Europace (2026) **28**, euag021
https://doi.org/10.1093/europace/euag021

EHRA DOCUMENT

Transseptal puncture in cardiovascular interventions: a clinical consensus statement of the European Heart Rhythm Association, the Heart Failure Association, the European Association of Percutaneous Cardiovascular Interventions, the European Association of Cardiovascular Imaging of the ESC, and the Association for European Paediatric and Congenital Cardiology

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The authors thank the EHRA Scientific Document Committee: Prof Katja Zeppenfeld, (Chairperson), Prof. Jens Cosedis Nielsen, (Co-Chairperson), Dr. Maria Frausing, Dr. Estelle Gandjbakhch, Prof. Isabelle C. van Gelder, Dr. Georgios Kollias, Prof. Michael Kühne, Prof. Radoslaw Lenarczyk, Assoc. Prof. Petr Peichl, Dr. Archana Rao, Dr. Avi Sabbag, Prof. Frederic Sacher, Dr. Michelle Samuel, and Dr. Hadrian Wijnmaalen

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Received 16 September 2025; accepted after revision 26 November 2025; online publish-ahead-of-print 29 May 2026

With the rapid increase in percutaneous left heart interventions, transseptal access to the left atrium has become a widely used procedure. This technique is crucial for electrophysiological procedures, particularly for atrial fibrillation ablation, which is estimated to be performed in more than 250 000 patients per year worldwide, as well as for various structural heart interventions, like percutaneous mitral valve repair. Although transseptal puncture (TSP) is generally considered a simple technique, it is associated with a small risk of potentially life-threatening complications. To ensure a successful and safe procedure, a thorough understanding of TSPs' clinical use, and the anatomy of the interatrial septum—including the fossa ovalis and its anatomical variants—is critical. Since the first fluoroscopy-guided TSP, advancements in echocardiographic imaging have enhanced the precision of the puncture, allowing targeting of specific regions of the fossa ovalis and facilitating difficult procedures. While most TSPs are performed using a Brockenbrough needle and a (steerable) sheath, wide variation in technique exists, and alternative methods have been developed initially aiming for complex cases but now routinely used. Understanding potential complications—such as cardiac tamponade, aortic puncture, and embolism—is essential for prevention, early recognition, and effective management, ultimately improving patients' outcomes. Finally, understanding how to approach specific complex scenarios is crucial for procedural success.

Keywords Transseptal puncture • Transseptal access • Atrial fibrillation • Catheter ablation • Percutaneous mitral valve intervention

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Abbreviations

ACT	activated clotting time
AF	atrial fibrillation
AP	accessory pathway
ASD	atrial septal defect
BRK	Brockenbrough
CMR	cardiac magnetic resonance
CT	computed tomography
ECMO	extracorporeal oxygenation membrane
EMS	electroanatomic mapping system
EP	electrophysiology
EPA	entrustable professional activities
HF	heart failure
IAS	interatrial septum
iASD	iatrogenic atrial septal defect
ICE	intracardiac echocardiogram
IVC	inferior vena cava
LA	left atrium
LAA	left atrial appendage
LAAC	left atrial appendage closure
LAO	left anterior oblique
LV	left ventricle
MR	mitral regurgitation
NOAC	Non-vitamin K antagonist oral anticoagulants
PFO	patent foramen ovale
PVI	pulmonary vein isolation
RA	right atrium
RAO	right anterior oblique
RF	radiofrequency
TOE	transoesophageal echocardiogram
TEER	transcatheter edge-to-edge repair
TSP	transseptal puncture
SVC	superior vena cava
VKA	Vitamin K antagonist

Introduction

As left heart catheter interventions are increasingly performed, transseptal puncture (TSP) has consequently become a widespread procedure.[1–6] TSP periprocedural imaging modalities, as well as new puncture techniques and technologies, have evolved, and new left atrial (LA) and left ventricular (LV) procedures requiring specific TSP sites have been introduced.

However, TSP carries a risk for potentially fatal complications and should be only performed while respecting procedure settings and caveats.[7]

This document does not represent a guideline but aims to serve as a practical overview to safe and efficient TSP in a variety of interventional procedures by including authors from all cardiovascular specializations involved in TSP. Furthermore, it shall direct operators in specific scenarios and is designed to advise management in the event of complications related to TSP.

The definitions of the category of advice and areas of uncertainty are provided in *Table 1*. Each statement listed in the table of advice has been discussed among the writing group members in an online meeting followed by separate online voting.

When to perform percutaneous transseptal left atrial access

Left heart electrophysiological mapping and ablation procedures (atrial and ventricular)

The principle catheter ablation strategy for atrial fibrillation (AF) aims for electrical isolation of the pulmonary left atrial veins (PVI).[8] In the 2024 ESC AF guidelines, PVI is highlighted as the mainstay of any AF ablation strategy, with suggested use of TSP in a wide variety of AF settings.[1,5]

Similarly, in the most recent ESC guidelines on SVTs, LA access is also indicated in other left atrial (non-AF) ablation procedures including left-sided accessory pathway (AP) ablation.[9] A 2018 meta-analysis found that left-sided AP ablation success using a transseptal route was significantly higher (98% vs. 94%); while the overall complication rate was comparable since

Table 1 Definition of categories of advice and areas of uncertainty

Definition	Categories of advice
Evidence or general agreement that a given measure is clinically useful and appropriate	Advice TO DO
Evidence or general agreement that a given measure may be clinically useful and appropriate	May be appropriate TO DO
Evidence or general agreement that a given measure is not appropriate or harmful	Advice NOT TO DO
No advice can be given because of lack of data or inconsistency of data. The topic is important to be addressed	Areas of uncertainty

more cardiac tamponades but fewer vascular access complications occurred in the TSP group.[10] In children, TSP is the preferred left-sided AP ablation access because of aortic and coronary damage risk and catheter-induced *trans*-aortic flow restriction.[10]

Endocardial LV ablation has been shown to be effective in LV arrhythmia management and is advised in many instances in the most recent ESC guidelines on ventricular arrhythmia management, mostly depending on the clinical setting.[4] Antegrade transseptal LV access might be preferred for certain LV locations, and, additionally, it allows for LV mapping/ablation with bulky catheters and simultaneous LV access with two catheters.[11–14] Moreover, in a recent randomized study, procedure-related cerebral lesions and vascular complications were reduced in the TS access group.[15]

Finally, the TS approach is preferred in aortic obstruction [e.g. after (mechanical) valve replacement] and with intraprocedural haemodynamic support (LVAD or Impella) to avoid device interference.[5,16–18]

Transseptal puncture in left atrial appendage closure procedures

According to the most recent ESC AF guidelines, interventional closure of the left atrial appendage (LAAC) may be considered in patients with AF and contraindications for long-term anticoagulant treatment to prevent ischaemic stroke and thromboembolism.[8]

Percutaneous mitral valve interventions

In heart failure (HF) patients with functional mitral regurgitation (MR) not eligible for surgery, transcatheter edge-to-edge repair (TEER) is advised according to the ESC/EACTS guidelines because it improves symptoms and outcomes.[19,20] TEER is also advised in primary MR in patients who are judged inoperable or at high surgical risk. Evolving TEER indications include MR in acute myocardial infarction, hypertrophic obstructive cardiomyopathy, and recurrent MR after surgical mitral repair.[21,22]

More recently, transseptal replacement is also performed in degenerated bioprosthesic valves (valve-in-valve) or rings (valve-in-ring) and there have been first trials to use this approach also in calcified native valves (valve-in-MAC), but this has not been approved yet.[23–25]

In symptomatic mitral stenosis and without unfavourable characteristics, a percutaneous mitral commissurotomy (PMC) through a TSP approach is advised. Following the ESC guidelines, the same is true for high-risk patients ineligible for surgery and for asymptomatic patients at high thromboembolic risk or with acute decompensation.[19,26]

Heart failure devices

In an HF setting, TSP is used for short-term circulatory support in cardiogenic shock.

In Tandem Heart procedures, LA-to-systemic arterial circulatory support with an inflow cannula transseptally reaching the LA, a centrifugal pump, and an outflow cannula in the femoral or axillary artery, is used.[27]

In selected patients, LA venting during veno-arterial extracorporeal membrane oxygenation (ECMO) to reduce intracardiac pressure, and LA balloon septostomy, creating an iatrogenic left-to-right shunt for LV decompression, is used.[28]

Rarely, a LA-veno-arterial ECMO is implanted for simultaneous drainage of the right atrium (RA) and LA.[28] In chronic HF, evidence for the clinical benefit of inter-atrial shunt devices is still evolving.[29,30]

When not to perform transseptal puncture or access to left atrium

The need for transseptal access should be carefully and thoroughly evaluated if there is a markedly increased risk for periprocedural thromboembolism or bleeding aiming at avoiding TSP. Regarding increased thromboembolic risk, any attempt to access the LA should be avoided in patients with recent onset intra-atrial/LAA thrombus. In selected patients with longer persistent thrombus, TSP might be performed if several consecutive imaging procedures, e.g. transoesophageal echocardiogram (TOE), over several months found—despite appropriate oral anticoagulation—a stable thrombus with a high probability of fibrous attachment to the LA/LAA wall; in two series from 2018 and 2020, implantation of a LAAC device in the presence of a chronic, distal LAA thrombus seemed to be safe; the role of cerebral protection systems in this situation is not (yet) clear.[31,32] Regarding the increased risk of bleeding, the need for TSP and LA access should be carefully evaluated and—unless utterly necessary—avoided when periprocedural anticoagulation is impossible due to the risk of (intra-cranial) haemorrhage. In conclusion, for patients at risk for bleeding, careful consideration of risks and benefits of the procedure should be performed on the individual patient's level.

Strength of evidence

Advised TO DO

For transseptal puncture, it is advised to follow recommendations for the indication of the respective planned procedure.

>90% agree

For all endocardial left-atrial interventional procedures, a transseptal route is advised.

>90% agree

May be appropriate TO DO

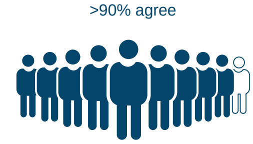
In left ventricular catheter ablation, a transseptal approach may be appropriate to reduce vascular, aortic damage, and (a)symptomatic cerebral lesions.

Advised NOT TO DO

Transseptal puncture and access should be avoided in new incident left atrial thrombus.

>90% agree

Transseptal puncture should be avoided in case of impossibility for peri-procedural anticoagulation (e.g. acute intra-cranial hemorrhage).



>90% agree

Anatomic considerations

Atrial septal anatomy and fossa ovalis

The interatrial septum (IAS) is formed by the septum primum and the septum secundum. Histologically, the septum primum is formed by fibrous and elastic tissue, that stems from the RA side and corresponds to the floor of the fossa ovalis. In contrast, the septum secundum is a muscular infolding of the atrial wall and surrounds the fossa ovalis.[33] The wall structure of the septum secundum consists of three layers that correspond to the muscular tissue of the RA and LA and in between the adipose tissue layer that can be differentiated with cardiac magnetic resonance.[34]

The fossa ovalis is, therefore, considered the true IAS. The superior and inferior landmarks of the IAS are the orifices of the superior and inferior vena cavae, respectively, while the anterior-inferior border is formed by the coronary sinus orifice and the anterior-superior border by the aortic non-coronary sinus. The anterior border is the hinge of the septal tricuspid valve leaflet, while the posterior border is formed by the limbus fossa ovalis, which is merely a raised muscular ridge stemming from the septum secundum'. (*Figure 1*) The size, shape, and location of the fossa ovalis are highly variable.[35]

Haemodynamics: physiology

During foetal development, the foramen ovale allows for right—to—left shunt on the atrial level to bypass the pulmonary circulation. After birth, with decreasing pulmonary vascular resistance and reversal of RA and LA pressure levels, this functional valve closes and normally precludes shunting of the oxygenated LA blood from left—to—right atrium. However, in 20–34% of adults, a patent foramen ovale (PFO) can be found, which is typically located superior-anteriorly, allowing only a very anterior entrance to the LA and may be in addition tunnel-shaped.[36] In contrast to PFO, a true atrial septal defect stems from a malformation of the septum secundum, and is in consequence located more inferiorly and posteriorly than a PFO. It can allow for haemodynamically relevant left—to—right interatrial shunting and is the second most common type of congenital heart disease.[37] In patients with either PFO or atrial septal defect, these interatrial communications may be used for LA access for left heart catheterization procedures, albeit hampering the free choice for the optimal puncture site (see paragraph on PFO and *Figure 2*).[38]

Variation of puncture site according to procedure

Puncture of the IAS through any part of the fossa ovalis has been considered sufficient for performing left-sided interventions. However, with emerging complex procedures, site-specific TSP has been proposed and can be facilitated by adjunctive use of TOE or intracardiac echocardiography (ICE). In *Figure 2*, the suggested sites for specific TSP locations are summarized.

In LA ablation procedures using large diameter steerable sheaths (usually with large single shot PVI catheters), a central and more inferior TSP is favoured to properly access the posteriorly and inferiorly located right inferior PV and achieve coaxial alignment of the ablation catheter with the long axis of the right inferior PV (*Figure 2*).[32]

In LV ablations, TSP should facilitate access to the anteriorly located mitral annulus. Therefore, anterior and inferior puncture sites are favoured.[39,40] In LAAC interventions, coaxial alignment of the delivery sheath with the LAA long axis is key for proper device implantation and coaxial device-LAA alignment is achieved in conventional anatomies with a posterior and inferior TSP (*Figure 2*).[41] However, in case of reverse chicken wings anatomy, a slightly more anterior puncture is advisable to address the orientation of the LAA ostium. Finally, TSP should be

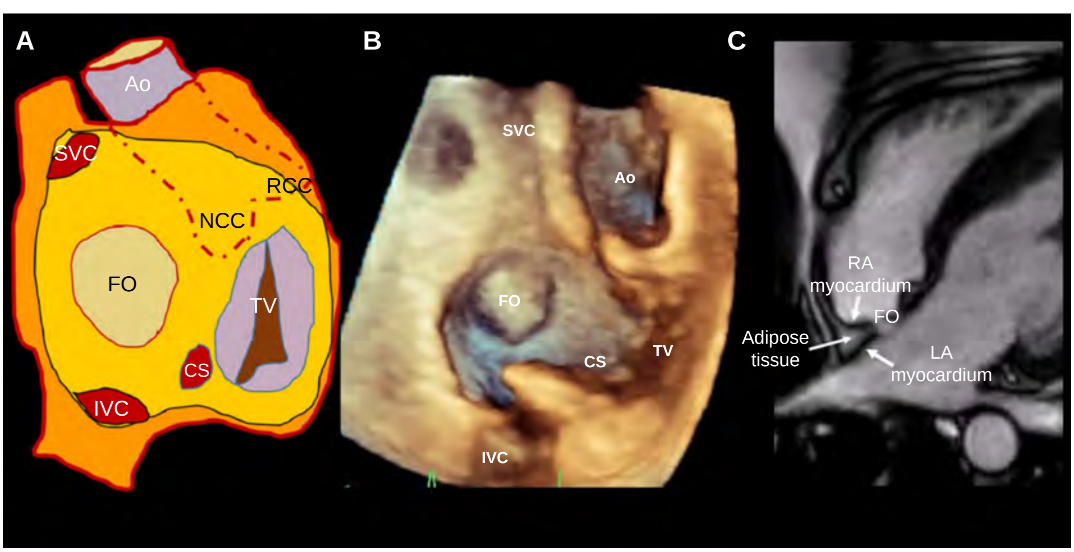


Figure 1 Anatomy of the interatrial septum as assessed with transoesophageal echocardiography and cardiac magnetic resonance. (*A*) The schematic view of the right atrial side of the interatrial septum and fossa ovalis with the main anatomical landmarks. On transoesophageal echocardiography, the same structures can be identified (*B*). The three-layered composition of the septum secundum can be visualized on cardiac magnetic resonance (*C*). Ao, aorta; CS, coronary sinus; FO, fossa ovalis; IVC, inferior vena cava; LA, left atrium; NCC, non-coronary cusp; RCC, right coronary cusp; TV, tricuspid valve.

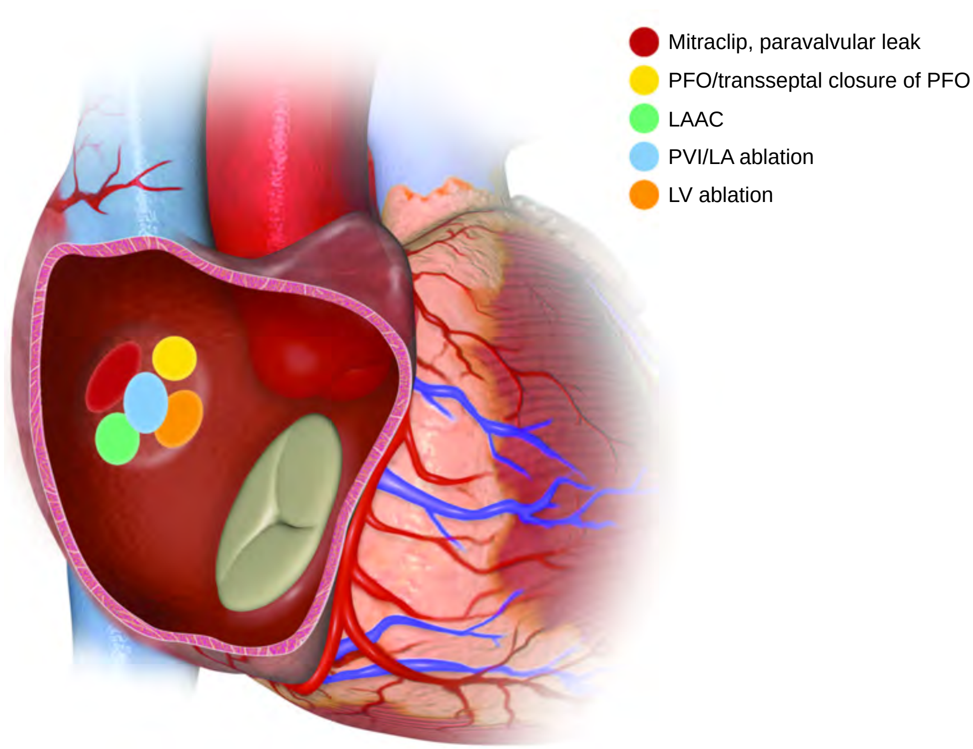


Figure 2 Site specific TSP—optimal locations per procedure. Suggested TSP site according to the planned transseptal procedure. In mitral valve interventions (red), the TSP should be placed more posteriorly and depending on the specific anatomy more superior or mid-height. PFOs are typically located superior and slightly anterior, and this is also where they can be closed (yellow). For LAAC, the TSP should be directed more posterior-inferior (green). LA access for PVI/left atrial ablation is directed more centrally (blue), whereas for left ventricular ablation, a more anterior inferior-to-mid-height location is preferable.

performed posterior for transcatheter mitral edge-to-edge repair, while a more superior or inferior approach is tailored to the specific anatomy (*Figure 2*).[42]

Anatomical variants: implications for transseptal puncture

Anatomical variants in the structure of the IAS and/or the venous system may pose challenges to perform TSP and might impede procedural efficacy and safety. Additionally, anatomic deformations of the thorax/rib cage and/or spine might also add to TSP complexity.[43]

Patent foramen ovale

As mentioned above, PFO, resulting from incomplete membrane fusion and is present in almost one-fourth of the population.[44] Its size varies significantly, with an average diameter of 5 mm.[44,45] While its presence allows access to the LA without TSP, the cranial and anterior location of the PFO may hinder catheter manoeuvrability especially in the caudal parts of the LA.[38] Due to these caveats, physicians often opt for TSP, even in the presence of a PFO.

Atrial septal aneurysm

An atrial septal aneurysm is a saccular deformity of the IAS that protrudes into the RA and/or the LA. Despite variations in the proposed cutoffs, a length of protrusion >10 mm beyond the plane of the atrial septum is the most accepted definition[46] and it can be classified according to a predominantly RA or LA protruding.[47] The aneurysmal septum results in lateral displacement of the sheath-needle assembly during TSP, limiting the remaining space to the lateral wall of the LA (*Figure 3B*). The aforementioned caveat increases the risk of inadvertent lateral wall puncture and perforation by the transseptal cutting needle. Blunt (RF) needles or a guidewire device may avoid such a risk

Lipomatous atrial septal hypertrophy and double atrial septum

Lipomatous atrial septal hypertrophy is characterized by a benign infiltration of the IAS, sparing the central area of the fossa ovalis.[48] This results in a distinctive dumbbell shape of the IAS, with thickened peripheral edges and a narrowed central portion (*Figure 3A*). During TSP, the narrow central region should be targeted. Puncturing the thicker portion should be avoided due to extreme difficulties in advancing the transseptal sheath and the risk of intramural haematomas or perforation; pre-procedural imaging has been reported to facilitate optimal puncture site identification.[37,48] In double atrial septum, where a doublure of the septal membranes is present, TSP should be performed under intra-procedural TOE or ICE guidance; the TSP proceedings can be employed—despite the unusual anatomic aspect—as usual.[49]

Inferior vena cava interruption

The inferior vena cava (IVC) comprises of sequential segments (hepatic, suprarenal, renal and infrarenal) formed by the regression of embryological veins. Defects in embryologic

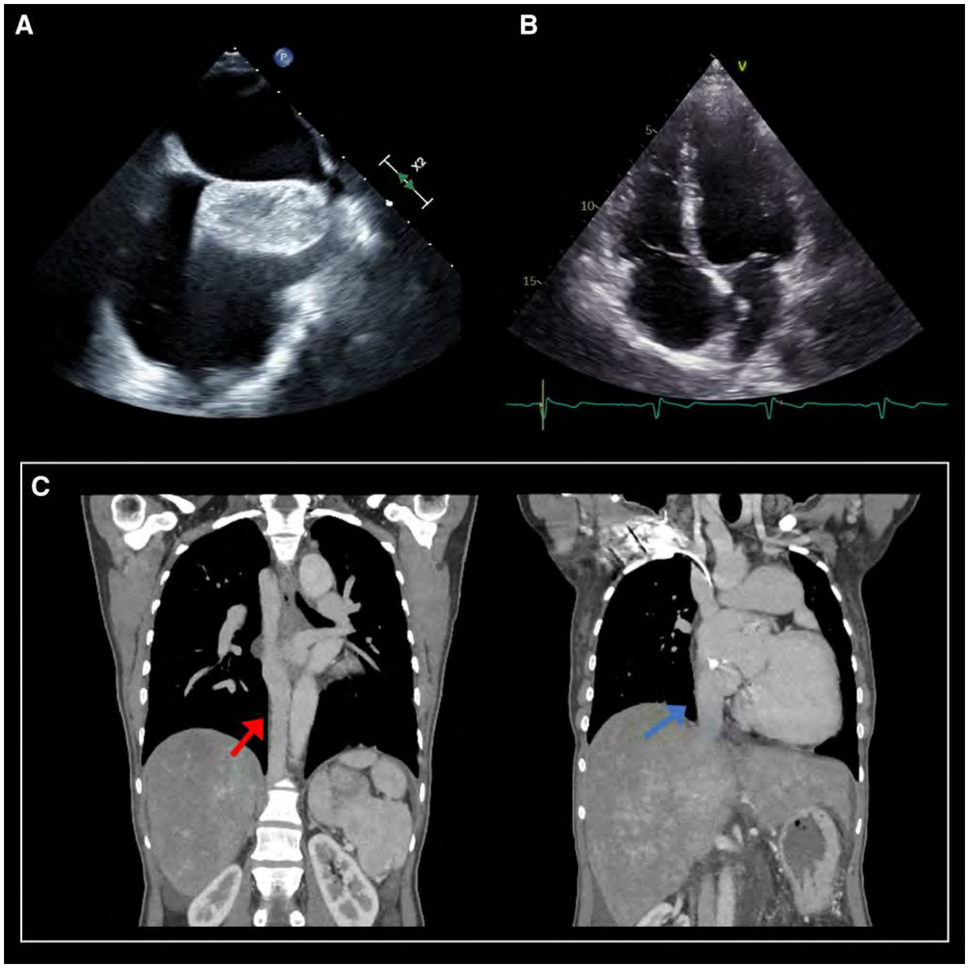


Figure 3 Anatomical variants affecting TSP. (*A*) Lipomatous atrial septal hypertrophy. (*B*) Aneurysmatic atrial septum. (*C*) Infrahepatic IVC interruption with azygos continuation. The red arrow indicates the azygos vein (left panel) while the blue arrow indicates the hepatic veins draining directly in the right atrium (right panel).

development or intrauterine/perinatal thrombosis can disrupt normal IVC formation, leading to anomalies that hinder inferior access to the RA (*Figure 3C*). The most frequent IVC anomaly is azygos continuation of IVC, with a prevalence ranging from 0.6%.[50,51] This vascular abnormality results from the interruption of the suprarenal/infra-hepatic segment of the IVC. Venous drainage is redirected through the azygos vein, while hepatic venous flow is maintained via the hepatic portion of the IVC. Thus, direct access to the RA and the IAS from the femoral approach is not possible. As mentioned later (see chapter on 'specific scenarios'), possible solutions include a transhepatic approach or access via a superior route through the internal jugular vein.[52]

Dextrocardia

In dextrocardia, the heart's longitudinal axis is oriented to the right, due to abnormal cardiac looping of the embryonic heart tube (d-looping or l-looping errors) during early cardiogenesis. No matter if it occurs in association with situs solitus, situs in vs., or situs ambiguous (heterotaxy), the anatomy of the IAS and more specifically the fossa ovalis is in principle preserved. Various approaches of compensating for the axis deviation during TSP have been described, with the most common method suggesting a kind of 'mirroring' while taking the usual anatomical landmarks for TSP.[53,54]

Overview of the procedure

Preprocedural imaging

When transseptal access is planned, imaging can provide crucial information both pre- and intra-procedurally. Before any intracardiac procedure, a recent transthoracic echocardiogram (TTE) should be available to exclude major cardiac abnormalities (e.g. ventricular thrombus, low LVEF, major valvular disease, or a dilated CS suggesting a persistent left superior vena cava). Additionally, contrast echocardiography with intravenous agitated saline may be used to detect pre-existent intracardiac shunt and, specifically, a PFO. More detailed information can be depicted by cardiac computed tomography (CT) or CMR, which can help to identify anatomical hurdles to access the RA (e.g. azygos continuation) or at the septum (e.g. hypertrophic or aneurysmatic septum), or an anomalous position of the heart in the thorax (e.g. clockwise rotation, hemidiaphragm elevation).[39,55,56] This information can then be used to plan optimal intraprocedural imaging for guiding the TSP in advance. As pointed out in the recent ESC AF management guidelines, preprocedural imaging should be considered to rule out intracardiac thrombi prior to TSP in high-risk patients (high CHADS-VA Score, persistent AF, hypertrophic cardiomyopathy, amyloidosis).[1]

Intra-procedurally, in addition to the fluoroscopic approach (optimally supported by pressure recordings, dye injection or wire insertion into the LA/PVs), echocardiography—either TOE or ICE—can be used to guide the TSP, assisting in the visualization of the IAS, the manipulation of the sheath and needle to the optimal site for puncture, and, finally, the advancement into the LA.[2,39,56,57]

Periprocedural anticoagulation in atrial fibrillation ablation

In patients undergoing catheter ablation of AF who are on Vitamin K antagonist (VKA), evidence from observational studies and randomized trial data suggest that optimal periprocedural efficacy and safety are achieved with uninterrupted VKA.[2] Patients undergoing RF catheter ablation of AF who have subtherapeutic INRs or interrupted VKA are at higher risk of silent cerebral ischaemic events on brain magnetic resonance imaging after the procedure.[58] Complete peri-procedural interruption of NOAC therapy is associated with an increased risk of thromboembolic events, and it is not a recommended regimen.[1,2,8,52] The last ACC/AHA/ACCP/HRS guidelines for the diagnosis and management of AF, the current ESC AF guideline and the EHRA consensus document on AF ablation recommend that AF catheter ablation in patients on VKA should be performed on uninterrupted therapeutic anticoagulation with a goal INR of 2.0 to 3.0 and in patients on a NOAC who are undergoing catheter ablation of AF, catheter ablation should be performed with either continuous or minimally interrupted oral anticoagulation.[1,2,59]

Intraprocedural anticoagulation during catheter ablation

Periprocedural anticoagulation during TSP with unfractionated heparin (UFH) is critical to reduce the risk of thrombotic complications. In AF ablation, it may be appropriate to administer UFH prior to TSP and to target further on throughout the procedure an ACT value >300 s.[2,60]

Venous access, advancing sheath, and needle

The right-side venous femoral access is usually preferred, but both groins should be prepared in case of unfavourable right venous anatomy or venous occlusion (e.g. after surgery in congenital heart disease).

Anticipated inaccessibility of IVC should favour in experienced centres a jugular or subclavian venous access, possibly with deflectable sheaths to engage the fossa ovalis.[61]

Since ultrasound-guided cannulation has been proven to reduce risks of major and minor vascular complications, it is now the advised access technique.[2,62,63] The needle should be inserted at a 30–45° angle to the skin plane and remain coaxial with the vein to minimize the risk of inadvertent arterial puncture. The safe distance from the artery should ideally be assessed using ultrasound or, in alternative, palpation (*Figure 4*).

Following venous puncture, a wire is advanced and should follow the right border of the vertebral column without resistance. Lancet is usually slid over the wire to allow a smooth sheath introduction, and a 7–11F short sheath is introduced to prepare the exchange for the long wire/long transseptal sheath. Alternatively, a long 0.032-inch guide wire can be introduced over the needle to allow for direct introduction of the long transseptal sheath.[64] In people with pacemaker/internal cardioverter defibrillator, the wire should be advanced posteriorly and septally to the leads to avoid lead displacement. Over the wire, the (long) transseptal sheath is advanced through the IVC and the RA to the SVC.

Fluoroscopic anatomical landmarks during TSP comprise (i) the heart silhouette in AP (RA is right lateral, LA is the superior left boundary) and LAO (the LA forms the most left lateral aspect) (*Figure 5*); (ii) the aortic root, which can be visualized by a wire or a pig-tail after arterial puncture; alternatively, a catheter close to the His-region will mark the inferior (RA) boundary of the aortic root; and (iii) the coronary sinus (marked with a diagnostic catheter), with the appropriate direction for safe TSP generally in the middle between the coronary sinus course and the spine in RAO view. TS sheaths and dilators should be carefully flushed to prevent air bubbles. After advancing the sheath to

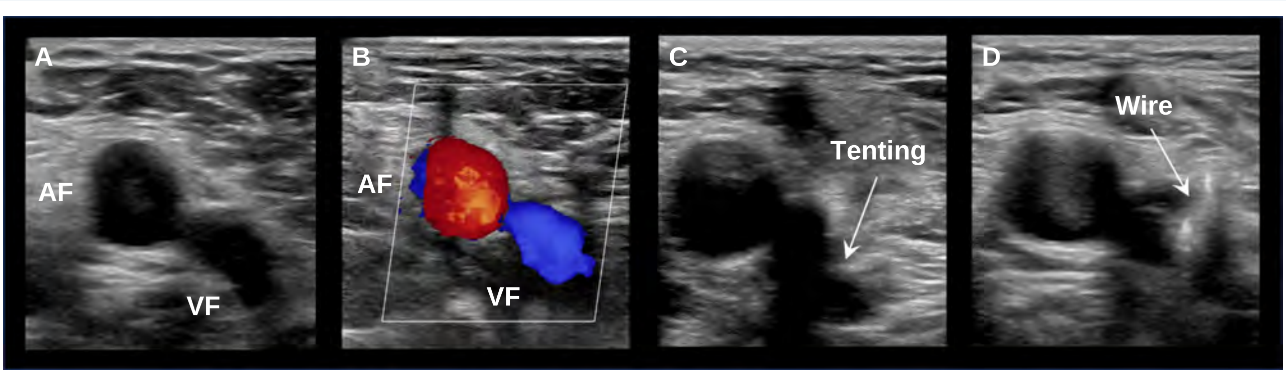


Figure 4 Ultrasound-guided femoral venous access. *A*: 2D ultrasound short-axis view showing the femoral artery located lateral to the femoral vein. *B*: Colour-doppler short axis view showing the femoral artery (red, lateral) and femoral vein (blue, medial). *C*: Tenting of the needle in the femoral vein. *D*: The wire has been introduced through the needle into the femoral vein. AF: femoral artery, VF: femoral vein.

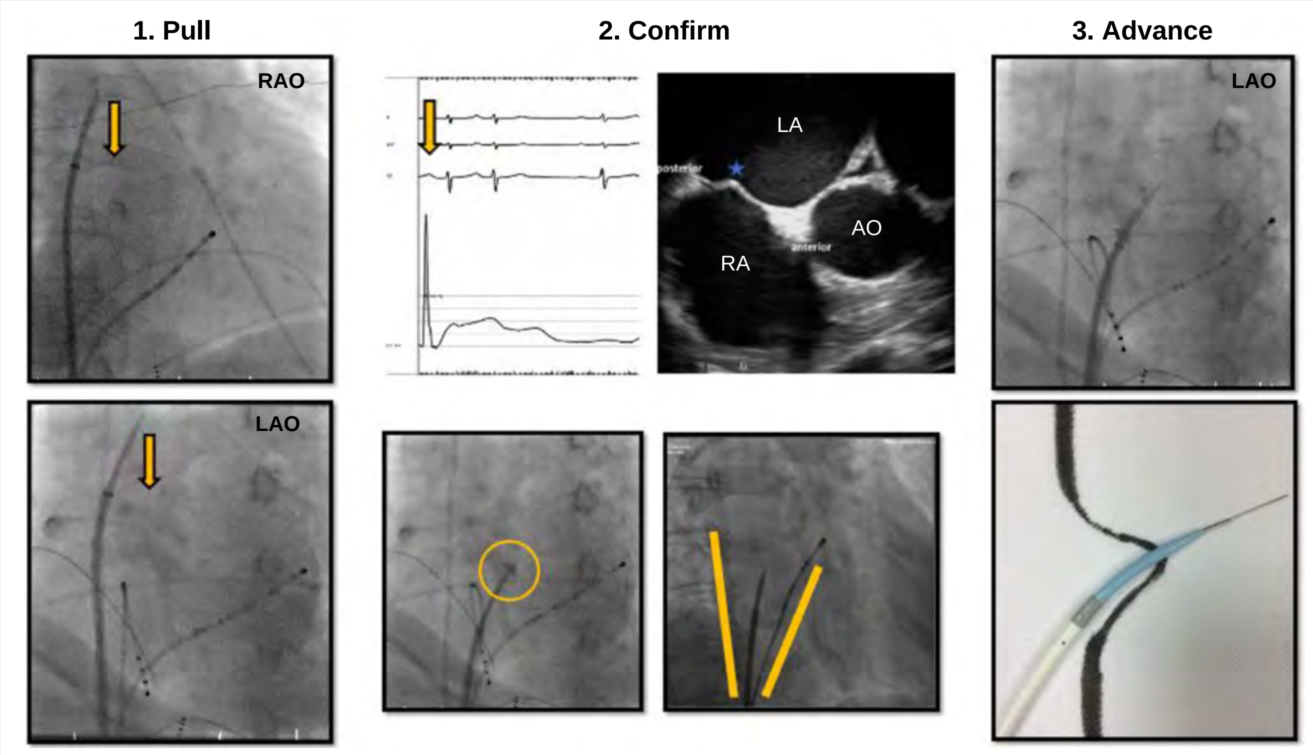


Figure 5 Steps in TSP. TSP in three steps. **Step 1 *Pull*** the sheath with the needle inside (pointing towards 4–6 o'clock) into the fossa ovalis. **Step 2 *Confirm*** the optimal position with multiple options: pressure recording at the needle tip, TOE visualization, contrast dye injection in the septum and/or after passing the septum by evaluating the fluoroscopic orientation (in RAO, the puncture site should be in the middle between the axis of the CS and the spine). **Step 3 *Advance*** the needle, the dilator and the sheath in the LA.

the SVC with the side infusion port oriented at 4 o'clock, the wire is pulled back; aspiration and flushing with saline are performed to remove any air bubbles from the dilator. The needle is advanced until 2 cm from the dilator orifice, with the arrow-like handle oriented (in conventional anatomies) at 4–5:30 o'clock. For needle advancement, a stylet may be introduced into the needle to avoid scraping of the inner sheath lumen; the stylet is then removed after reaching the tip of the sheath.[65] The needle should be advanced through the sheath carefully to accommodate the pathway to the vascular tortuosity. For increased safety, it may be appropriate to connect the needle to a pressure gauge to obtain pressure waveforms (*Figure 5*).

With the needle/sheath curve, a controlled pressure is applied towards the medial part of the SVC/cranial RA. In some instances, adding a proximal curvature to the needle (about 10 cm from the tip) is needed to obtain further-on a good needle-to-septum contact.

Optimal transseptal puncture site confirmation

To ensure an optimal TSP site, which is important for optimal manoeuvrability of the respective device, intraprocedural imaging with TOE, ICE, and fluoroscopy is used. In fluoroscopy, at least two different views should be used, most commonly LAO (to control the height of the TSP) and RAO (for anterior-posterior alignment) (*Figure 5*). On TOE, the bicaval view (90° to 110°) visualizes the superior-inferior axis of the atrial septum. Orthogonal short-axis view (30° to 45°) provides visualization of the anterior-posterior axis.[56] The sheath-needle assembly is withdrawn from the SVC under echocardiographic/fluoroscopic monitoring until it falls into the fossa ovalis, typically with a distinctive 'jump' on Xray. While withdrawing the 'needle-sheath assembly' it is important to keep the fixed relationship between sheath and needle. On TOE view, once sheath tenting of the fossa is achieved, the optimal position can be checked on the short axis: as mentioned above, it should be central and inferior for most LA ablation procedures, posterior-inferior for LAAC, a little bit anterior and inferior for left ventricular ablation, and posterior-high in most patients undergoing mitral interventions to achieve enough working distance between the TSP site and the mitral annular level (see also *Figure 2*).[39] In TEER procedures, the TOE should now be switched to the four-chamber view, and the puncture height (the distance between the tenting and the mitral annulus) should be measured.

Sheath advancement into the left atrium

Then, the needle is pushed out of the sheath dilator across the septum. The sheath should not be advanced over the needle until the correct position has been confirmed by either TOE/ICE, blood aspiration, pressure curve, or contrast injection through the needle or a combination of these modalities (*Figure 5*).[39]

Once correct LA access has been confirmed, both the transseptal sheath and the needle should be advanced (under TOE/ICE guidance or using fluoroscopy) until 1 to 2 cm is in the LA. Then, holding the needle, the sheath is advanced over the needle. Finally, the needle and the dilator are kept steady, and the sheath is advanced over the dilator. When the tip of the sheath is close to the edge of the heart shadow, but still with a distance of 1–2 cm, the needle and, eventually, the dilator can be slowly retrieved. After that, a 0.032-inch guidewire can be placed into the left superior PV with slight sheath clockwise rotation (the TOE four-chamber view is useful to confirm that the guidewire is not in the appendage).[26,66] Alternatively, after LA access with the dilator, the needle is slowly withdrawn and replaced by a long wire placed in the left superior PV and the sheath is advanced over the wire. During TSP and throughout the procedure, TOE/ICE can be used for pericardial effusion monitoring.

Strategy of anticoagulation therapy post catheter ablation for left atrial tachyarrhythmia

Immediately after the ablation procedure, a transthoracic echo should be performed to rule out pericardial effusion. For access site management, compression, Z- or purse-string suture, and venous vascular closure devices are currently used, with the latter two expediting haemostasis without increasing vascular or thromboembolic complication rates.[67–69] The role of antagonizing unfractionated heparin with protamine to achieve swifter haemostasis is still under debate. In AF ablation procedures, two randomized trials and a meta-analysis found that protamine administration shortened time to haemostasis by approximately 3 h without leading to an increase in vascular or thromboembolic complications, while adverse effects (mainly profound hypotension) were observed in 1.2% of patients.[2,67–69]

The risk of thromboembolic and stroke events increases after the ablation procedure due to vascular and cardiac instrumentation, release of tissue factor, and myocardial injury. Anticoagulation should be continued for at least two months after ablation, irrespective of stroke risk or rhythm status.[1,2,70] Immediately post-procedure, if a patient was on a NOAC, most operators would restart the medication three to five hours after sheath removal. If a patient was on VKA and the procedure was performed on therapeutic INR (uninterrupted strategy), a VKA dose can be given at the usual time of night.[1]

Strength of evidence

Advised TO DO

Before TSP, it is advised that cardiac imaging, at least a TTE, is performed to rule out major anatomic variants preventing safe and/or successful TSP. — >90% agree

In anticoagulated patients undergoing AF ablation, it is advised to perform TSP under uninterrupted OAC with VKA; DOAC can be used uninterrupted or with omitting the preprocedural dose.

It is advised that vascular access is established under ultrasound-guidance to reduce vascular complications.

Continued

Continued

Strength of evidence

It is advised that TSP is performed with intraprocedural imaging (fluoroscopy and/or TEE or ICE). — >90% agree

It is advised that in fluoroscopy-based TSP, access to the left atrium is confirmed by blood aspiration, pressure monitoring, dye injection, guide wire insertion, or a combination of these modalities. — >90% agree

Administration of heparin during AF ablation procedures to maintain an ACT level of at least 300 s is advised.

May be appropriate TO DO

Heparin administration prior to TSP may be appropriate to prevent thromboembolism.

Materials

Puncture of the IAS has traditionally been accomplished by extending a sharp needle beyond the tip of a sheath and dilator assembly positioned against the fossa ovalis. Additional tools have since been introduced to improve this approach.[71] This section will provide an overview of the range of equipment options that are currently available for transseptal access.

The traditional TSP kit consists of a long pre-shaped plastic sheath, an introducer, and a needle. The lumen through the centre of the needle allows for pressure monitoring and delivery of contrast. A variety of sheaths with different distal curvatures may be used for this purpose, but care must be taken to ensure the needle, dilator, and sheath are all compatible and licensed for use together.

The Brockenbrough (BRK) needle is the usual device for TSP. Its design is based on the original Ross needle, in which the distal 1.5 cm tip diameter has been reduced from 21 to 18 gauge.[39] The BRK needle is made of stainless steel and has a stylet inside the lumen to prevent friction while advancing it into the sheath. The standard BRK has a 19° angle between the distal curved part and the needle shaft, whereas the BRK 1 is characterized by a 53° angle curvature. Nevertheless, the needle curve can be re-shaped by the operator to better fit with the anatomy.

The needles' lengths range from 56 to 98 cm. The standard length of 71 cm accompanies standard 63 cm non-steerable sheaths, and 98 and 89 cm BRK needles are commonly used to accompany 71 and 61 cm steerable sheaths (e.g. Agilis sheath™ Abbott; CARTO VIZIGO™, Johnson&Johnson MedTech), respectively. (*Figure 6*). As with any needle designed to puncture the atrial septum with mechanical force, sharpness is critical for the needle to be effective. The XS ('Extra sharp') BRK series features smaller bevel angles (30°) compared to the standard BRK series, which has a 50° bevel angle. Furthermore, while the bevel

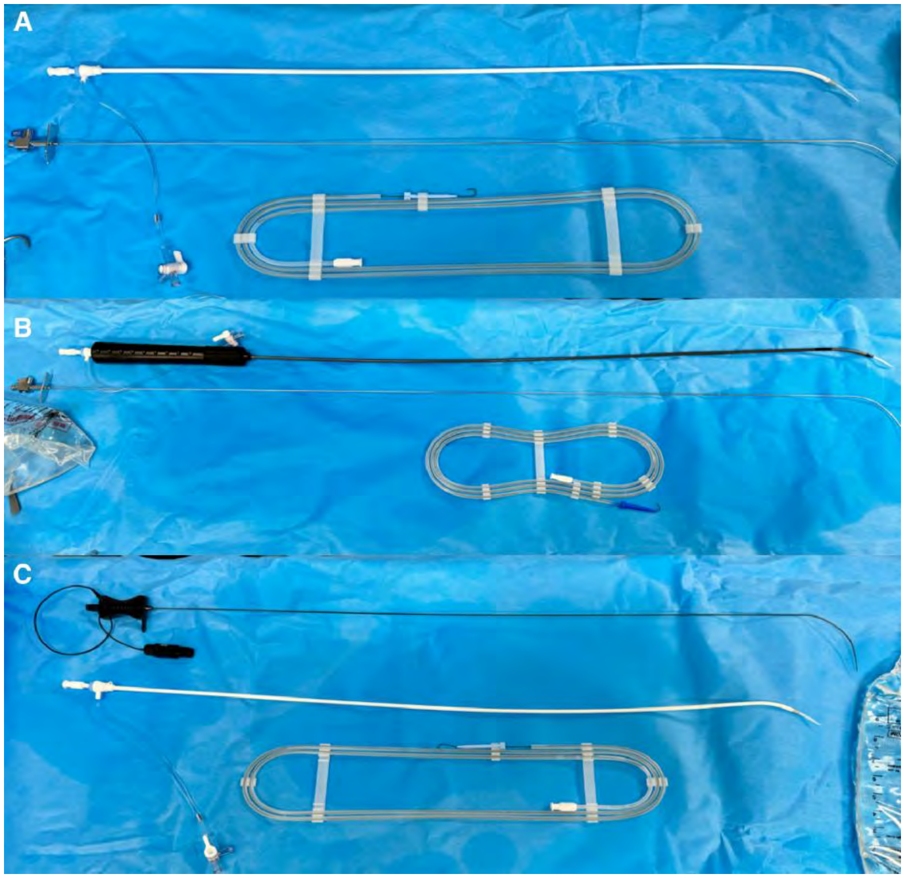


Figure 6 Commonly used transseptal sheath, dilator and needle sets. *(A)* Non-steerable LAMP 45® sheath with 71 cm BRK-1 needle. *(B)* 71 cm steerable Agilis® sheath with 98 cm BRK-1 needle. *(C)* Non-steerable LAMP 45® sheath with 71 cm NRG-1® radiofrequency needle.

of the BRK is oriented in the same direction as the curve of the needle, the XS BRK bevel is oriented opposite to the needle curve. This makes the XS a sharper needle, designed to facilitate puncture through the septum with less force. (*Figures 7A* and *B*).

In case of thick or aneurysmal IAS, puncture may not be achievable with BRK needles alone, and alternative options might be needed. In diathermy-assisted puncture, a dispersive electrode is placed on the lateral side of the thigh or leg and radiofrequency is applied to the proximal part of the needle by an electrosurgical cautery generator.[72] Electric current is then concentrated at the tip of the needle, creating heat and vaporizing the tissue to allow tissue penetration. The diathermy generator is set at 30–70 watts in pure cut mode.[73] Echocardiographic guidance (TOE/ICE) is mandatory to visualize the BRK tip progression and the microbubbles (created by tissue vaporization) in the LA indicating a successful puncture. It is important to emphasize that standard electrocautery generators are not validated for such an approach. Energy may be applied too long or at high output, leading to thermal tissue trauma, coring of the septum or char formation.[74] For these reasons, custom-built RF kits and generators have been designed and tested for optimal use.

A custom-made needle designed for RF perforation of the IAS is the NRG needle (Baylis Medical).[65] It has a preformed curve C-1 (analogous to BRK-1) and is available in two lengths (71-cm or 98-cm), with a diameter of 18 gauge proximally and 21 gauge distally. Its distal tip is an uninsulated electrode designed for RF energy transmission, while the rest of the needle is fully uninsulated (*Figure 7C*). It is attached to the RFP 100–115 RF Puncture Generator (Baylis Medical), which is connected to a grounding pad placed over the left thigh. The generator is usually set to an output power of 10 W for 2 s and produces continuous monopolar RF power output at a fixed frequency of 500 kHz.

The SafeSept™ guidewire (Pressure products) is a nitinol wire with a sharp distal tip and a preformed J shape, designed to penetrate the IAS with less mechanical force (*Figure 7E*). The wire can be advanced, straightened, through the TSP needle until it reaches the tip of the dilator. Once the TSP sheath is tenting at the correct location in the fossa ovalis, the wire can be advanced to perforate the IAS. Once in the LA, and no longer supported by the needle and dilator, the wire immediately bends back to recover its origin J shape, making it atraumatic. By placing the wire in the direction of the LSPV, the rest of the assembly can be advanced over the wire into the LA, reducing the risk of LA perforation.[75]

A wire-based RF system (VersaCross™) has recently been shown to further decrease procedure time and potentially enhance safety.[76] This technique uses a single wire to position the transseptal assembly within the SVC, to puncture the fossa ovalis with RF energy, and to then lead the sheath and dilator

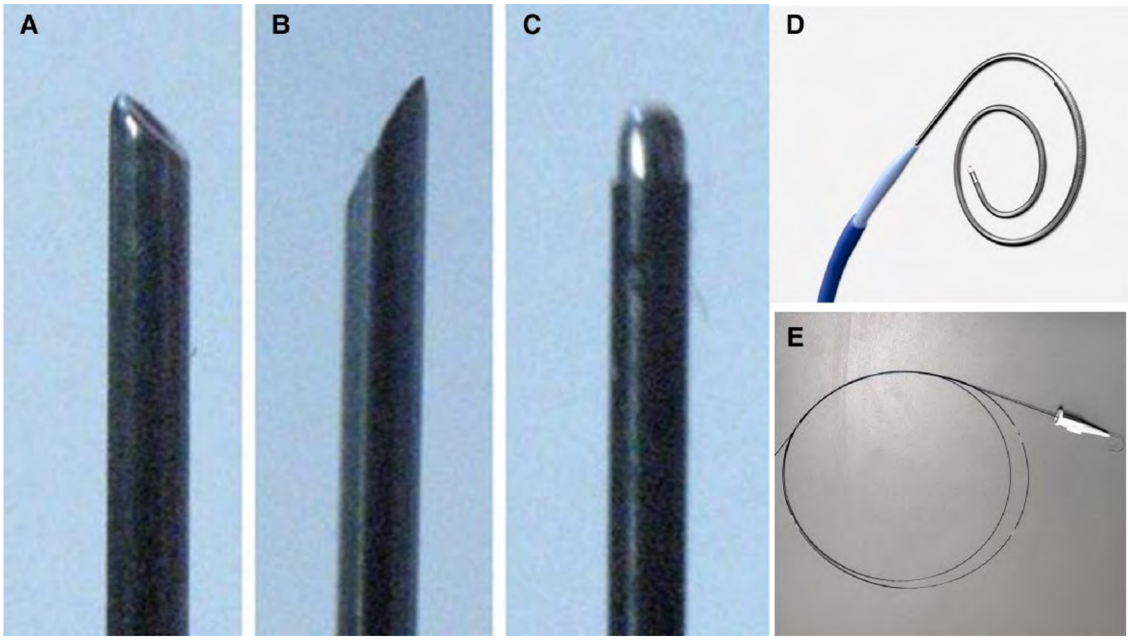


Figure 7 Different types of commonly used needle tip designs. Different types of commonly used needle tips: *A*. BRK, *B*. BRK XS, *C*. NRG-C0, *D*: VersaCross® wire system with tip configurations J-tip (9 mm) and pigtail (24 mm), diameter 0.035’, length 180 cm, 230 cm. *(E)* SafeSept® wire, with a sharp distal tip and a preformed J shape.

assembly into the LA over the wire. The atraumatic guidewire with a tip-electrode allows RF-based septal perforation; this can be extended into the LA in a pigtail shape, and the sheath is then advanced over the guidewire into the LA. The VersaCross™ wire is also compatible with an 8.5 F VersaCross™ steerable sheath and dilator system, which allows for precise puncture of particular part(s) of the septum (*Figure 7D*). The dilator curves are available in D0 or D1, and the sheath is available in small (17 mm), medium (22 mm), and large (50 mm) curves, with bidirectional curve angles (90°CCW, 180°CW). These systems may reduce the need for multiple needle and guidewire exchanges, thereby minimizing the risk of air ingress and thrombus formation.

	Strength of evidence
Advised TO DO	
It is advised that the sizes and lengths of the various components of the transseptal assembly are carefully checked for compatibility with each other.	 >90% agree
May be appropriate TO DO	
Use of a (wire based) RF system under ultrasound visualization may be appropriate for thick and/or aneurysmal septa to improve ease and safety of puncture.	 >90% agree

Imaging modalities to guide transseptal puncture

Since its introduction into clinical practice, TSP has primarily been performed under fluoroscopic guidance.[77] To minimize radiation exposure, assist with challenging punctures, and help direct the puncture to a specific part of the fossa ovalis, which may facilitate certain procedures, TOE, ICE, and electroanatomical mapping systems can be utilized to guide TSP.[78–82] This section will describe the most commonly used imaging modalities in daily practice for guiding TSP.

Fluoroscopy

The majority of TSPs can be effectively and safely performed using fluoroscopy guidance alone. In a study involving 4690 consecutive TSPs for various left-sided ablations, 99% were successfully achieved under fluoroscopy, with a low TSP-related tamponade rate of 0.59%.[83] To guide TSP, fluoroscopy in the right anterior oblique (RAO)/anterior-posterior (AP) and left anterior oblique (LAO) views is typically used, with one or more catheters positioned as anatomical landmarks (*Figure 5*). A multipolar catheter is frequently inserted into the coronary sinus, and additional catheters—such as one at the His bundle during electrophysiology (EP) procedures or a pigtail catheter in the aortic root for patients undergoing left heart catheterization—can be used to indicate the position of the aorta. After placing the reference catheters, the assembly, including the sheath and transseptal needle, is advanced to the SVC and directed medially and posteriorly by rotating the system clockwise, starting at a 4 o’clock position (*Figure 5*). Under fluoroscopy, the system is then slowly pulled back until two drops of the needle-sheath assembly are observed (*Figure 5*): the first indicating entry into the RA and the second indicating the position of the fossa ovalis, which is located superior to the coronary sinus ostium. At this point, small adjustments to the needle position can be made, with clockwise rotation for a more posterior location or counterclockwise rotation for a more anterior positioning, controlled in the RAO view to ensure optimal positioning (*Figure 5*). Optionally, a small amount of contrast can then be used to confirm the correct position and tenting of the fossa ovalis. After this, the needle is advanced, and contrast may be used again to verify the correct entry into the LA (*Figure 5*). Alternatively, pressure measurement can be used to confirm access to the LA.

Transoesophageal echocardiography

For guiding TSP using TOE, the midoesophageal short-axis view at the level of the aortic valve (30–45°) or the bicaval view (90–110°) are the most frequently used. In the midoesophageal short-axis view at 30–45°, the IAS is oriented antero-posteriorly, with the anterior portion closer to the aortic valve and the posterior portion farther from it (*Figure 8A*). The midoesophageal bicaval view shows the IAS oriented superiorly (towards the SVC) and inferiorly (towards the IVC) (*Figure 8B*). In this view, the IVC must be differentiated from the coronary sinus, which is oriented towards the posterior wall of the LA (pointing superiorly within the echocardiographic sector), while the IVC points inferiorly (*Figure 8C*). Current TOE probes with three-dimensional imaging capabilities allow for simultaneous visualization of both plane views (the short axis of the aortic valve and the bicaval view), facilitating the guidance of TSP (*Figure 8D*). These two views do not correlate with the movement of the catheters on fluoroscopy: on the bicaval view, catheter movement towards superior or inferior appears as a movement to the right and left, respectively, while on the short-axis view, catheter movement is not seen as anterior or posterior but rather superior and inferior. This can create confusion between interventional echocardiographers and interventional cardiologists. To improve communication, the three-dimensional zoom view can be reconstructed from the bicaval and short-axis views to visualize the IAS from either the LA or RA, localizing the fossa ovalis and anatomical landmarks that cannot be seen on fluoroscopy. Orienting the three-dimensional rendering of the IAS to match its appearance on fluoroscopy may facilitate the identification of the fossa ovalis and the movement of the catheters (*Figure 9*). In case of LA ablation procedures, the TOE probe should be withdrawn cranially in case of

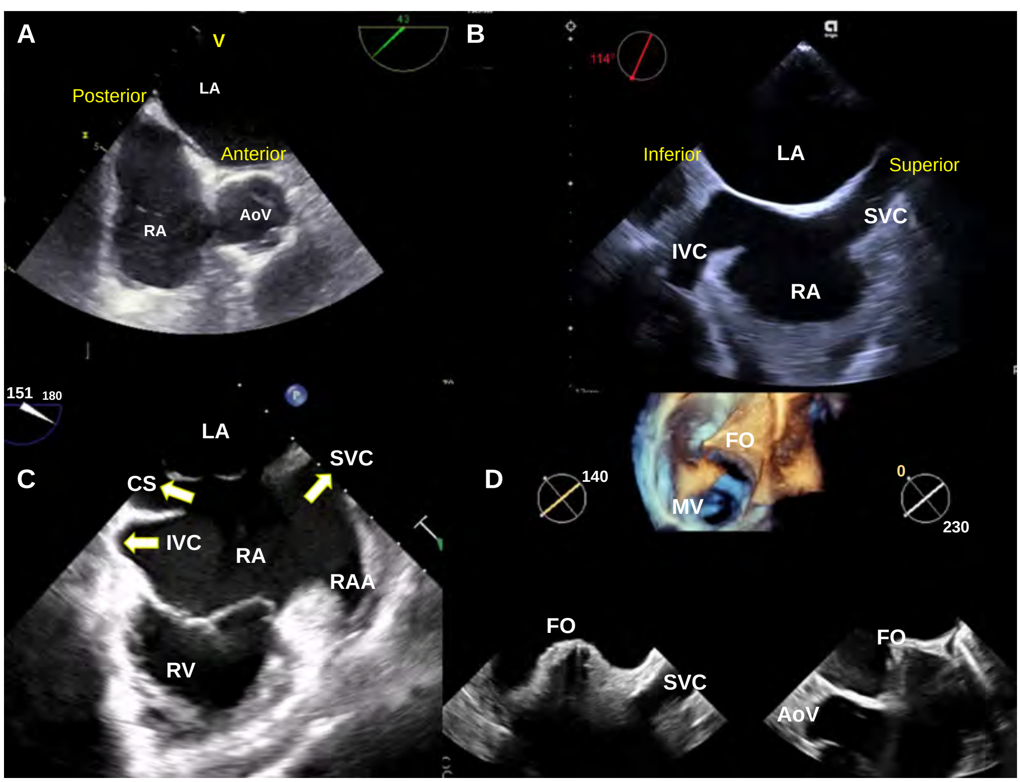


Figure 8 Transoesophageal echo to guide TSP. From mid-oesophageal view, the short-axis view of the aortic valve (AoV) provides the view of the interatrial septum spanning anteriorly and posteriorly (*A*) whereas from the bicaval view, the interatrial septum is visualized along the superior and inferior axis with the superior (SVC) and the inferior (IVC) venae cavae as landmarks (*B*). It is important to differentiate between the IVC and the coronary sinus (CS) which starts at the level of the septum. The Eustachian valve can be used as landmark to differentiate between both structures (*C*). (*D*) The simultaneous biplane view of the interatrial septum (bicaval view on the left and short-axis view on the right) and the three-dimensional volume rendering on top to see how the puncture is performed visualized from an en-face view of the right and left atrium. The puncture is performed through the fossa ovalis in a rather floppy septum. AoV, aortic valve; CS, coronary sinus; FO, fossa ovalis; IVC, inferior vena cava; LA, left atrium; MV, mitral valve; RA, right atrium; RAA, right atrial appendage; RV, right ventricle.

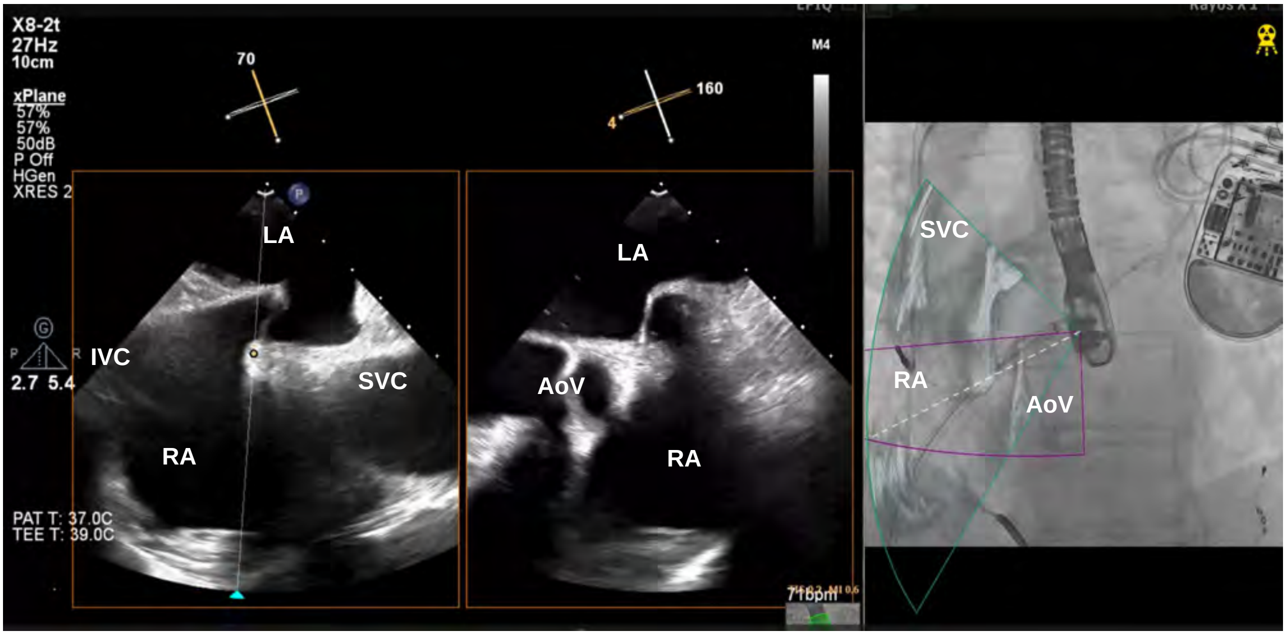


Figure 9 Fusion imaging overlaying three-dimensional transoesophageal echocardiography and fluoroscopy. (*A*) The panels of the left show the simultaneous biplanar view of the interatrial septum taking as reference plane the bicaval view and short-axis view of the aortic valve as the perpendicular view. (*B*) This image is overlaid onto the fluoroscopy with the green sector showing the bicaval view. AoV, aortic valve; IVC, inferior vena cava; LA, left atrium; RA, right atrium.

ablation directed at the LA posterior wall to avoid excessive LA-oesophagus contact during ablation.

Further advances in fusion imaging allow the overlay of echocardiographic views onto live fluoroscopy, enabling catheter movement to be guided by fluoroscopy while benefiting from the soft-tissue resolution provided by echocardiography (*Figure 9*). Modern TOE probes have been miniaturized, providing two- and three-dimensional imaging capabilities, improving patient tolerance, and eliminating the need for general anaesthesia. Complications related to TOE are rare, with an incidence of oesophageal haematoma reported at 0.2% and oesophageal perforation in <0.05%.[84] However, it is important to recognize contraindications, such as oesophageal varices at risk of bleeding and thrombocytopenia (platelet count <30 000/μL).

Intracardiac echocardiography

In contrast to TOE, ICE allows the TSP to be performed without the need for general anaesthesia or deep sedation. There are currently two types of ICE catheters in use: rotational ICE devices, which are not steerable and provide only near-field imaging (≤5 mm), offering excellent visualization of the IAS, and phased-array devices, which are steerable and provide far-field imaging, facilitating the guidance of structural heart disease interventions (e.g. LAAC).[85] From a mid-RA position, the IAS is visualized, and this is the most common position used to guide the TSP (*Figure 10A–C*). By rotating the probe clockwise from the home view, the IAS is aligned, and the fossa ovalis can be better visualized by flexing the probe posteriorly. This view allows for biplane simultaneous imaging and live three-dimensional multiplanar reconstruction of the IAS, enabling precise catheter guidance.

The use of ICE (or TOE) provides continuous, real-time visualization of the heart during the procedure, which offers the advantage of promptly identifying complications as they arise. Additionally, it can enable for a zero-fluoroscopy TSP approach when performed by experienced operators.[86] However, the routine use of ICE increases the overall cost of the procedure, and its cost-effectiveness should be evaluated on a case-by-case basis.[87,88]

Non-fluoroscopic 3D mapping system

The routine use of 3D electroanatomic mapping systems (EMS) has transformed daily clinical practice in the electrophysiology labs. Several studies have demonstrated the ability of EMS to precisely identify the fossa ovalis using various techniques, including impedance mapping,[81] voltage mapping[79,80,82,89], and the protrusion technique[89,90]. These methods rely on the distinct structural characteristics of the fossa ovalis,[91] which has lower voltage and impedance than the surrounding IAS and is more elastic, allowing visualization of the characteristic 'tenting' with minimal pressure. The success rate of voltage mapping for identifying the fossa ovalis varies across studies[79,89,92] ranging from 33% to 100%, while the protrusion technique using a circular multipolar mapping catheter[89,90] and impedance mapping using an ablation catheter[81] have been able to identify the fossa ovalis in 98% and 97% of the cases, respectively. Once the fossa ovalis is identified using any of these methods, TSP can be performed, either using fluoroscopy after positioning a catheter at the previously identified optimal TSP site or by directly visualizing the TSP needle on the EMS, enabling a 'zero fluoroscopy' approach.[79,90,93,94] EMS is particularly valuable in challenging cases with unusual septal anatomy and orientation,[95] allowing for a precise 3D reconstruction of the fossa ovalis and accurate selection of the optimal TSP site within the fossa ovalis itself (*Figure 11*). While initial data are promising, they arise from single-centre studies involving a limited number of patients.

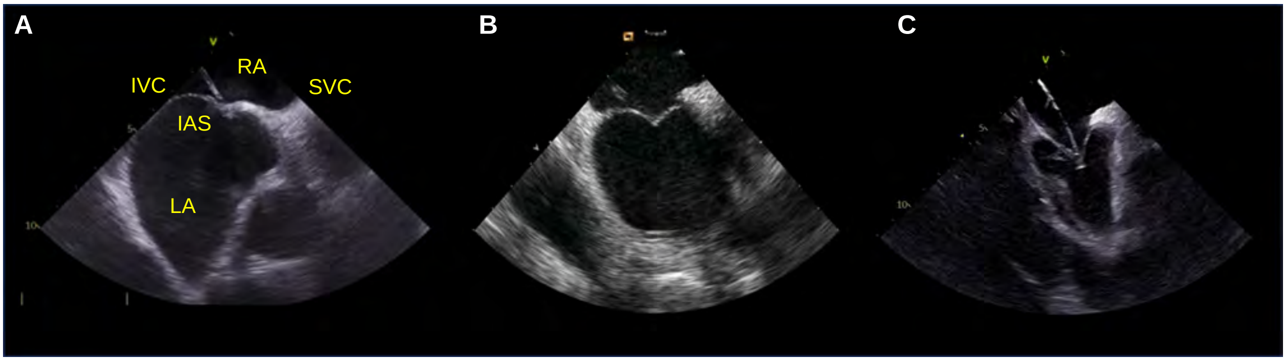


Figure 10 Intracardiac echocardiography to guide TSP. (*A*) The interatrial septum is visualized from the mid-right atrium (RA) position, applying posterior deflection of the posterior-anterior knob and applying slight rightward rotation of the right-left knob which identifies the superior (SVC) and inferior (IVC) venae cavae as landmarks of the superior and inferior borders of the septum. In (*B*), central position of the needle in the fossa ovalis is visualized, allowing for direct imaging of puncture height. (*C*) Septum tenting and finally crossing of the needle is visualized in real-time. IAS, inter-atrial septum; IVC, inferior vena cava; LA, left atrium; RA, right atrium; SVC, superior vena cava.

	Strength of evidence
Advised TO DO	
When TSP is performed with fluoroscopic guidance alone, it is advised to use at least one catheter as an anatomical landmark.	 >90% agree
It is advised that an alternative imaging modality to fluoroscopy (TEE/ICE) is readily available to guide TSP.	 >90% agree
If fluoroscopy alone is insufficient to identify the fossa ovalis or when the TSP aims to target a specific location, it is advised that an alternative imaging modality (TEE/ICE) is employed to guide TSP.	 >90% agree
When TEE or ICE is planned to be used during the procedure, it is advised to use it for guiding TSP.	 >90% agree

Complication prevention and management

TSP is generally a safe procedure when performed in the appropriate setting by experienced operators. However, complications can still occur. Early recognition and timely management of these complications are crucial to minimizing their severity and improving patient outcomes. This chapter reviews the most common complications associated with TSP and outlines strategies for their prevention and management.

Haemopericardium and cardiac tamponade

Haemopericardium, which can lead to cardiac tamponade, is the most common and potentially life-threatening complication of TSP. The reported risk of tamponade ranges from 0.5% to 2%, with a low mortality rate of 0.018–0.08%.[96–100] However, most studies—particularly those focused on AF ablation—address the tamponade risk associated with the entire procedure rather than isolating the risk related specifically to TSP.

Cardiac perforation may result from a misdirected TSP, where the puncture exits posteriorly from the RA into the pericardium before entering the LA, or from septal bulging, particularly in the case of an aneurysmatic or fibrotic fossa ovalis, leading to perforation of the lateral wall or the roof of the LA (*Figures 12* and *14F*).[2,98] Additionally, tamponade may accompany inadvertent puncture of the ascending aorta (*Figure 13*). Risk factors for cardiac perforation include anatomical variations such as aneurysms, advanced patient age, repeated procedures, failed first pass crossing, and low operator experience.[101] TOE or ICE guidance, along with special transseptal tools may reduce the risk.[101]

Early recognition and prompt treatment of cardiac tamponade are critical, as delays can be fatal.[2] Real-time echocardiographic monitoring can aid in the early detection of haemopericardium.[101,102] If blood accumulation is detected while the sheath is still in place, slow retraction while leaving the guidewire in place is suggested.[98,103] Posterior perforations may only become apparent after sheath removal at the end of the procedure.[39]

Managing cardiac tamponade involves immediate percutaneous drainage, typically performed using a pigtail catheter through subxiphoid access. Direct autotransfusion of the aspirated pericardial blood into the femoral vein may reduce the need for allotransfusion. Alternatively, a direct connection (male-to-male) using a three-way stopcock for autotransfusion during pericardiocentesis can be utilized.[104] Uninterrupted periprocedural anticoagulation and intraprocedural heparin may increase bleeding volume if cardiac perforation occurs. Anticoagulation reversal[105] may be helpful to stop bleeding, but thrombus formation in the pericardial sac may interfere

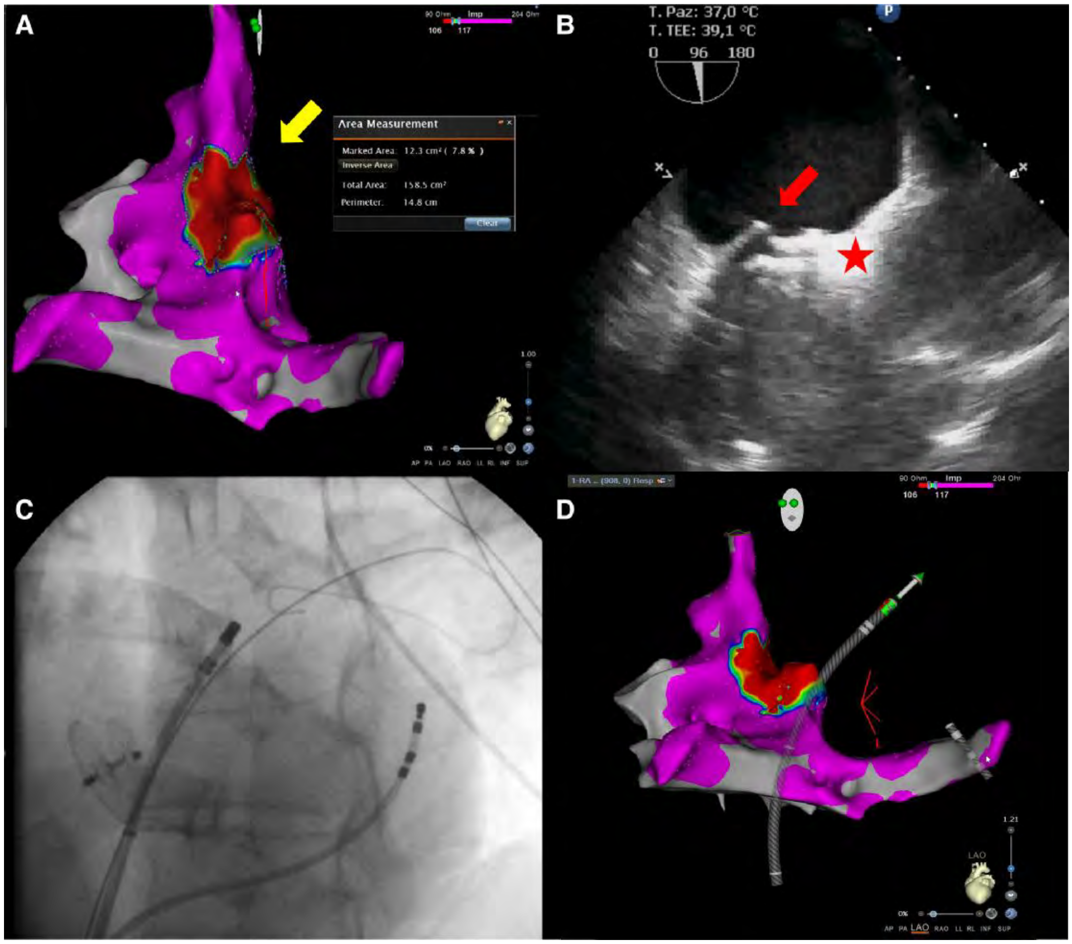


Figure 11 TSP in a patient with ASD occluder using 3D mapping with impedance guidance. An example of the workflow of a non-standard transeptal puncture guided by impedance mapping in a patient with a PFO occluder. (*A*) A right-atrial impedance mapping of the FO is acquired (here, a left-lateral view is shown); FO tenting is clearly visible (yellow arrow). (*B*) The ablation catheter is positioned in the optimal site for TSP inside the FO using the 3-D electroanatomic mapping system. In this case the position was confirmed by trans-oesophageal echocardiography. The red arrow indicates the TSP needle protruding in the fossa ovalis and the red star the PFO occluder. (*C*) The TSP is performed in the identified site and the ablation catheter is advanced in left atrium directly adjacent to the wire (LAO 30°). (*D*) The (shaft of the) ablation catheter is visualized on the impedance map, showing the (transseptal) crossing of the shaft exactly in the pre-defined area. (LAO 30°). PFO, patent foramen ovale; FO, fossa ovalis; TSP, transseptal puncture; LAO, left anterior oblique view; LL, left lateral view; RAO, right anterior oblique view. Images courtesy of Dr. Francesco Pentimalli & Dr. Matteo Astuti.

with drainage. Therefore, the reversal should only be performed once the aspiration rate decreases significantly[2] and tamponade subsides. The pericardial drain is typically left in place for at least 12 h but may be removed earlier in the electrophysiology laboratory once blood re-accumulation is excluded.[106,107] Surgical revision via sternotomy may be necessary for large tears with persistent bleeding or when blood is already clotted.

Aortic puncture

Aortic puncture is an infrequent but potentially life-threatening complication of TSP, occurring in less than 0.1% of cases. The risk of aortic puncture may increase due to anatomical variations that lead to misdirection of the needle (e.g. an anteriorly positioned fossa ovalis, dilated ascending aorta, severe kyphoscoliosis, or pectus excavatum) (*Figure 13*). Using anatomical landmarks during fluoroscopy-guided TSP, such as a pigtail catheter in the non-coronary aortic sinus and a coronary sinus catheter, pressure monitoring, and echocardiographic guidance may help prevent this complication.[96,108]

Aortic puncture can occur at three anatomical levels: antero-inferiorly (non-coronary sinus), antero-superiorly (sinotubular junction), and highly superior (ascending aorta).[103] Non-coronary sinus perforation is the most common, often resolving spontaneously without causing significant pericardial effusion if no large sheaths are advanced. More superior punctures, however, can result in cardiac tamponade requiring percutaneous or surgical pericardial drainage. When aortic puncture is confirmed by pressure monitoring or contrast injection with a needle only, retraction typically has no significant consequences. However, when the sheath is inadvertently advanced, a wire should be maintained in the aorta while the

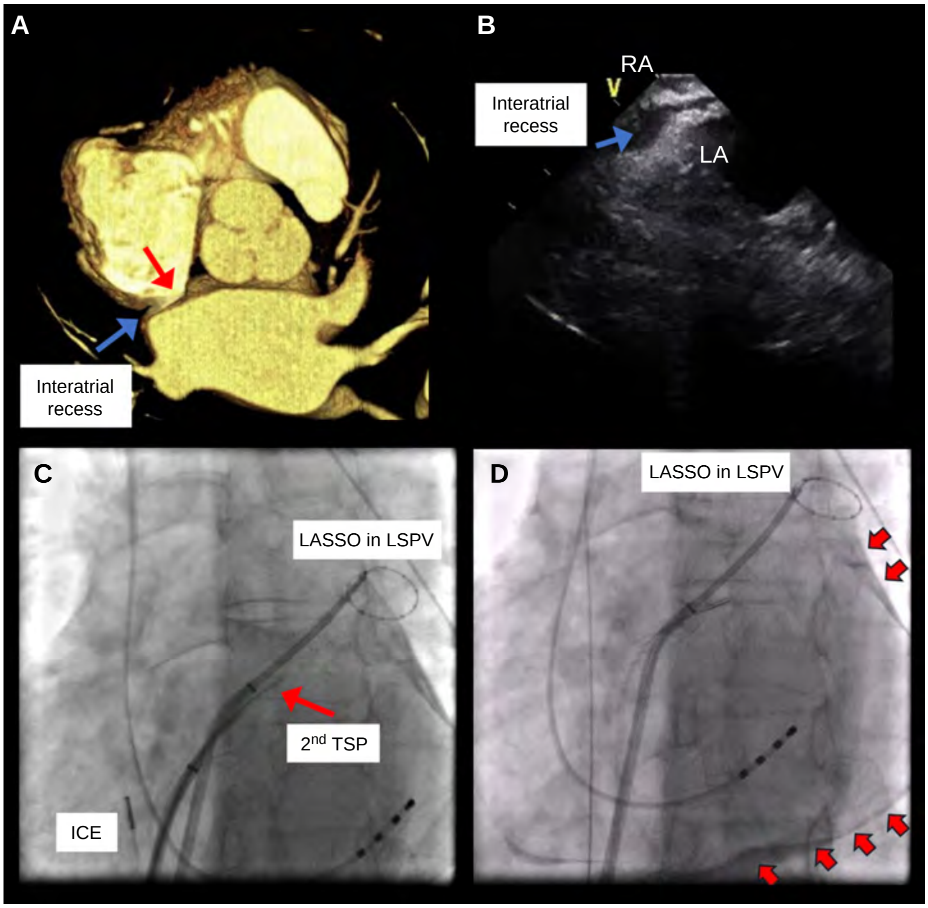


Figure 12 Interatrial recess and the risk of too posterior puncture site. Interatrial recess and risk of too posterior puncture site: *A*. anatomic situation in CT scan. *(B)* Interatrial recess in TOE. *(C)* During the second TSP for AF ablation, due to very limited ICE visibility, the needle was positioned too posteriorly. However, after septum perforation, a routinely injected bolus of saline was not visible in ICE imaging inside the LA. Thus, contrast agent was injected. *(D)* It was found that the needle penetrated shallowly into the pericardium recess without reaching the LA, so that the pericardial space was stained with contrast medium. Courtesy Petr Peichl, MD, Prague, Czechia.

patient is closely monitored (*Figure 13*). This may allow for rapid reinsertion of the sheath to prevent pericardial effusion and facilitate advanced treatment strategies. Surgical correction is reported in most cases, but implanting a closure device across the perforation may also be feasible and effective.[96,108]

Embolism

Transseptal sheaths in the LA may cause embolization of air, blood clots, or solid particles, potentially leading to cardiac or cerebrovascular ischaemia. This risk is particularly high with large bore sheaths used in single-shot AF ablation and interventional procedures such as M-TEER. Therefore, precautions to avoid it should be maximized in these scenarios. International guidelines and expert consensus documents offer limited guidance on preventing this risk.[2,109]

Several steps can help reduce embolization risk:

Blood aspiration and saline flushing: During and after every insertion or exchange of wire, needle, dilator, or catheter, aspiration of air and flushing of sheaths with heparinized saline is advised. A syringe filled with heparinized saline connected to the open sideport of the sheath can help to prevent air ingress. Additionally, continuous flushing of sheaths and catheters with heparinized saline throughout the procedure is advised to prevent clotting.

Heparin: Administration of heparin before TSP may prevent clots at the tip of the system entering the LA. After TSP and throughout the procedure, maintenance of an activated clotting time of >300 s is advised.[2]

Needle: Custom-made needles with preset curves and cutting-edge tips should be combined with corresponding transseptal sheaths.

Sheath management: Sheaths should be only slightly larger (1 Fr) than the catheter to minimize air and clot formation and should have haemostatic valves to prevent air ingress.

Innovative alternatives: Needles incorporating a J-tipped guidewire may allow direct access of the sheath to the LA without additional exchanges reducing embolization risk.[110]

Despite these precautions, embolization can still occur. Air embolism to the right coronary artery may cause transient ST-segment elevation in the inferior leads. In most cases, this resolves without intervention or can be managed by increasing the blood pressure with high-rate atrial pacing or vasopressors.[2] However, in rare severe cases, ST elevation may persist for

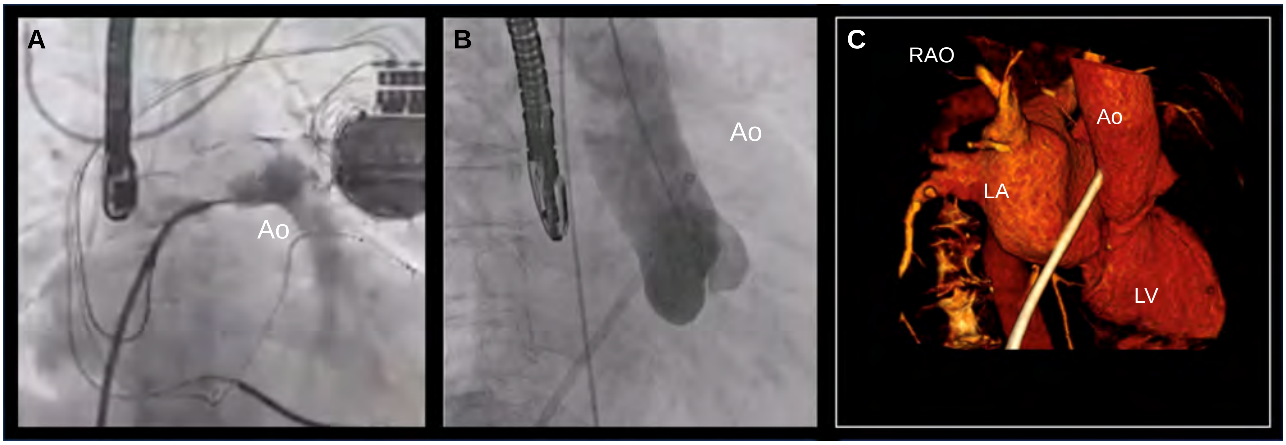


Figure 13 Inadvertent puncture of the aorta. Inadvertent puncture of the aorta during TSP attempt. *A*: Injection of dye through the transeptal needle shows contrast retained in the sinus of Valsalva. *B*: Contrast injection through the transeptal sheath confirms that the sheath has been advanced into the aortic root. *C*: 3D reconstruction of CT scan showing the transeptal sheath entering the aortic root.

several minutes and be complicated by bradycardia, total AV block, ventricular fibrillation, and hypotension, necessitating emergent coronary angiogram with aspiration of air, temporary pacing and haemodynamic support, ECMO treatment and prolonged mechanical resuscitation. In this scenario, the patient may be positioned in Trendelenburg to minimize the risk of cerebral embolism.[111] Brain thromboembolism may lead to stroke symptoms and may require acute neurological intervention.

Iatrogenic atrial septal defects

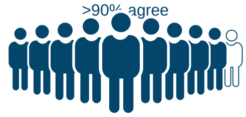
The creation of an iatrogenic atrial septal defect (iASD) is inherent to TSP. While most iASDs close spontaneously, larger sheath sizes increase the likelihood of persistent iASDs.[112] Studies have primarily focused on patients undergoing M-TEER with 24-Fr sheaths, showing a 42% incidence of iASD at 19 months, all with left-to-right shunts, but no clinical impact.[113] For AF ablation, smaller sheaths of 8–8.5 Fr resulted in a 30% of persistent iASD after a single TSP and passage of 2 catheters into the LA, while no iASD was seen with double TSP.[114] The use of larger sheaths, such as those employed for cryoballoon and pulsed field ablation, may increase the risk of persistent iASD;[115] however, the clinical impact appears limited.

Indications for iASD closure include bidirectional or right-to-left shunts with hypoxaemia, large ASDs >8 mm, or concerns about paradoxical embolism, especially in patients with deep venous thrombosis risk.[39] A recent randomized study did not show clinical benefit from routine iASD closure after large-bore LA access.[116] In patients with right-to-left shunting and thrombosis risk managed conservatively, oral anticoagulation might be advisable.[39] Right-to-left shunting with refractory hypoxaemia has been reported in patients with LV assist devices after left-sided ablation via a TSP approach.[117,118]

	Strength of evidence
Advised TO DO	
Immediate percutaneous drainage is advised in cases of cardiac tamponade.	 >90% agree
In case of cardiac tamponade, protamine administration is advised to reverse heparin after the aspiration rate through percutaneous drainage has decreased significantly.	 >90% agree
In case of aortic puncture with advancement of the sheath, a wire should be maintained in the aorta to facilitate rapid reinsertion of the sheath in case of pericardial effusion occurs.	 >90% agree
Continuous flushing of the TSP sheath with heparinized saline is advised to prevent thromboembolism.	
Flushing the sheath before, during, and after catheter insertion and catheter retraction is advised to prevent air embolism.	 >90% agree

Continued

Continued

	Strength of evidence
May be appropriate TO DO	
In case of cardiac tamponade, direct autotransfusion of the aspirated pericardial blood may be appropriate.	
In case of air embolism, air expelling from the coronaries might be facilitated by high-rate pacing and/or norepinephrine administration.	
Areas of uncertainty	
It is unknown whether removal of the pericardial drain in the EP laboratory after drainage of pericardial blood causing cardiac tamponade is safe.	

Specific scenarios: tips and tricks

Transseptal puncture in patients with an atrial septal closure device

In patients with atrial septal closure devices, TSP presents unique challenges, as the device may partially or completely cover the septum, complicating optimal access to the LA.[56] Two approaches can be considered in this scenario: TSP through the native septum outside the implanted device or directly through the device.[119]

The first approach requires identifying an appropriate space outside the occluder to perform a safe puncture. In most cases, the suitable remnant fossa ovalis is located inferior-anterior to the device rim; in exceptionally large devices, a superior-posterior puncture site may be the only option, albeit with a considerable risk of RA/LA roof perforation (*Figure 14A–F*). In general, this 'TSP-beside-the-occluder' approach carries potential risks, including too posterior puncture with pericardial access, too anterior puncture with aortic root laceration, too superior puncture across the RA or LA roof, septal tear during the transseptal passage, device dislodgement, and thrombus formation on the device.[120]

The second approach—TSP through the device—is feasible with all commercially available occluders in Europe (Abbott, Gore, Occlutech), though it requires device-specific considerations.[121] This technique often necessitates adjustments to needle shape and puncture angles. Additionally, balloon predilation with increasingly larger diameters may be needed to facilitate sheath delivery.[122] Post-procedural closure of the TSP orifice with a dedicated occluder may be required in case a large sheath (>12 Fr) has been used.[56]

Double and repeated transseptal access

If double transseptal access is required, the first sheath can serve as a radiological landmark to guide the second puncture. Alternatively, after TSP, a wire may be advanced into a left PV, allowing the long sheath to be retracted into the RA. At this stage, a second puncture can be performed, or direct engagement of the fossa ovalis can be attempted using a deflectable ablation catheter. In the latter case, the long sheath can then be advanced over the catheter into the LA. This approach is considered safe, though failures have been reported in cases involving a small transseptal hole.[123] Another approach, a one-puncture, double-transseptal catheterization technique, involves advancing two wires into the left veins through the first introducer, which are then used to advance two long sheaths into the LA through a single femoral access. Intraprocedural TOE or ICE can aid in tool manipulation, potentially reducing the risk of cardiac tamponade. Importantly, studies have found no differences in complication rates between different TSP techniques.[124]

Prior instrumentation of the IAS for transseptal access is an intrinsic factor contributing to the difficulty of subsequent TSP due to fibrosis and scarring from earlier procedures. Excessive forward pressure when attempting to cross a resistant septum may lead to perforation of the contralateral wall of the LA. However, punctures can still be performed safely using wire-mediated crossing techniques. Radiofrequency-facilitated punctures can also be helpful, though intraprocedural imaging might be needed to ensure safety.[56]

Transseptal puncture in the paediatric population

TSP in paediatric patients should be performed only in highly experienced, specialized centres; additionally, national regulations might define specific requirements for centres performing TSP in this specific patient population.

Technically, TSP in paediatric patients is performed similarly to the procedure in adults. However, unique considerations must be taken into account for this population. While TSP has been demonstrated to be safe in paediatric patients[125,126] it can present challenges, particularly in infants and smaller children, due to the limited size of vessels and LA. In this setting, a higher rate of complications has been observed during the first year of life.[125,127] Additionally, anatomical obstacles in children with congenital cardiovascular malformations or the presence of devices or patch material within the IAS can further complicate TSP in these patients.[128]

In most paediatric cases, a Brockenbrough approach with a standard transseptal sheath-needle assembly is sufficient to achieve LA access. For infants and smaller children, it is common practice to use the smallest available sheath compatible with a Brockenbrough TSP needle and the required catheters.[125] Due to the smaller size of the LA in these patients, the risk of perforation may increase when using the Brockenbrough approach. To mitigate this risk, a 'blunt' needle technique, where the transseptal needle is not fully advanced out of the sheath dilator, has been proposed.[125]) As an alternative to the Brockenbrough technique, radiofrequency energy can be used to perforate the IAS and gain LA access. RF-assisted TSP might be particularly beneficial in infants with a small LA or a hypertrophied IAS, which might be related to an increased risk of LA injury when using the traditional approach.[14] If advancing a sheath over the IAS into the LA proves difficult after a successful TSP, placing a high-torque 0.018' wire—accommodated by the lumen of a standard Brockenbrough needle—into the upper left PV may help. Balloon atrioseptostomy can then facilitate sheath advancement into the LA.[129] Although most reports on paediatric TSP rely primarily on fluoroscopic guidance, the use of TOE or ICE offers significant advantages. These imaging modalities can enhance the safety of TSP, particularly in patients with congenital heart disease or altered atrial anatomy.[130]

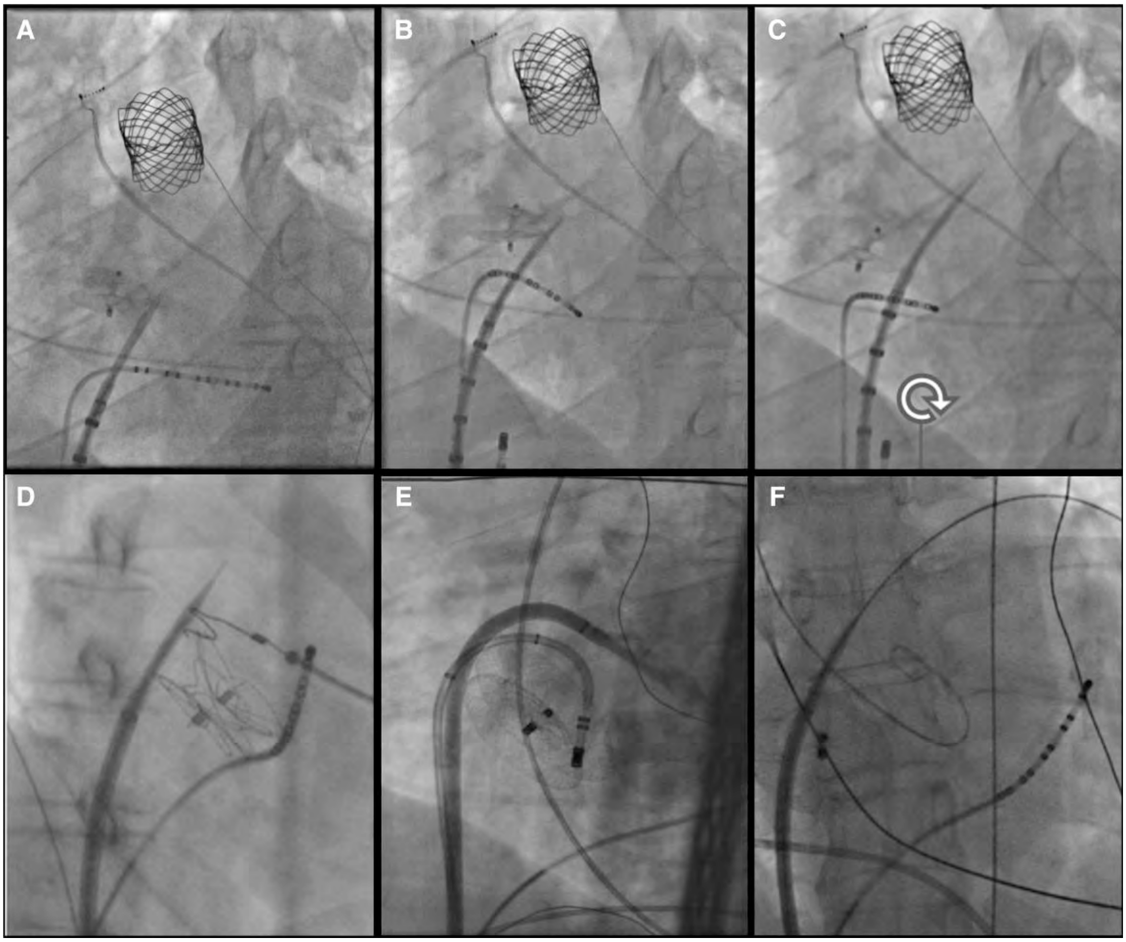


Figure 14 TSP in patients with ASD occluder: inferior and superior puncture. TSP in various ASD occluder settings. *A*–*C*. Patient with surgically corrected tetralogy of Fallot, transcatheter pulmonary valve replacement and 22 mm diameter ASD occluder. All panels in LAO 44° view. TSP is achieved inferior to the device after overcoming the resistance of the fibrotic septum which causes a temporary dislodgment of the CS catheter. *(D)* TSP superior-posteriorly to a 22 mm diameter ASD occluder placed for a septum secundum ASD (RAO 38°). (*E*) TSP in a large, 32 mm diameter ASD occluder: Left atriography after single TSP with double LA access posteriorly-superiorly to the large occluder (LAO 45° view). *(F)* Same patient as in (*E*), repeated TSP 1 year later with too superior-anterior puncture which resulted in epicardial position of the wire advanced over the TSP site (diagnostic standard wire positioned in the Aorta/sinus Valsalva to highlight aorta; A.

Transseptal puncture in patients with aneurysmatic or hypertrophic interatrial septum

Septal aneurysm, typically located at the level of the fossa ovalis, is a localized deformity of the IAS.[131] Conversely, lipomatous atrial septal hypertrophy is characterized by excessive fat deposition in the IAS, sparing the fossa ovalis.[48] Both anatomical variants can be associated with a difficult TSP (*Figure 3A* and *B*). In these cases, crossing the fossa often requires applying greater force to the sheath-needle assembly, which can displace the system towards the lateral wall or roof of the LA, thereby increasing the risk of LA perforation. To reduce this risk of contralateral perforation in aneurysmatic septa, one can either use a wire- or radiofrequency mediated septal crossing requiring less pressure to the septum or try to increase left atrial pressure (e.g. during general anaesthesia) to 'push the septum over the needle' instead of pushing the needle over the septum. Still, puncturing through a hypertrophied area may reduce catheter manoeuvrability once inside the LA. Guidance with 2D/3D TOE or ICE is, therefore, advisable since these imaging techniques can help align the sheath with the fossa, monitor the distance to the LA wall during TSP, and detect potential effusion in the event of perforation.[132]

Transseptal puncture through a superior access

In patients with interruption or absence of the IVC (*Figure 3C*), engaging the fossa ovalis for TSP has to be performed by a superior access, i.e. via the right internal jugular vein or the left subclavian vein. Since, if coming from superior, the septum is oriented away from the needle tip so that no mechanical force can be exerted to perforate the septum, a RF needle or RF wire in conjunction with a steerable sheath were mainly used in these cases. Using this combination, single or even double transseptal access was achieved in all patients in the largest published case series.[133]

Strength of evidence

In patients with an ASCD, it is advised to review the characteristics of the closure device and have additional imaging (TEE/ICE) to fluoroscopy available for detailed characterization of cardiac anatomy.

Infrastructural and training requirements

Centre requirements

TSP is a critical component of various left-sided interventional cardiac procedures, which are increasingly performed. However, TSP is associated with complications, and institutions should meet stringent standards to ensure procedural safety. Centres must be fully equipped with the necessary infrastructure and equipment to perform the procedure, including fluoroscopy, sheaths, and TSP needles, as well as to detect and manage complications. This includes having on-site transthoracic echocardiography, equipment for pericardial drainage and anticoagulant reversal agents. Access to TOE and/or ICE to assist in challenging TSP cases is also advisable.

In addition to proper infrastructure, staff competency is crucial for performing TSP safely and successfully. Non-medical team members should be experienced in handling procedural equipment, administering analgesia/sedation and assisting in cardiac tamponade management. It is also suggested that the team regularly conducts simulations to practise the management of procedural complications, including cardiac tamponade. The availability of on-site cardiothoracic surgery is optimal for managing cardiac perforation. However, if on-site cardiothoracic surgical support is unavailable, centres must have established protocols for transferring patients to a cardiothoracic centre, including transport teams and communication channels to expedite the patient transfer.[2]

Training requirements

Training in TSP should ideally be conducted in a training centre accredited by an official organization (e.g. the European Heart Rhythm Association of the ESC) or a National Cardiac Society. During the training period, trainees should acquire theoretical knowledge on the indications and contraindications of TSP, required materials and equipment, and the use of fluoroscopic, TOE, and ICE guidance. Additionally, they should learn measures for preventing complications as well as recognizing and managing them when they occur. Practical skills in TSP performance should be guided and evaluated using the Entrustable Professional Activities system, which consists of up to five levels of progressive independence, culminating in the ability to perform a professional activity unsupervised.[134] Training should begin at level 1, where the trainee only observes the procedure, progress through levels 2 to 4, where the trainee performs the TSP under decreasing levels of supervision, and finally, reach level 5, where the trainee is able to teach others how to perform a TSP. Simulator-based training at the beginning of the programme may help avoid complications related to operator inexperience.[135] In a small randomized study, TSP simulation-based training using virtual reality resulted in shorter training time and superior post-training performance compared to conventional training.[136,137] While the core curricula of scientific societies do not specify a required number of TSPs for accreditation, data indicates that the rate of TSP-related tamponade decreases as the number of TSPs performed by an operator increases, with rates as low as 0.4% for those who have performed more than 100 procedures.[83]

Open questions

The added value of diathermy- or RF-facilitated puncture systems remains to be proven. There are to date no data comparing head-to-head the traditional to the RF-based TSP systems, with RF systems being substantially more expensive. However, the writing group agreed that RF-based systems might provide advantages in specific (anatomic) scenarios.

The use of ICE remains controversial: there is agreement, that it provides high-quality intraprocedural imaging, including visualization of ablation lesion formation and tiny intra-cardiac structures. However, an additional femoral access is needed and the existing catheters/imaging systems are quite expensive. Thus, possible advantages of ICE over intraprocedural TOE remain to be proven.

In case of cardiac tamponade, the timing of protamine administration and the value of autotransfusion have not been investigated in a structured way. Here, the writing group feels that more data are needed.

The benefit of anticoagulation in iatrogenic ASD patients managed conservatively remains unknown, mainly because possible risk factors for paradoxical embolization in these patients are unclear.

Future perspectives

In the last decade, TSP has become an increasingly common first step in an evolving field of interventional approaches for various cardiac diseases. Alongside, important steps forward regarding safety, accuracy of puncture and efficiency of the TSP process have been achieved. While the growing number of TSP procedures creates the need for more efficient, seamless approaches, the increasing complexity of new procedures generates the need for more accurate, visually controlled TSP. This need includes improvements in the ease of use of TSP devices, greater TSP efficiency even in challenging anatomical scenarios, and easy-to-use, direct (3D) visualization of each step for greater control during TSP. To achieve this, improving access to specialized facilities for physicians' hands-on training, along with the development of more streamlined TSP procedures—including, for example, dedicated equipment packs—and further refining the accommodation of TSP processes to better align with specific planned procedures, are important steps forward.

Conflict of interest: I.D.: Speaker honoraria from Abbott Medical, Johnson&Johnson MedTech, Boston Scientific, BMS, Abiomed, Medtronic, Volta Medical; research grants (to the institution) from Abbott Medical, Johnson&Johnson MedTech, Daiichi Sankyo. B.C.A.: no conflict of interest. N.A.M.: Speaker fees from Philips Ultrasound, GE Healthcare, Abott Vascular; research grants (paid to the Institution) from Pfizer, Astra Zeneca, Edwards Lifesciences, Pie Medical. M.d.R.S.: No conflict of interest. S.C.: No conflict of interest. N.A.: Speaker fees from Boston Scientific, Abbott Vascular, GE Healthcare. Research funding by institution from GE Healthcare. U.K.: No conflict of interest. M.A.: speaker honoraria from Novartis, AstraZeneca, Bayer and Boehringer Ingelheim. S.T.: Speaker fees from Boston Scientific. L.B.: Consultant/speaker for Medtronic, Boston Scientific, J&J Biosense-Webster and ArgaMedTech; research grant (for the institution) from Medtronic, Boston Scientific and Philips. V.D.: speaker fees from Abbott Structural, Edwards Lifesciences, GE Healthcare, JenaValve, Medtronic, Philips, Products & Features and Siemens; institutional research grants from Astra Zeneca. D.W.: consultant fees from Johnson & Johnson MedTech. C.B.: Consultant fees from Abbott and Johnson & Johnson MedTech Biosense Webster. M.A.: speaker honoraria from Abbott, Edwards Lifesciences and Medtronic. P.S.: Advisory board member for Abbott, Boston Scientific, Johnson & Johnson MedTec and Medtronic. D.G.: No conflict of interest.

Data availability

The data underlying this article are available in the article and in its online supplementary material.

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