia M, Willoughby MC, Demo H, Keshmiri H, Wang T, D'Silva OJ, et al. Fluoroless Catheter ablation of cardiac arrhythmias: a 5-year experience. Pacing Clin Electrophysiol. 2017;40(4):425-33.
25. Voong C, Lee E, Sohinki D. Entrapment of a spline from a multielectrode mapping catheter in the side hole of a nonsteerable guiding sheath, with dislodgement and subsequent suction retrieval of a proximal spline electrode. HeartRhythm Case Rep. 2022;8(7):475-8.
26. Žižek D, Antolič B, Prolič Kalinšek T, Štublar J, Kajdič N, Jelenc M, et al. Intracardiac echocardiography-guided transseptal puncture for fluoroless catheter ablation of left-sided tachycardias. JICE. 2021;61(3):595-602.
27. Eerenberg ES, Kamphuisen PW, Sijpkens MK, Meijers JC, Buller HR, Levi M. Reversal of rivaroxaban and dabigatran by prothrombin complex concentrate: a randomized, placebo-controlled, crossover study in healthy subjects. Circulation. 2011;124(14):1573-9.
28. Pollack CV, Jr., Reilly PA, van Ryn J, Eikelboom JW, Glund S, Bernstein RA, et al. Idarucizumab for dabigatran reversal-full cohort analysis. N Engl J Med. 2017;377(5):431-41.
29. Michowitz Y, Rahkovich M, Oral H, Zado ES, Tilz R, John S, et al. Effects of sex on the incidence of cardiac tamponade after catheter ablation of atrial fibrillation: results from a worldwide survey in 34 943 atrial fibrillation ablation procedures. Circ Arrhythm Electrophysiol. 2014;7(2):274-80.
30. Maleki K, Mohammadi R, Hart D, Cotiga D, Farhat N, Steinberg JS. Intracardiac ultrasound detection of thrombus on transseptal sheath: incidence, treatment, and prevention. J Cardiovasc Electrophysiol. 2005;16(6):561-5.
31. Pręgowski J, Kłapyta A, Chmielak Z, Skowroński J, Szymański P, Mintz GS, et al. Incidence, clinical correlates, timing, and consequences of acute thrombus formation in patients undergoing the MitraClip procedure. Kardiol Pol. 2020;78(1):45-50.
32. Ren JF, Marchlinski FE, Callans DJ. Left atrial thrombus associated with ablation for atrial fibrillation: identification with intracardiac echocardiography. J Am Coll Cardiol. 2004;43(10):1861-7.
33. Chen H, Fink T, Zhan X, Chen M, Eckardt L, Long D, et al. Inadvertent transseptal puncture into the aortic root: the narrow edge between luck and catastrophe in interventional cardiology. Europace. 2019;21(7):1106-15.
34. Schamroth Pravda N, Codner P, Vaknin Assa H, Hirsch R. Management of ascending aorta perforation during transseptal puncture for left atrial appendage closure: a case report. Eur Heart J Case Rep. 2021;5(4):ytab154.
35. Yu HP, Feng AN, Tsai SK, Hsiung MC, Yin WH. Transcatheter repair of iatrogenic aortic perforation complicating transseptal puncture for a catheter ablation of atrial arrhythmia. Acta Cardiol Sin. 2014;30(5):490-2.
36. Mijangos-Vázquez R, García-Montes JA, Zabal-Cerdeira C. Aortic iatrogenic perforation during transseptal puncture and successful occlusion with Amplatzer ductal occluder in a case of mitral paravalvular leak closure. Catheter Cardiovasc Interv. 2016;88(2):312-5.