RESEARCH/REVIEW ARTICLE

Transseptal Access to the Left Atrium: Tips and Tricks to Keep it Safe Derived from Single Operator Experience and Review of the Literature

Antonis S. Manolis*

Third Department of Cardiology, Athens University School of Medicine, Athens, Greece

ARTICLE HISTORY

Received: July 08, 2017
Revised: September 13, 2017
Accepted: September 20, 2017

DOI:
10.2174/1573403X13666170927122036

Abstract: ***Background***: Transseptal puncture (TSP) remains a demanding procedural step in accessing the left atrium with inherent risks and safety concerns, mostly related to cardiac tamponade.

Objective: Based on our own experience with 249 TSP procedures and in-depth literature review, we present our results and offer several tips and tricks that may render TSP successful and safe.

Methods: This prospective study comprised 249 consecutive patients (146 men), aged 41.6±17.4 years, undergoing TSP by a single operator for ablation of a variety of arrhythmias, mostly related to left accessory pathways (n=145) or left atrial tachycardias (n=33) and more recently, atrial fibrillation (n=70). TSP was guided by fluoroscopy alone in all patients without the use of echocardiography imaging. In addition, an extensive literature review of TSP-related topics was carried out in PubMed, Scopus and Google Scholar.

Results: Among 249 patients, 33 patients were children or young adolescents (aged 7-18 years); 14 patients were undergoing a repeat procedure. Patients with a manifest accessory pathway were the youngest (mean age 33.7±15.9) and patients with atrial fibrillation the oldest (mean age 56.0±10.8 years). A successful TSP was accomplished in 247 patients (99.2%). Two (0.8%) procedures were complicated by cardiac tamponade managed successfully with pericardiocentesis or surgical drainage. Review of the literature revealed no systematic reviews and meta-analyses of TSP studies; however, several patient series have documented that fluoroscopy-guided TSP, with various modifications in the technique employed in the present series, have been effective in 95-100% of the cases with a complication rate ranging from 0.0% to 6.7%, albeit with a mortality rate of 0.018%-0.2%. Echo imaging techniques were employed in cases with difficult TSP.

Conclusion: Employing a standardized protocol with use of fluoroscopy alone minimized serious complications to 0.8% (2 patients) among 249 consecutive patients undergoing TSP for ablation of a variety of cardiac arrhythmias. Based on this single-operator experience and review of the literature, a list of practical tips and tricks is provided for a successful and safe procedure, reserving the more expensive and patient inconveniencing echo-imaging techniques for difficult or failed cases.

Keywords: Transseptal puncture, left atrial catheterization, catheter ablation, cardiac arrhythmias, cardiac tamponade.

1. INTRODUCTION

Catheterization of the left atrium (LA), effected *via* transseptal puncture (TSP) [1-3], has been increasingly and commonly required over the past two decades in order to perform ablation of a variety of arrhythmias [4], most notably for ablation of LA tachycardias and pulmonary vein isolation (PVI) in patients with atrial fibrillation (AF) [5, 6]. Furthermore, the transseptal approach has always been an alternative method to the transaortic technique for ablation of left-sided accessory pathways [4] or occasionally for performing ablation of left ventricular tachycardias or of the atrioventricular node. With regard to structural heart disease, TSP has been the route to access the LA for mitral valvuloplasty and lately for the MitraClip insertion for the percutaneous management of inoperable severe mitral regurgitation [2]. Finally, TSP has recently been utilized to perform percutaneous LA appendage (LAA) closure in patients with AF who cannot safely receive oral anticoagulants [2].

TSP remains a challenging and demanding procedural step in accessing the LA and has its inherent risks and safety concerns, with its major complication being cardiac perforation and development of cardiac tamponade [7, 8]. The TSP procedure has traditionally been guided by fluoroscopy alone [7], however, over the recent years, echo imaging techniques have been employed [9-11], albeit at higher cost and with patient inconvenience. Based on our own experience with

*Address for correspondence to this author at the Third Department of Cardiology, Vas. Sofias 114, Athens 115 27, Greece; Tel: +30-210-2088470; Fax: +30-213-2088676; E-mail: asm@otenet.gr

1573-403X/17 $58.00+.00

249 consecutive procedures of TSP and on in-depth literature review, we present our results and offer several tips and tricks that may render the transseptal access guided by fluoroscopy alone successful and safe.

2. METHODS

2.1. Study Patients

The study population comprised 249 consecutive patients who underwent a TSP by a single operator for ablation of a variety of arrhythmias over 15 years at four institutions. All data were prospectively collected. These were initially patients with supraventricular tachycardias, mostly related to manifest or concealed left accessory pathways or LA tachycardias and in the more recent years, patients with paroxysmal or persistent AF. A written informed consent was obtained from each patient before the procedure.

2.2. Transseptal Puncture Technique

Initially a 4F or lately a 2F femoral artery sheath is placed for continuous blood pressure monitoring. Then a 6F steerable multi-electrode catheter is inserted into the coronary sinus (CS), which can be used as a landmark to guide the TSP. A 6F quadripolar electrode-catheter is also inserted and placed against the septal leaflet of the tricuspid valve for His bundle recording; other electrophysiology catheters are positioned after completion of the TSP, unless there was a need for performance of an electrophysiology study prior to LA catheterization. Subsequently, an 8F Mullins 67-cm-long sheath with its dilator is introduced and advanced from the femoral vein into the superior vena cava over a guide wire. After removal of the guide wire, the Brockenbrough needle is inserted and advanced to the tip of the dilator with the precaution not to be exposed yet (the thumb is kept at the hub to avert this possibility). Directing the whole system medially and posteriorly by pointing the needle tip to the 4-5 o'clock position in the anteroposterior view, it is slowly withdrawn under fluoroscopy until two falls of the catheter tip are observed, one from the aorta and the other into the fossa ovalis. These typical maneuvers and the position of the CS catheter are used as guidance to direct and position the dilator tip above the ostium of the CS at the fossa ovalis (Fig. **1**, Video). When felt that the dilator tip is in place, this is further checked at the left anterior oblique (LAO) (30^o) fluoroscopic position to ensure its posterior orientation. In some patients and particularly in our smaller pediatric patients,

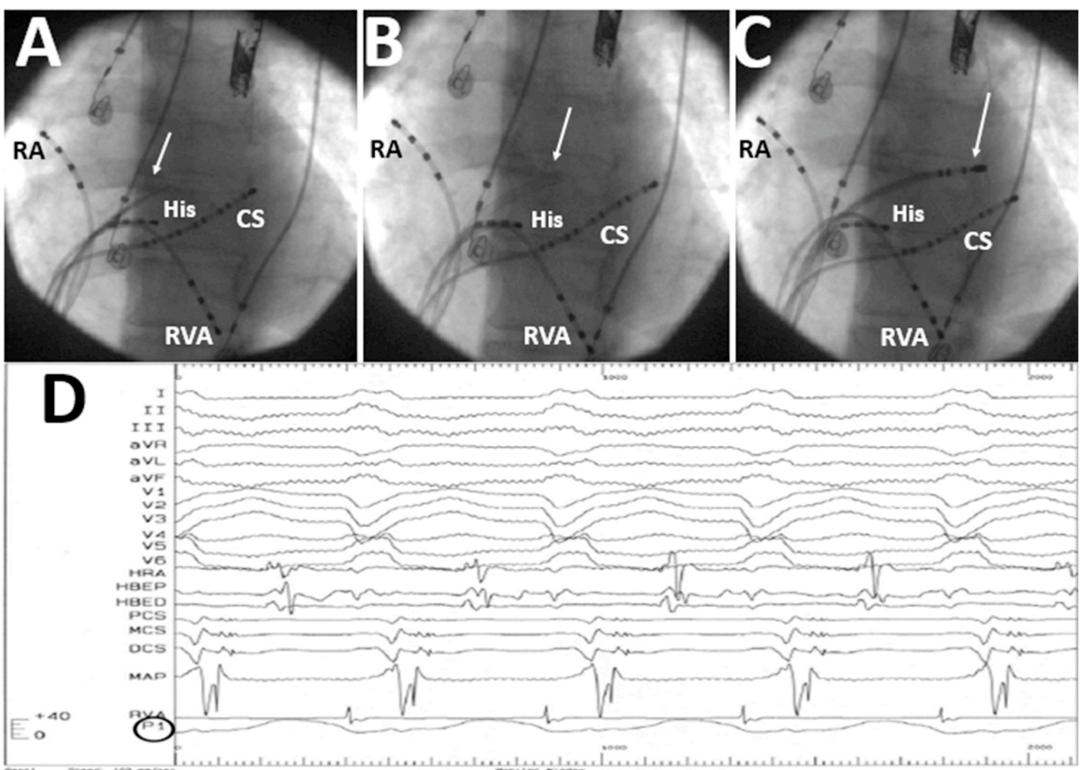

Fig. (1). A suggested sequence of steps to perform transseptal puncture (TSP) guided by fluoroscopy alone (16^o LAO/13^o cranial views) is displayed in a patient undergoing ablation of a left free wall accessory pathway: **A**: After withdrawing the sheath/dilator/needle assembly from the superior vena cava and observing two consecutive falls (not shown here; watch video (*video is available on the publisher's web site*); also see text and Table **2** for discussion), the Brockenbrough needle (white arrow) is advanced and exposed only when one is certain that it has landed in the fossa ovalis which is located above the CS os; in steeper LAO view (not shown) the needle is directed posteriorly. Successful TSP is confirmed by withdrawing arterial blood, recording LA pressure waveform and injecting contrast dye swirling in the LA and directed toward the left ventricle. **B**: Then, the dilator and the sheath (white arrow) are advanced into the LA, the dilator is removed and (**C**) the map/ablation catheter (white arrow) is introduced through the sheath into the LA, and then steered/curved toward the atrial aspect of the mitral annulus facing the CS catheter to ablate the atrial insertion of the accessory pathway. All this process is being monitored with ECG and intracardiac recordings (**D**), but most importantly *via* continuous BP monitoring (circled P1 recording). BP = blood pressure; CS = coronary sinus (catheter); His = His catheter; LA = left atrium/atrial; RA = right atrial (catheter); RVA = right ventricular apex (catheter).

often a small pigtail catheter was introduced into the aortic root to serve as guidance of avoiding inadvertent puncture of the aorta (Fig. **2**).

The interatrial septum is then punctured by advancing the needle; this is always preceded by de-airing, aspirating and flushing the needle to remove any air-bubbles or thrombi. At this point, blood is withdrawn and tested for oxygen saturation and the needle is then connected to a pressure transducer. When arterial oxygenation is confirmed and low pressure (LA waveform) recorded, a small amount of contrast dye is injected to further confirm LA position. Only then are the dilator and the sheath advanced over the needle into the LA, followed by withdrawal of the needle and the dilator, leaving the sheath in the LA. Intravenous heparin is administered at this point as a bolus of 5000-8000 u (80-100 u/kg) and throughout the procedure, either as 2000 u every hour or as needed to maintain the active clotting time ≥300-350 sec.

If accessory pathway or atrial tachycardia radiofrequency (RF) ablation is to be performed, through the Mullins sheath, the ablation catheter is introduced and maneuvered at the mitral annulus or the LA seeking target sites for RF ablation (Fig. **1**). If PVI with cryoablation is being performed, the Mullins sheath is exchanged with the bigger sheath (Fig. **2**) to accommodate the larger sized balloon catheter. This is done with use of a stiffer guidewire introduced into the Mullins sheath and positioned at the left superior pulmonary vein. With each exchange of catheter through the long sheath, blood is aspirated to remove possible clots formed inside the sheath, which is then thoroughly flushed with saline solution. Particular attention is paid to avoid air embolism by aspirating and flushing. The sheath is continuously perfused with heparinized saline solution throughout the procedure. There was no intraprocedural use of any echo imaging (TEE or ICE) in any patient. Transthoracic echocardiography was summoned and performed only when a complication occurred.

2.3. Ablation

The procedures for patients with accessory pathway-related or LA tachycardias were performed in the fasting state after all antiarrhythmic agents had been discontinued for at least five drug elimination half-lives. PVI procedures were also performed in the fasting state, but antiarrhythmic drugs were continued; anticoagulation was discontinued 2-3 days earlier and procedures were performed when the INR was ≤1.7; for patients receiving a non-vitamin K antagonists, the drug was withheld just 1-2 days prior to the procedure. No sedation was given in the majority of patients. In pediatric patients, mild conscious sedation was occasionally employed with use of small aliquots of midazolam and/or propofol.

2.4. Intraprocedural Monitoring

Patients were being closely monitored throughout the procedure with their blood pressure being recorded *via* the intra-arterial line (Fig. **1**), heart rhythm being monitored *via* two separate monitors, and when possible their oxygenation status *via* oximetry. For patients with preexcitation syndrome or AF, adhesive defibrillating pads were placed in an antero-posterior position for possible cardioversion/defibrillation if needed.

2.5. Statistical Analysis

Data are presented as mean±standard deviation or median and range. Statistical comparisons for quantitative data were performed with use of the Student's t-test or analysis of variance. Dichotomous variables were compared by the chi-square test or z-statistic. Differences with a p value of <0.05

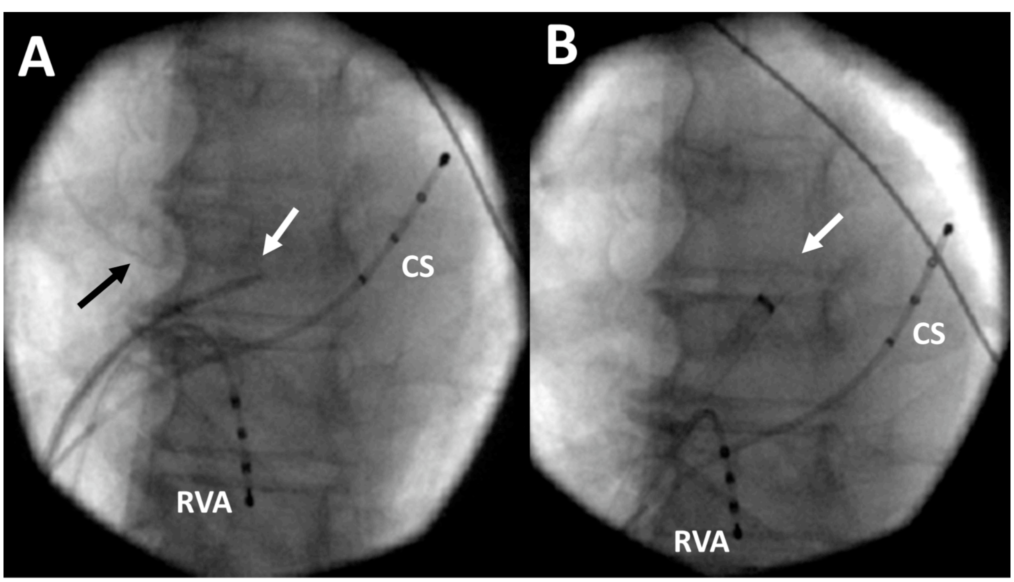

Fig. (2). An alternative approach that provides landmarks and safely guides TSP (white arrow) and avoids aortic root injury employs a pigtail catheter introduced *via* the femoral artery into the aorta (panel **A**, black arrow), while the CS catheter delineates the lower and lateral aspect of the LA. This is followed by advancing the sheath (panel **B**, white arrow) into the LA and then through the sheath introducing the catheter required for the specific procedure that is planned (in this instance, PVI is to follow in a patient with AF). AF = atrial fibrillation; CS = coronary sinus (catheter); LA = left atrium; PVI = pulmonary vein isolation; RVA = right ventricular apex (catheter). Shallow LAO (14^{o}) fluoroscopic views are displayed.

were considered statistically significant. Analyses were performed with the software package MedCalc v. 16.8.4 (*MedCalc* Software, Ostend, *Belgium*).

2.6. Literature Review

An extensive literature review of the topics of TSP, atrial septal/septum puncture, transseptal access, transseptal catheterization, transseptal catheterization of the LA, transseptal left heart catheterization, transseptal needle, Brockenbrough needle, LA access, LA catheterization, or iatrogenic pericardial effusion/ tamponade/ hemopericardium was carried out in PubMed, Scopus and Google Scholar.

3. RESULTS

3.1. Clinical and Procedural characteristics

The clinical and procedural characteristics of patients submitted to TSP are presented in Table **1**. These were 249 patients, 146 men and 103 women, aged 41.6±17.4 years, who were undergoing ablation for tachycardias related to left-sided accessory pathways (n=145) or LA foci (n=33), or PVI for AF (n=70); one patient underwent percutaneous closure of an elongated sigmoid-shaped patent foramen ovale (PFO) which could not be crossed with the guidewire and required access to the LA *via* TSP (Fig. **3**). A total of 33 patients were children or young adolescents (aged 7-18 years). A total of 14 patients were undergoing a repeat procedure. Patients with a manifest accessory pathway (Wolff-Parkinson-White syndrome) were the youngest (mean age 33.7±15.9) and patients with AF the oldest (mean age 56.0±10.8 years), while the ages of patients with concealed accessory pathways (37.0±16.5 years) and patients with left atrial tachycardia (40.9±16.5 years) were in-between (P<0.001). Measurements of the LA diameter were available only for AF patients (42±5 mm).

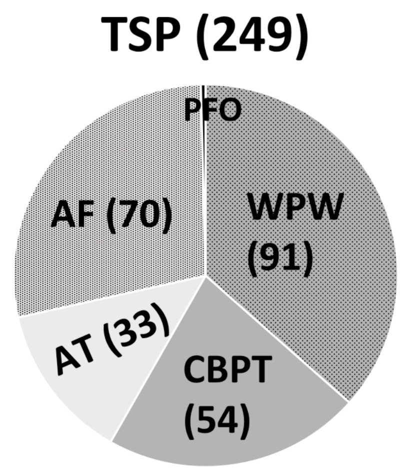

Fig. (3). The clinical indications for performing transseptal catheterization of the left atrium are displayed for 249 patients. AF = atrial fibrillation; APs = (left) accessory pathways; AT = (left) atrial tachycardia; cBPT = concealed bypass tracts; PFO = patent foramen ovale; WPW = Wolff-Parkinson-White (syndrome).

Table 1. Clinical and procedural characteristics of 249 patients undergoing transseptal access to the left atrium.

	Number	Age (y)
All patients	249	41.6±17.4
Men/Women	146/103	
Age (y)	41.6±17.4	
Young (7-18y)	33	
Left APs	145	
Manifest	91	33.7±15.9
Concealed	54	37.0±16.5
Left AT	33	40.9±16.5
AF	70	56.0±10.8
LA diameter (AF patients)	42±5 mm	
PFO closure	1	
Repeat TSP	14	
Successful TSP	247 (99.2%)	
TSP attempts	1.12±0.39	
Complications	2 (0.8%)	
Tamponade	2*	

AF = atrial fibrillation; AP = accessory pathway; AT = atrial tachycardia; PFO = patent formamen ovale; TSP = transseptal puncture
* managed successfully with pericardiocentesis (n=1) or thoracotomy (n=1).

3.2. Procedural Success and Complications

Among the 249 patients undergoing TSP, a successful procedure was accomplished in 247 (99.2%) after a mean of 1.12±0.39 attempts. Two (0.8%) TSP procedures were complicated by cardiac tamponade managed successfully with pericardiocentesis (n=1) or surgical drainage *via* thoracotomy (n=1). The ablation procedure was aborted in these two patients. The ablation procedures were initially successful in all but four (98.4%) of the other patients; one patient with persistent AF with successful PVI developed tamponade a few hours later requiring thoracotomy for drainage; he has remained free of arrhythmia over the subsequent 3 years.

3.3. Literature Review

Although there are no systematic reviews and meta-analyses of patient series undergoing TSP, several patient series have documented that fluoroscopy-guided TSP with various modifications of the technique that was employed in this series has been effective in 95-100% of the cases with a complication rate ranging from 0.0% to 6.7%, albeit with a mortality rate of 0.018%-0.2% [4, 12-24]. Echo imaging techniques were employed in cases with difficult TSP [10, 19]. These issues will be analyzed and discussed further in the Discussion section.

4. DISCUSSION

The main finding of the present study is that TSP is a demanding procedure, especially with sole use of fluoroscopy; however, using a standardized protocol can minimize serious complications, which were encountered in 2 (0.8%) of 249 consecutive patients in this series undergoing TSP mostly for ablation of a variety of cardiac arrhythmias related to left accessory pathways, LA foci or AF. Based on this single-operator experience and review of the literature, a list of practical tips and tricks is being provided how to have a successful procedure and keep it largely safe (Table **2**). It should be clarified that the present report and review describes complications strictly related to TSP, and not those

Table 2. Tips and tricks (steps and precautions) for safe transseptal puncture when guided by fluoroscopy alone.

Step	Comments	Precaution
1) BP monitoring	Place a small (4F/2F) arterial sheath in the femoral artery for BP monitoring and/or access to the aorta if contemplating to use a pigtail catheter in the aortic root for guidance/some may forego this part in specific instances	Try to avoid vascular complications / 2F sheath is preferable
2) CS & His catheters for EP procedures	Secure a steerable (6F) electrode catheter into the CS, advancing it to the left heart border if possible, to keep track of the course of the mitral annulus (Figs. **1** and **2**). A His catheter against the septal leaflet of the tricuspid valve would also be of assistance. The CS catheter marks the inferior margin of the interatrial septum (CS os) and the posterior and lateral aspects of the LA. The His catheter demarcates the superior margin of the interatrial septum and lies in juxtaposition to the noncoronary cusp of the aortic valve (its most inferior aspect)	Do not over-advance or wedge the CS catheter / Multipolar CS catheter is stiffer c/w quadripolar catheter
3) Transseptal needle curve	Make an additional smooth bend to prevent it from getting directed high toward the LA roof or the aortic root / Alternatively, one may choose among other types of needles with different curves	Avoid bending the thinner distal part of the needle
4) Transseptal sheath	Insert the sheath (Mullins, Medtronic, Minneapolis, MN, USA; Agilis SXT/SL0/SL1, St Jude Medical Inc., St Paul, MN, USA; Channel sheath, Bard electrophysiology, Lowell, MA, USA; Preface, Biosense Webster, Inc., Irwindale, CA, USA) with its dilator over a guidewire through the femoral vein into the SVC	Some sheaths, *e.g*. the Mullins sheath, can accommodate only a ≤0.32" guidewire Verify that the sheath and needle have about the same length & at what point the needle exits the dilator
5) Brockenbrough needle insertion	Remove the wire and insert the Brockenbrough needle, with smooth push / do not force (to avoid severing the dilator and the sheath) allowing it to follow through over the course of the dilator / may use the stylet inside the needle to avoid perforation and/or scraping of the plastic dilator	Keep your thumb at the proximal end of the needle at the hub of the dilator to avoid inadvertent premature needle exposure at the tip of the dilator/if using the stylet, it should not exit the dilator to avoid traumatizing the SVC
6) Withdrawing sheath-needle assembly from SVC to fossa ovalis	In the AP projection, retract the whole system (assembly) by keeping the needle indicator pointing at 4-5 o'clock direction at patient's leg	
	Observe two falls (jumps) in the anteroposterior fluoroscopic view, one obvious (passing over the aortic knob and SVC-RA junction) and a more subtle one (passing over the limbus into the fossa ovalis). The second one indicates the needle's landing into the fossa ovalis.	If not certain about the two falls, withdraw the needle, perform a good flush, re-insert the guidewire and start all over again
	The landing zone is the *fossa ovalis* which lies above the os of the CS, but not too high	Always de-air and aspirate your needle and system before puncturing or flushing

(Table 2) Contd…

Step	Comments	Precaution
7) Orientation by fluoroscopic views	When you think that your dilator has engaged the fossa ovalis, advance it a bit against the septum, move your view to LAO to confirm that it is directed posteriorly toward the septum, away from the aorta and the His catheter and either attempt puncturing the septum in this view or switch back to AP view to do this. The RAO view (adjusted so that the proximal electrode of the His catheter is in the same vertical plane as the CS catheter) helps locate the dilator tip posterior to the site of the His catheter and oriented posterior and parallel to the projected course of the CS catheter (the His catheter should be recording a His bundle electrogram in order to be used as a reliable anatomic landmark). In the LAO view, typically the tip of the dilator should be at the same level but well to the left (posterior) of the His catheter and above the CS catheter	
8) Septal staining technique	Staining of the septum with injection of 1-2 ml of contrast dye *via* the needle against the atrial septum can help visualize the fossa ovalis	
9) Pigtail catheter	If having difficulty in locating the fossa ovalis, employ a pigtail catheter positioned in the aortic root to avoid puncturing the aorta (Fig. **2**). This may be most important in the pediatric patient	
10) TS puncture	Cautiously, advance to expose the needle and if you feel that the septum has yielded, try to ● withdraw blood; it should be arterial blood, may want to check its saturation, if immediately available, flush carefully and ● connect your BP transducer, asking to switch the scale to 40 or 50 mmHg scale. If LA pressure recording is confirmed (normal recordings ~5-12 mmHg), may want to ● inject contrast dye to see its flow initially directed downward toward the LV (and not directly upward toward the aorta)	If arterial BP is recorded, do not advance the dilator and/or the sheath, withdraw the needle & monitor patient closely for development of tamponade / have the echo machine & pericardiocentesis tray standby or perform an initial echocardiogram
	For patients with a challenging anatomy of the septum (thick, aneurysmal and/or excessively mobile septum), a deep inspiration maneuver has been suggested to push the septum rightward and thus facilitate puncture	Perform this maneuver only when there is no doubt about the correct location of the needle
	Excessive septal *tenting* may pose difficulty in puncturing the septum and also increase the risk of cardiac perforation / Echo imaging (ICE/TEE) is superior as it provides direct imaging of the septum	When the septum finally yields, the operator should promptly withdraw the needle. Echo imaging modalities may be safer in these situations
	If you think that you have successfully punctured the septum based on the hand tactile feeling but cannot withdraw any blood or obtain any pressure recording through the needle, provided that this is not due to excessive tenting or pushing against the septum (non-penetration), consider needle lumen occlusion by blood clotting ● This is best prevented if you use over-heparinized saline solution	In this case, it is imperative not to attempt flushing forward, but to withdraw and remove the needle, clean it by either flushing its lumen with heparinized saline and/or inserting the thin stylet into the needle to unclog it; then repeat the TSP attempt
11) Confirm LA position	Confirm that the tip of the needle is in the LA after the initial puncture, before further advancing the dilator or sheath	Do not advance dilator and/or sheath if doubtful about the needle position
	Measurement of the pressure from the needle can differentiate between the LA pressure and the aortic pressure prior to advancing the sheath	Differentiate between LA, aortic or PA pressure
	Advancing a coronary angioplasty or other thin wire (0.014") into a pulmonary vein, *e.g.* the LSPV (outside the shadow of the heart) is helpful	N.B.: proximal kinking of the wire may indicate a RVOT or left pulmonary artery location
12) Difficulty in puncturing the septum	An alternative useful technique to safely enter the LA is using a thin (0.014") nitinol guidewire ("SafeSept", Pressure Products, Inc., San Pedro, CA, USA) through the needle to puncture the septum with its sharp tip while it resumes a safe and atraumatic J shape upon entering the LA. This works only if the needle is correctly located in the fossa ovalis, and is safer than other stiffer or thicker guidewires (*e.g.* the Inoue guidewire). Radiofrequency (RF) energy has been proposed and used for difficult TSP, with current delivered through either a thin wire or the TSP needle. There is also a modified TSP needle (Baylis Medical, Montreal, Canada) specifically designed for RF delivery from a dedicated RF generator	

(Table 2) Contd…

Step	Comments	Precaution
13) Inadvertent puncture of the aorta	If only the needle enters the aorta, it can usually be safely withdrawn without causing undue complications, but one should be vigilant for hemopericardium and tamponade	
	In case of puncture of the aortic root with the Brockenbrough needle, and inadvertent advancement of the sheath resulting in perforation of the aortic root: ● it is crucial not to withdraw the sheath, otherwise catastrophic complications may ensue, and to call the cardiothoracic surgeon to prepare the patient for an emergency surgical repair; in some instances, in the presence of the surgeon and an open operating room, sheath withdrawal has been accomplished without reported sequelae	
14) Double LA access	For AF patients undergoing conventional PVI requiring double LA access, after obtaining initial access into the LA, insert a guidewire through the sheath and park it in the LA or the left upper pulmonary vein, and then withdraw the sheath into the right atrium over the guidewire. Insert the mapping catheter by passing it through the puncture site alongside the guidewire. Then, re-insert the initial sheath over the guidewire. This will obviate the need for a second TSP with its attendant risks	
15) Repeat TSP	Extra caution is required during TSP in patients presenting for repeat LA procedures	
16) Challenging cases	In cases with known or apriori suspected challenging anatomy or cases failing the conventional approach, echo imaging techniques (TEE, ICE, 3DE) should be utilized.	
17) Accidental sheath movement into the RA	In case of accidental withdrawal of the sheath from the LA into the right atrium during the procedure, there is usually no need to repeat the TSP with its attendant risks, but rather attempt to manipulate and guide it again toward the septum at the level of the puncture site (a retained fluoroscopic image for guidance is always useful in such cases) and guide and re-advance the steerable catheter through the sheath into the LA. If this does not work or in the absence of a steerable catheter, one can use the assembly of the dilator and/or the needle inside the sheath to follow the initial steps of the TSP process without the need to re-puncture but simply advance the dilator and the sheath through the preexisting hole in the septum.	
18) Systemic embolism / OAC / Heparin / Bleeding	Performance of TSP has been considered relatively safe when performed without discontinuation of OAC therapy in patients undergoing AF ablation by maintaining a therapeutic INR with VKA, otherwise OAC is held for 2-5 days before the TSP procedure; bridging with heparin is reserved for "high-risk" patients / regarding NOACs, see text for discussion	In the event of significant bleeding or cardiac tamponade, protamine is given to reverse heparin. Additional measures include fresh frozen plasma, prothrombin complex concentrates (PCC: Factors II, VII, IX, and X), or recombinant activated factor VII (rFVIIa)
	Great caution is advised during the TSP process and, of course, during the remainder of the procedure(s) to avoid embolism of air and/or thrombi by careful flushing the catheters and the needle; we have found that the use of over-heparinized saline solution may assist in this direction to keep the sheath and the needle free of clotting	Just keep this in mind in case of bleeding complications when they ever happen in order to calculate the dose of protamine to reverse the effect of heparin
	Administration of heparin is usually reserved for after obtaining and securing a safe access into the LA, although others administer it just before TSP	Ensure meticulous de-airing of the system at all stages/maintain an ACT ~300-350 sec
19) Pericardiocentesis tray / Echo availability	Always have the pericardiocentesis tray available and be prepared and ready to perform pericardiocentesis, should it become necessary. The echo machine should be promptly available to visualize the pericardial space	When hypotension occurs during a TSP, do not lightly attribute it to vagotonia, as it is most likely due to hemopericardium and tamponade until proven otherwise
20) Cardiac surgery back-up	In the event of tamponade not responding to pericardiocentesis, surgical intervention is life-saving; such circumstances prove the importance of cardiac surgical back-up being available in centers performing TSP procedures.	Remember to reverse heparin with protamine

AF = atrial fibrillation; BP = blood pressure; CS = coronary sinus; ICE = intracardiac echocardiography; 3DE = three-dimensional echocardiography; LA = left atrium; LAO = left anterior oblique; LSPV = left superior pulmonary vein; LV = left ventricle; OAC = oral anticoagulant; PA = pulmonary artery; PVI = pulmonary vein isolation; RA = right atrium; RAO = right anterior oblique; RVOT = right ventricular outflow tract; SVC = superior vena cava; TEE = transesophageal echocardiography; TSP = transseptal puncture.

Table 3. Comparison of fluoroscopy versus echo-imaging guidance of TSP.

Parameter	Fluoroscopy Guidance	Echo Imaging (TEE/ICE) Guidance
Ease of use	↑	↓
Patient convenience	↑	↓
Anesthesia	Local	General / Conscious sedation (TEE)
Cost	↓	↑
Direct imaging of IAS	↓	↑
Detailed anatomy	↓	↑
Site specific TSP	?	Yes
Safety & success in difficult cases	↓	↑
Extra venous access	No	Yes (ICE)
Extra operator	No	Yes

IAS = interatrial septum; ICE = intracardiac echocardiography; TEE = transesophageal echocardiography; TSP = transseptal puncture.

resulting from the ensuing procedures, *e.g.* the ablation part of the procedure. The importance of such information is realized when one considers the number of procedures requiring TSP nowadays, which is growing at a very fast pace, especially with the introduction of PVI for patients with AF, as well as the newer procedures, such as the MitraClip procedures and occlusion of the LAA [2].

4.1. Indications for LA Access

The need for LA access essentially started with mitral valvotomies for patients with rheumatic mitral stenosis and suitable anatomy of the valve apparatus [1], continued with the advent of catheter ablation for left-sided atrial arrhythmic foci and left accessory pathways [4, 25], and some left ventricular foci, but it really took off with the ablation procedures for AF [5, 6, 26]. More recently, additional expansion and growth of the TSP procedures took place with further development of transcatheter techniques for mitral valve disease (MitraClip for mitral regurgitation, valve-in-valve implantation for failed mitral bioprosthesis, mitral paravalvular leak repair, even transcatheter mitral valve replacement) [26]. Lately, LA appendage closure was added to the list of procedures performed *via* TSP [2]. Another indication may include placement of transseptal left ventricular assist device systems.

The distribution of procedures requiring TSP in our cohort is presented in Fig. (**3**), indicating that the majority were performed for left-sided accessory pathways, with AF ablation coming next. However, nowadays AF ablation procedures dominate having surpassed in numbers all other procedures requiring TSP [14].

4.2. TSP Procedure

The steps to be taken for the TSP procedure are detailed in Table **2**. Briefly, one starts with establishing blood pressure monitoring during the procedure with use of an intraarterial line (femoral or radial), although some may forego this step in routine procedures of ablation in order to avoid vascular complications [27]. However, this appears particularly important for structural heart interventions [28], or for procedures requiring general anesthesia or deep sedation. We have found that use of a very small (2French) sheath that has recently become available may be a most practical and nonintrusive approach. The most important step during the TSP procedure appears to be the correct landing of the transseptal sheath/needle assembly into the fossa ovalis and the avoidance of inadvertent puncture of adjacent structures, particularly the aorta. Several landmarks may be used with fluoroscopic guidance alone utilizing different (AP/LAO/RAO) fluoroscopic views or in difficult or demanding situations guidance is best provided with echo imaging. Upon puncturing the inter-atrial septum, it is imperative to ensure that the needle has entered the left atrium (LA) before attempting to advance the dilator and then the sheath over it into the LA. Pressure recording from the LA, withdrawing arterial blood, and contrast injection (and observing its downward course toward the left ventricle), all *via* the needle, can provide such confirmation. If unsure, the needle is withdrawn and all recommended steps are repeated (Table **2**). Alternative techniques providing useful information and guidance are also described in Table **2** and can be viewed in the online video.

4.3. Puncture Site (Fossa Ovalis)

Key to a successful TSP procedure is to place the sheath bearing the needle against the interatrial septum at the level of the fossa ovalis (Figs. **1**, **2** and **4**). In order to achieve this, certain procedural steps and the surrounding landmarks can assist the operator to land the needle at the right site. According to a survey of Italian centers, the main reason for TSP not being performed was related to difficulties in localization and puncturing of the fossa ovalis [14]. Traditional TSP techniques employed a pigtail catheter positioned in the aortic root to avoid puncturing the aorta. This may still be important in the pediatric patient where distances are small in the small heart, however, this seems not to be routinely necessary in the adult patient. A major advantage of an electrophysiologist performing the TSP relates to its familiarity

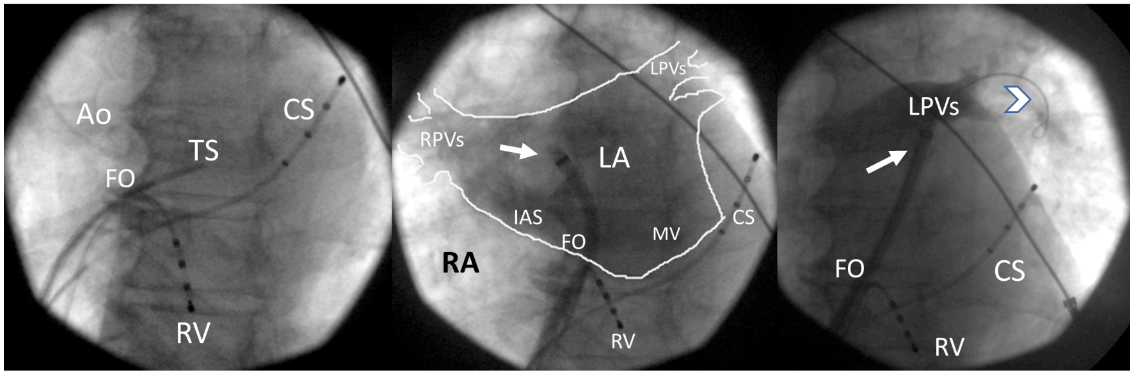

Fig. (4). The figure illustrates the anatomic landmarks for a transseptal puncture. Shallow left anterior obliques views (15°) are displayed. An angiogram of the left atrium (LA) is shown in the mid panel with a superimposed diagram. The transseptal needle (TS) has punctured the fossa ovalis (FO) and has entered the LA (left panel); a pigtail catheter indicates the position of the aorta (Ao). The LA position of the needle is confirmed with pressure recording, withdrawing arterial blood, and injecting contrast dye *via* the needle before the dilator and the sheath (arrows) are advanced into the LA. Another way to ensure correct LA entrance is to advance a thin wire *via* the needle into the left pulmonary vein (arrowhead, right panel) (outside the heart shadow). CS = coronary sinus; IAS = intra-atrial septum; LPVs = left pulmonary veins; MV = mitral valve; RPVs = right pulmonary veins; RV = right ventricle; TS = transseptal (system).

with positioning of a steerable catheter into the CS serving as an excellent guide to TSP, marking the inferior margin of the interatrial septum (CS os) and the posterior and lateral aspects of the LA (Figs. **1, 2** and **4**) [13, 15, 16]. Furthermore, a catheter in the His bundle position demarcates the superior margin of the interatrial septum and is in juxtaposition to the noncoronary cusp of the aortic valve (Fig. **1**).

4.4. Complications

The major complications produced by TSP relate to trauma of adjacent structures causing hemopericardium and cardiac tamponade when puncturing posterior to the fossa ovalis (injuring the free wall) or anterior to the fossa ovalis (piercing the aortic root) [8, 29]. Furthermore, inadvertent puncture of the superior atrioventricular segment of the membranous ventricular septum can lead to direct left ventricular–right atrial communication [30]. Other complications may comprise transient ST elevation that may be attributed to air embolism [31], although some have attributed it to vagotonia [32], coronary vasospasm [31], thrombus formation in the transeptal system (sheath/dilator/needle) and thromboembolism [21, 33]. An incidence of 0.4% of transient ST elevation was reported in a large cohort study, whith no observed sequelae [32]. Other rare complication that may be encountered includes detached tips of the transseptal sheaths [34].

The complication rate was 0.80% in our cohort, which compares well with the 0.74-1.3% rate reported in much larger series [7, 14, 35]; a higher (2.8%) complication rate during TSP has been reported in smaller series [21]. Previous series have also reported a definite, albeit small, mortality risk with TSP ranging from 0.018% to 0.08% [7, 14]. Complications may occur during the needle puncture or during the advancement of the dilator and the sheath [36]. With inadvertent puncture of adjacent structures, if noted early and dilator/sheath advancement avoided, usually catastrophies may be averted. However, expanding the iatrogenic hole with sheath advancement could be potentially catastrophic [37]. Thromboembolic complications may well be prevented by adequate anticoagulation (discussed below) and meticulous aspiration and flushing routine during the procedures, especially when exchanging wires and/or catheters; de-airing is also very important in order to avoid air embolism.

4.5. Iatrogenic ASD

An important issue of TSP and subsequent use of large-bore sheaths through the septum relates to persistent or iatrogenic atrial septal defects [38] which have been reported to be detected in the majority (87%) of patients in the immediate post-procedural period, but with significantly decreasing percentage (7%) over the ensuing 12 months [39]. Fortunately, no increased rate of system thromboembolization has been reported in these cases. In rare cases with large defects with septal tears associated with hemodynamic compromise, these defects need to be closed in the index procedure [40]. Particularly, in transcatheter mitral valve repair procedures entailing the use of very large sheaths (21F) across the septum and prolonged procedural time, a persistence rate of 50% iatrogenic ASD has been reported and most importantly, persistent interatrial shunting was associated with worse clinical outcomes and increased mortality [41]. A lower (20%) rate of persistent iatrogenic ASDs at 1 year has been reported in procedures employing smaller (15F) sheaths [42]. However, there may be a difference of iatrogenic ASD between the different ablation techniques. According with a study comparing cryoballoon with radiofrequency ablation, the incidence of iatrogenic ASD at 1-year follow-up following the procedure was significantly higher in the cryoballoon compared with the radiofrequency ablation group (22.2% *vs.* 8.5%; P = 0.03) [43]. Fortunately, no adverse events were recorded in these patients during the follow-up.

4.6. Echo Imaging *versus* Fluoroscopy

Imaging modalities such as intracardiac (ICE) or transesophageal echocardiography (TEE) may improve the safety and efficacy of TSP [9-11, 44], albeit at an incremental cost, patient inconvenience and increased complexity of the procedure, which limit usage of these methods. Although imaging has been adopted routinely in the US for performing a TSP, particularly with use of ICE during AF ablation [45-

48], with few exceptions [49], this has not been the case in other countries [50]. Some investigators have suggested an added value of TEE to traditional fluoroscopic approach during TSP performed by inexperienced operators in guiding the TSP assembly in a correct puncture position (which could not be achieved by fluoroscopy alone in 16% and needed repositioning based on TEE) and thus avoiding TSP-related complications [51]. However, there have been no randomized prospective comparative studies to examine this issue.

A Swedish study analyzed 4690 consecutive TSP procedures performed between 2000 and 2015 for ablation of a variety of arrhythmias, done under fluoroscopy, pressure monitoring, and contrast dye injection [50]. In 27 procedures, ICE or TEE was used to guide the TSP. They reported 34 (0.72%) tamponades that required pericardial drainage, of which 28 (0.59%) could possibly be TSP related. A higher rate of tamponades was observed in the AF group than in the accessory pathway group (0.88 *vs*. 0.17%, $P < 0.02$). The highest rate of tamponades was registered during the operators' first 51-100 cases (1.3%), and decreased to 0.4% in cases 101-200 ($P = 0.04$). The authors concluded that TSP can safely be done under fluoroscopy and pressure monitoring without routine use of additional techniques, while increased experience may further decrease complication rate.

According to an observational study comparing 91 patients undergoing TSP for AF ablation guided by either fluoroscopy (n=57) or TEE (n=34), TEE-guided TSP was associated with shorter procedures and only a trend toward lower complication rates (20.6% *vs*. 31.6%) with no statistically significant difference (p=0.37) [10] (N.B.: these rates refer to the total procedure complication rates and not just to TSP complications). Some comparative elements between the fluoroscopic and echo imaging techniques are presented in Table **3**.

Simple fluoroscopy has also been safely used to guide TSP in the pediatric population. Among 157 consecutive children (median age 12.5 years) undergoing TSP for ablation of LA arrhythmic targets guided by fluoroscopy (TEE used in only 3 patients), successful TSP was possible in 99.4% of the cases, with no complications associated with the TSP [24]. Similarly, TSP procedures were successfully performed by fluoroscopy guidance alone in 321 pediatric patients and 34 patients with congenital heart disease with 1.9% complication rate (pericardial effusions) [20].

4.7. Other Techniques

Other techniques have been suggested, such as use of a very thin guidewire within the needle [52, 53] or use of an RF needle to facilitate septal puncture [21], especially for patients with thick, fibrous or aneurysmal interatrial septum. For the latter patients, a deep inspiration maneuver has been suggested to push the septum rightward and thus facilitate puncture, but only when there is no doubt about the correct location of the needle [54]. We used the thin guidewire method in half-a-dozen of our patients having a PVI procedure and found it quite practical and useful. This is a 0.014" nitinol wire which is inserted into the lumen of the transseptal needle and with its sharp distal tip it can penetrate the septum and immediately upon its entry into the LA assume a J-shape that renders it atraumatic [12]. The prerequisite for this approach to be successful is the correct positioning of the needle against the thin membranous part of the septum at the level of the fossa ovalis. A limitation of this technique is the inability to freely inject contrast with the wire in situ, although it can be done to a limited degree through the tip of the needle, and the recorded pressure is often dampened. Another important advantage of using the thin wire is its ability to help confirm the correct LA anatomic location by advancing it into the left superior pulmonary vein and seeing its course outside the shadow of the heart (arrowhead, Fig. **4**). Caution has been advised with use of the RF energy delivery *via* the transseptal needle as tissue coring or plugging of the needle may occur with a potential embolic risk [55].

4.8. Tips and Tricks

A comprehensive list of tips and tricks for a successful and safe TSP is presented in Table **2**. It starts with the need for continuous BP monitoring during the procedure and proceeds with the type of catheters utilized during the electrophysiology procedures serving as topology guides. It provides suggestions for optimizing the angulation of the transseptal needle which is usually not curved enough when taken out from its package, and the operator needs to make an additional smooth bend to prevent it from getting directed high toward the LA roof or the aortic root. While shaping the distal end of the needle, one should avoid touching and pressing on the tapered thinner distal part of the needle for risk of fracture which could be potentially disastrous if it occurs inside during TSP [56]. Alternatively, one may choose among other types of needles with different angulations.

The most important step in performing a successful TSP is reaching the landing target of the transseptal sheath/needle assembly, which is the *fossa ovalis*, where puncture is attempted. Occasionally, when one thinks that one has successfully punctured the septum based on the hand tactile feeling but cannot withdraw any blood or obtain any pressure recording through the needle, provided that this is not due to excessive tenting or pushing against the septum (non-penetration), one has to consider needle lumen occlusion by blood clotting. In this case, one needs to withdraw the needle, clean it by either flushing its lumen with heparinized saline and/or inserting the thin stylet into the needle to unclog it. This is best prevented if one uses over-heparinized saline solution.

One important factor that may pose difficulty in puncturing the septum and also increase the risk of cardiac perforation relates to the degree of excessive septal *tenting* that may occur while pushing the needle against the septum, especially if the needle is not located in the fossa ovalis or if its tip is not that sharp. An atrial septal aneurysm may also be the reason of deep tenting of the septum into the LA. When the needle gets finally through the septum, the power applied for pushing may lead to perforating the LA free wall if the operator does not immediately retrieve back the needle the moment that the septal wall yields and gets punctured. Echo imaging modalities may be safer in these situations.

4.9. Fluoroscopic Views

Different fluoroscopic views may be very helpful in getting anatomically oriented (Table **2**). The right anterior oblique (RAO) view (30-40°) helps locate the dilator tip posterior to the site of the His catheter and angled posterior and parallel to the projected course of the CS catheter. The LAO view (30-35°) helps locate the dilator tip well to the left (posterior) of the His bundle catheter and above the CS catheter pointing toward the spine.

4.10. Double LA Access

In patients with AF undergoing PVI with use of the conventional point-by-point RF ablation technique, there is need to introduce two separate catheters into the LA, which is effected with either double TSP or single TSP-double transseptal catheterization of the LA, thus increasing procedure complexity and risk [17, 57]. When PVI is performed with use of the single-shot techniques, either circular RF ablation or cryo-balloon ablation, a single TSP is required [5].

4.11. Repeat Procedures

Patients, particularly those with who have undergone ablation for AF, having a repeat procedure pose more difficulties and complications during repeat TSP attributable to thickened or distorted septum, requiring extra caution and guiding tools [22, 58]. One of the two patients having a complication in our series was undergoing his third TSP; he had his first procedure 7 years earlier for accessory pathway ablation and the second TSP 1 year earlier for persistent AF. Nevertheless, TSP was successful in 13 (92.9%) of 14 patients having a repeat procedure guided by fluoroscopy alone. Other investigators have reported only 81% successful repeat TSP among 16 patients despite ICE guidance [58], however, larger series had higher success rates with ICE guidance [19].

Indeed, ICE has been particularly advocated as the main tool to guide such procedures. Among 251 AF patients undergoing ablation after multiple prior TSP procedures (n=224) or prior atrial septal repair (n=27), ICE-guided TSP was accomplished in 212 (95%) and 20 (74%) respectively, with 2 (1%) complications in the first group, similar with those in the control arm (n = 6 or 1%) [19].

4.12. Access *via* a PFO

With regards to initially probing the septum for a possible PFO that would facilitate access to the LA obviating the need for a TSP, there are different views and suggested approaches. In addition to probing for a PFO, probing has also been used *via* a prior puncture site to introduce a second catheter into the LA. Some have reported more complications with the probing technique leading to cardiac tamponade [22].

4.13. Topology

Finally, when TSP proves difficult with use of fluoroscopy alone, guidance by TEE or ICE should be strongly entertained [58, 59]. Some have advocated that topology of the TSP site may be important to facilitate different procedures, *e.g.*, posteroinferior region for PVI, center or inferior aspect of the septum for LAA occlusion, and superior and posterior-mid aspect of the fossa ovalis for the MitraClip, but site-specific TSP is usually not necessary for other types of LA procedures [60, 61]. Nevertheless, guiding by echo imaging is important when this is deemed necessary, particularly for mitral valve techniques [62].

4.14. Closure Device in Place

Finally, TSP is expected to be technically challenging in patients with device closure of interatrial septal communications, whereby imaging methods prior to and during the procedure will be required to determine a safe puncture space [63, 64].

4.15. Periprocedural Anticoagulation

For TSP performed for AF ablation, periprocedural continuation of oral anticoagulant (OAC) therapy with warfarin and maintaining a therapeutic INR (2.0-3.0) and receiving heparin bolus before TSP has been recommended as leading to lower thromboembolic complications [46], but not necessarily followed by all operators [65]. Discontinuation of warfarin and bridging with heparin has been associated with high incidence of bleeding complications, hence the new trend toward performing the procedure on therapeutic OAC [65].

With regards to non-vitamin K OACs (NOACs), there was initial concern about an increased bleeding risk and lack of antidote, but this has not been entirely confirmed in studies [66]. Thus, it has been suggested that NOACs appear relatively safe to use in an uninterrupted manner, at least for AF ablation procedures. Indeed, the RE-CIRCUIT trial indicated that in patients undergoing ablation for AF, anticoagulation with uninterrupted dabigatran was associated with fewer bleeding complications than uninterrupted warfarin [66]. A prior meta-analysis of 25 studies including 11,686 AF patients undergoing ablation indicated that there was no significant difference between NOACs (whether interrupted or uninterrupted) and uninterrupted VKAs in thromboembolic or bleeding risk [67]. A lower risk of minor bleeding was observed with NOACs (OR 0.80), and no major differences were observed for the risk of thromboembolic events, cardiac tamponade or pericardial effusion requiring drainage, and groin hematoma. Another recent meta-analysis of 19 studies, comprising 7996 AF patients undergoing AF ablation, indicated that NOAC treatment was associated with fewer overall bleeding events than continuous warfarin treatment (RR = 0.78, $P = 0.01$), or interrupted warfarin treatment (RR = 0.58, $P = 0.0002$) [68]. However, in the subgroup analyses, the incidence of overall bleeding events (RR = 0.67, $P = 0.01$) and minor bleeding events (RR = 0.56, $P = 0.007$) in the interrupted NOAC group was lower than that in the continuous warfarin group. NOAC treatment did not increase the risk of thromboembolic complications compared with warfarin treatment ($P > 0.05$). The authors concluded that periprocedural NOAC therapy was as effective as continuous warfarin therapy for preventing thromboembolism and had a lower incidence of bleeding complications. Interrupted NOAC therapy during the periprocedural period might result in a lower incidence of bleeding complications compared with continuous NOAC therapy.

Finally, regarding intraprocedural use of heparin, the recommendation is to administer it just before or immediately after TSP and maintain an activated clotting time (ACT) around 300-350 sec [65].

CONCLUSION

Access to the LA *via* a TSP is a demanding procedure, especially with sole use of fluoroscopy; however, using a standardized protocol can minimize serious complications, which were encountered in 2 (0.8%) of 249 consecutive patients in this series undergoing TSP mostly for ablation of a variety of cardiac arrhythmias related to left accessory pathways, LA foci or AF. Based on this single-operator experience and review of the literature, a list of practical tips and tricks has been provided in order to have a successful and safe procedure, accomplished in the vast majority of patients. In difficult or failed cases, echo imaging techniques are most useful, albeit more expensive and patient inconveniencing methods.

LIST OF ABBREVIATIONS

AF	=	Atrial Fibrillation
CS	=	Coronary Sinus
ICE	=	Intracardiac Echocardiography
LA	=	Left Atrium
LAA	=	Left Atrial Appendage
PVI	=	Pulmonary Vein Isolation
RF	=	Radiofrequency
TEE	=	Transesophageal Echocardiography
TSP	=	Transseptal Puncture

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The author declares no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

Declared none.

SUPPLEMENTARY MATERIAL

Supplementary video is available on the publisher's web site along with the published article.

REFERENCES

[1] Ross J, Jr. Transseptal left heart catheterization a 50-year odyssey. J Am Coll Cardiol 2008; 51(22): 2107-15.
[2] Babaliaros VC, Green JT, Lerakis S, Lloyd M, Block PC. Emerging applications for transseptal left heart catheterization old techniques for new procedures. J Am Coll Cardiol 2008; 51(22): 2116-22.
[3] Earley MJ. How to perform a transseptal puncture. Heart 2009; 95(1): 85-92.
[4] Manolis AS, Wang PJ, Estes NA, 3rd. Radiofrequency ablation of left-sided accessory pathways: transaortic versus transseptal approach. Am Heart J 1994; 128(5): 896-902.
[5] Georgiopoulos G, Tsiachris D, Manolis AS. Cryoballoon ablation of atrial fibrillation: A practical and effective approach. Clin Cardiol 2017; 40(5): 333-42.
[6] Manolis AS. Ablation of atrial fibrillation: single-shot techniques poised to dominate rhythm control strategies/the future is here. J Thorac Dis 2017; 9(5): E313-21.
[7] Roelke M, Smith AJ, Palacios IF. The technique and safety of transseptal left heart catheterization: The Massachusetts General Hospital experience with 1,279 procedures. Cathet Cardiovasc Diagn 1994; 32(4): 332-9.
[8] Holmes DR, Jr., Nishimura R, Fountain R, Turi ZG. Iatrogenic pericardial effusion and tamponade in the percutaneous intracardiac intervention era. JACC Cardiovasc Interv 2009; 2(8): 705-17.
[9] Tucker KJ, Curtis AB, Murphy J*, et al.* Transesophageal echocardiographic guidance of transseptal left heart catheterization during radiofrequency ablation of left-sided accessory pathways in humans. Pacing Clin Electrophysiol 1996; 19(3): 272-81.
[10] Erden I, Erden EC, Golcuk E*, et al.* Impact of transesophageal echocardiography during transseptal puncture on atrial fibrillation ablation. J Arrhythm 2016; 32(3): 170-5.
[11] Lin D, Callans DJ. Use of intracardiac echocardiography during atrial fibrillation ablation to avoid complications. Future Cardiol 2015; 11(6): 683-7.
[12] Wadehra V, Buxton AE, Antoniadis AP*, et al.* The use of a novel nitinol guidewire to facilitate transseptal puncture and left atrial catheterization for catheter ablation procedures. Europace 2011; 13(10): 1401-5.
[13] De Ponti R, Zardini M, Storti C, Longobardi M, Salerno-Uriarte JA. Trans-septal catheterization for radiofrequency catheter ablation of cardiac arrhythmias. Results and safety of a simplified method. Eur Heart J 1998; 19(6): 943-50.
[14] De Ponti R, Cappato R, Curnis 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.
[15] Subinas A, Montero V, Ormaetxe JM, Martinez-Alday JD, Arcocha MF, Aguirre JM. Transseptal catheterization using electrophysiological landmarks in ablation procedures. Rev Esp Cardiol 2007; 60(1): 80-3.
[16] Yao Y, Guo J, Ding LG*, et al.* Improved approach to atrial septum puncture: experience in 539 cases. Chin Med J (Engl) 2012; 125(6): 1179-81.
[17] Fagundes RL, Mantica M, De Luca L*, et al.* Safety of single transseptal puncture for ablation of atrial fibrillation: retrospective study from a large cohort of patients. J Cardiovasc Electrophysiol 2007; 18(12): 1277-81.
[18] Wasmer K, Zellerhoff S, Kobe J*, et al.* Incidence and management of inadvertent puncture and sheath placement in the aorta during attempted transseptal puncture. Europace 2017; 19(3): 447-57.
[19] Arkles J, Zado E, Supple G*, et al.* Feasibility of transseptal access in patients with previously scarred or repaired interatrial septum. J Cardiovasc Electrophysiol 2015; 26: 963-8.
[20] von Alvensleben JC, Dick M, 2nd, Bradley DJ, LaPage MJ. Transseptal access in pediatric and congenital electrophysiology procedures: Defining risk. J Interv Card Electrophysiol 2014; 41(3): 273-7.
[21] Hsu JC, Badhwar N, Gerstenfeld EP*, et al.* Randomized trial of conventional transseptal needle versus radiofrequency energy needle puncture for left atrial access (the TRAVERSE-LA study). J Am Heart Assoc 2013; 2(5): e000428.
[22] Lehrmann H, Schneider J, Jadidi AS*, et al.* Transseptal access for left atrial ablation: the catheter-probing techniques are not without risk. J Cardiovasc Electrophysiol 2014; 25(5): 479-84.
[23] Braunwald E. Cooperative study on cardiac catheterization. Transseptal left heart catheterization. Circulation 1968; 37(5 Suppl): III74-9.
[24] Ehrlinspiel DM, Gass M, Balmer C. Transseptal puncture for radiofrequency catheter ablations of left-sided arrhythmias in a paediatric population. Cardiol Young 2017; 27(2): 267-72.

[25] Manolis AS, Wang PJ, Estes NA, 3rd. Radiofrequency catheter ablation for cardiac tachyarrhythmias. Ann Intern Med 1994; 121(6): 452-61.
[26] Alkhouli M, Rihal CS, Holmes DR, Jr. Transseptal techniques for emerging structural heart interventions. JACC Cardiovasc Interv 2016; 9(24): 2465-80.
[27] Maggi R, Viscardi V, Furukawa T, Brignole M. Non-invasive continuous blood pressure monitoring of tachycardic episodes during interventional electrophysiology. Europace 2010; 12(11): 1616-22.
[28] Tzikas A, Gafoor S, Meerkin D*, et al.* Left atrial appendage occlusion with the AMPLATZER Amulet device: an expert consensus step-by-step approach. EuroIntervention 2016; 11(13): 1512-21.
[29] Aras D, Ozeke O, Cay S, Ozcan F, Kara M, Topaloglu S. Inadvertent puncture of the aortic noncoronary cusp during postoperative left atrial tachycardia ablation. J Arrhythm 2015; 31(4): 235-7.
[30] Chavarria N, Goldbarg S. Left ventricle penetration - A rare complication of transseptal puncture and catheter ablation for supraventricular tachycardia. Heart Rhythm Case Reports 2015; 1: 382-3.
[31] Le BH, Black JN, Huang SK. Transient ST-segment elevation during transseptal catheterization for atrial fibrillation ablation. Tex Heart Inst J 2010; 37(6): 717-21.
[32] Tang RB, Dong JZ, Long DY*, et al.* Incidence and clinical characteristics of transient ST-T elevation during transseptal catheterization for atrial fibrillation ablation. Europace 2015; 17(4): 579-83.
[33] Storti C. Transseptal catheterization: technique and complications. G Ital Cardiol (Rome) 2012; 13(10 Suppl 2): 101s-4.
[34] El-Damaty A, Love M, Parkash R. Detached tip of a transseptal sheath during left atrial ablation. Catheter Cardiovasc Interv 2012; 79(3): 444-7.
[35] Wang Y, Xue YM, Mohanty P*, et al.* Dilator method and needle method for atrial transseptal puncture: a retrospective study from a cohort of 4443 patients. Europace 2012; 14(10): 1450-6.
[36] Tzeis S, Andrikopoulos G, Deisenhofer I, Ho SY, Theodorakis G. Transseptal catheterization: considerations and caveats. Pacing Clin Electrophysiol 2010; 33(2): 231-42.
[37] Mijangos-Vazquez R, Garcia-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.
[38] O'Brien B, Zafar H, De Freitas S, Sharif F. Transseptal puncture - Review of anatomy, techniques, complications and challenges. Int J Cardiol 2017; 233: 12-22.
[39] Singh SM, Douglas PS, Reddy VY. The incidence and long-term clinical outcome of iatrogenic atrial septal defects secondary to transseptal catheterization with a 12F transseptal sheath. Circ Arrhythm Electrophysiol 2011; 4(2): 166-71.
[40] Huntgeburth M, Muller-Ehmsen J, Baldus S, Rudolph V. Postinterventional iatrogenic atrial septal defect with hemodynamically relevant left-to-right and right-to-left shunt as a complication of successful percutaneous mitral valve repair with the MitraClip. Int J Cardiol 2013; 168(1): e3-5.
[41] Schueler R, Ozturk C, Wedekind JA*, et al*. Persistence of iatrogenic atrial septal defect after interventional mitral valve repair with the MitraClip system: a note of caution. JACC Cardiovasc Interv 2015; 8(3): 450-9.
[42] Sieira J, Chierchia GB, Di Giovanni G*, et al.* One year incidence of iatrogenic atrial septal defect after cryoballoon ablation for atrial fibrillation. J Cardiovasc Electrophysiol 2014; 25(1): 11-5.
[43] Mugnai G, Sieira J, Ciconte G*, et al.* One Year Incidence of Atrial Septal Defect after PV Isolation: A Comparison Between Conventional Radiofrequency and Cryoballoon Ablation. Pacing Clin Electrophysiol 2015; 38(9): 1049-57.
[44] Kuwahara T. Intracardiac echocardiography in catheter ablation for atrial fibrillation: It is better to see what you are doing? J Atr Fibrillation 2015; 7(6): 1215.
[45] Su W, Kowal R, Kowalski M*, et al.* Best practice guide for cryoballoon ablation in atrial fibrillation: The compilation experience of more than 3000 procedures. Heart Rhythm 2015; 12(7): 1658-66.
[46] Di Biase L, Briceno DF, Trivedi C*, et al.* Is transesophageal echocardiogram mandatory in patients undergoing ablation of atrial fibrillation with uninterrupted novel oral anticoagulants? Results from a prospective multicenter registry. Heart Rhythm 2016; 13(6): 1197-202.
[47] Russo AD, Russo E, Fassini G*, et al.* Role of Intracardiac echocardiography in Atrial Fibrillation Ablation. J Atr Fibrillation 2013; 5(6): 786.
[48] Ruisi CP, Brysiewicz N, Asnes JD*, et al.* Use of intracardiac echocardiography during atrial fibrillation ablation. Pacing Clin Electrophysiol 2013; 36(6): 781-8.
[49] Cheng A, Calkins H. A conservative approach to performing transseptal punctures without the use of intracardiac echocardiography: stepwise approach with real-time video clips. J Cardiovasc Electrophysiol 2007; 18(6): 686-9.
[50] Matoshvili Z, Bastani H, Bourke T*, et al.* Safety of fluoroscopy-guided transseptal approach for ablation of left-sided arrhythmias. Europace 2017; [Epub ahead of print].
[51] Bayrak F, Chierchia GB, Namdar M*, et al.* Added value of transoesophageal echocardiography during transseptal puncture performed by inexperienced operators. Europace 2012; 14(5): 661-5.
[52] Zucchetti M, Casella M, DelloRusso A*, et al.* Difficult case of a trans-septal puncture: Use of a "SafeSept" guidewire. World J Cardiol 2015; 7(8): 499-503.
[53] Knadler JJ, Anderson JB, Chaouki AS*, et al.* Utility and safety of the SafeSept transseptal guidewire for electrophysiology studies with catheter ablation in pediatric and congenital heart disease. J Interv Card Electrophysiol 2017; 48(3): 369-74.
[54] Aksu T, Guler TE, Yalin K, Golcuk SE, Ozcan KS, Guler N. A novel deep inspiration maneuver for difficult transseptal puncture. Am J Cardiol 2017; 119(3): 428-33.
[55] Greenstein E, Passman R, Lin AC, Knight BP. Incidence of tissue coring during transseptal catheterization when using electrocautery and a standard transseptal needle. Circ Arrhythm Electrophysiol 2012; 5(2): 341-4.
[56] Parker JO, West RO, Fay JE. The Brockenbrough transseptal catheterization: An unusual complication. Circulation 1964; 30: 743-4.
[57] Yamada T, McElderry HT, Epstein AE, Plumb VJ, Kay GN. One-puncture, double-transseptal catheterization manoeuvre in the catheter ablation of atrial fibrillation. Europace 2007; 9(7): 487-9.
[58] Marcus GM, Ren X, Tseng ZH*, et al*. Repeat transseptal catheterization after ablation for atrial fibrillation. J Cardiovasc Electrophysiol 2007; 18(1): 55-9.
[59] Sy RW, Klein GJ, Leong-Sit P*, et al.* Troubleshooting difficult transseptal catheterization. J Cardiovasc Electrophysiol 2011; 22(6): 723-7.
[60] Bazaz R, Schwartzman D. Site-selective atrial septal puncture. J Cardiovasc Electrophysiol 2003; 14(2): 196-9.
[61] Chierchia GB, Casado-Arroyo R, de Asmundis C*, et al.* Impact of transseptal puncture site on acute and mid-term outcomes during cryoballoon ablation: a comparison between anterior, medial and posterior transatrial access. Int J Cardiol 2013; 168(4): 4098-102.
[62] Sherif MA, Paranskaya L, Yuecel S*, et al.* MitraClip step by step; how to simplify the procedure. Neth Heart J 2017; 25(2): 125-30.
[63] Wagdi P, Alkadhi H. Can computer tomography help predict feasibility of transseptal puncture after percutaneous closure of an interatrial septal communication? J Interv Card Electrophysiol 2012; 34(2): 167-72.
[64] Zaker-Shahrak R, Fuhrer J, Meier B. Transseptal puncture for catheter ablation of atrial fibrillation after device closure of patent foramen ovale. Catheter Cardiovasc Interv 2008; 71(4): 551-2.
[65] Calkins H, Kuck KH, Cappato R*, 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.e621.

[66] Calkins H, Willems S, Gerstenfeld EP*, et al.* Uninterrupted dabigatran versus warfarin for ablation in atrial fibrillation. N Engl J Med 2017; 376(17): 1627-36.

[67] Wu S, Yang YM, Zhu J*, et al*. Meta-analysis of efficacy and safety of new oral anticoagulants compared with uninterrupted vitamin k antagonists in patients undergoing catheter ablation for atrial fibrillation. Am J Cardiol 2016; 117(6): 926-34.

[68] Zhao Y, Yang Y, Tang X, Yu X, Zhang L, Xiao H. New oral anticoagulants compared to warfarin for perioperative anticoagulation in patients undergoing atrial fibrillation catheter ablation: a meta-analysis of continuous or interrupted new oral anticoagulants during ablation compared to interrupted or continuous warfarin. J Interv Card Electrophysiol 2017; 48(3): 267-82.