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STRUCTURAL HEART DISEASE (RJ SIEGEL AND NC WUNDERLICH, SECTION EDITORS)

# Transseptal Puncture: Devices, Techniques, and Considerations for Specific Interventions

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## Abstract

**Purpose of Review** Transseptal puncture is a routinely performed interventional cardiology procedure for an array of cardiac diseases. We aimed to review the current status of available devices and techniques of transseptal puncture with consideration to specific interventions.

**Recent Findings** Except for a few modifications, devices for transseptal puncture technique has not changed much compared to when it was first described almost 60 years ago. For difficult transseptal puncture, a few newer techniques such as radio frequency needle puncture system have been used but there is lack of robust clinical study. Advanced imaging, such as intracardiac echocardiography and transesophageal echocardiography, has been found to make transseptal puncture safer. A new transseptal approach that incorporates 3D non-fluoroscopic catheter tracking systems has shown promising results in two human studies.

**Summary** While various modifications in the transseptal technique tailored to the specific interventions have improved procedural safety, further improvement in existing devices focusing on distinct procedure might be needed in the future.

**Keywords** Transseptal puncture · Fossa ovalis · Brockenbrough needle · Radio frequency needle · Intracardiac echocardiography

## Introduction

Transseptal puncture (TSP) was initially developed in 1958 for diagnostic purposes of left heart catheterization and LA pressure measurement [1, 2]. After the early days of its inception, there remained a hiatus in the widespread use of TSP until 1980s. Utilization of TSP took to the new height when percutaneous valvular replacement and pulmonary vein isolation became routine cardiac procedures [3]. Now one of the most commonly performed procedures in interventional cardiology, TSP is used in left-sided arrhythmia ablation, left atrial appendage closure, percutaneous left ventricular assist device, and various mitral valve disease procedures.

Interventionalist involved in TSP should have in-depth knowledge of the anatomy of interatrial septum and surrounding structures. The interatrial septum, formed by the fusion of septum primum and secundum, represents the anatomical target for TSP and is anatomically represented by the fossa ovalis and its adjacent muscular area called limbus. The surrounding limbus is thicker and may represent a greater challenge for puncture. Fossa ovalis (FO) is present towards the right atrium above and to the left of the orifice of inferior vena cava [4]. The other boundaries are formed by superior vena cava superiorly, non-coronary sinus of Valsalva in aortic valve by anterosuperiorly, and septal tricuspid annulus anteriorly and anteroinferiorly by the coronary sinus os [5] (Fig. 1). Total area of fossa ovalis is about 1.5–2.4 cm$^2$ in adults [6]. Only

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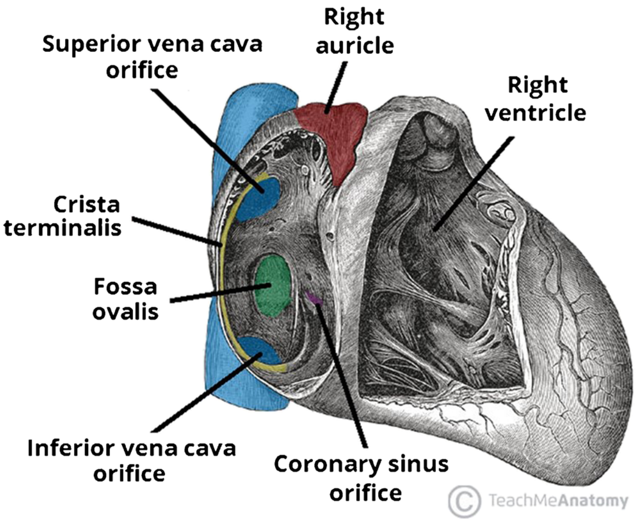


**Fig. 1** Anatomy of interatrial septum (with permission from TeachMeAnatomy)

a part of the FO can be punctured without exiting the heart. Crucial for TSP, this segment only represents about 20% of the total anatomical septum and is best represented in anteroinferior part of the FO.

## Devices and Techniques

Different instruments are utilized to perform safe transseptal access. Currently used transseptal needle represents a slight modification of original device described by Brockenbrough with addition of a smaller 21-gauge needle to the tip. The proximal end has a flange with an arrow that points to the needle tip. The standard adult BRK needle has a 19° angle between the distal curved region and the needle shaft, while the adult BRK-1 needle has 53° angle, offering increased curvature. The needle is available with different lengths (71, 89, and 98 cm) for adults. The needle comes with stylet within the lumen which prevents injuries to sheath by helping to keep it straight. Mullins sheath is the most commonly used needle delivery apparatus that comes with dilator. It has a curvature 270° at the end.

Identification of fossa ovalis and of surrounding anatomies is the most crucial step of TSP. Failure to localize the FO is the single most common cause of aborted TSP [7]. Traditionally, fluoroscopic images have been utilized in the localization of FO. However, various other aids are commonly employed in order to maximize fluoroscopic localization of TSP site and decrease untoward complication. Aortic valve and root are the important structures that need to be protected from puncturing during transseptal process. Position of pigtail catheter into the aortic root from femoral artery provides an anatomical marker of the aortic valve [8]. Alternatively, a diagnostic electrophysiology catheter can be used to mark the bundle of His which is positioned close to the aortic root or the coronary sinus os, which lies in the same vertical plane as the aortic root when viewed in the right anterior oblique projection [9].

TSP is ideally performed from right common femoral vein due to presence of less tortuosity than left side. Through the femoral access site, the sheath and dilator are advanced over the guidewire up to the level of the superior vena cava. The guidewire is then exchanged for the needle with protective stylet. The needle stylet is removed at this point, and the needle is connected to the pressure transducer with a three-way stopcock to allow blood sampling and injection of contrast or saline. The entire assembly is then rotated posteriorly with the arrow of the needle pointing to approximately the 4-o'clock position and then withdrawn towards the patient's feet. As the assembly is withdrawn, two distinct movements are appreciated. First one is felt when the assembly felt into the right atrium and the second one is appreciated when assembly falls into FO from thicker muscular intra-atrial septum. A monophasic pressure waveform confirms the contact between catheter tip and FO. Verification of the position within the FO can be achieved by ensuring the catheter is inferior and posterior to the pigtail catheter in right anterior oblique position. In left oblique view, the catheter tip should be directed posteriorly. Additionally, injection of the contrast through the needle may be used to demonstrate the tenting on the fossa ovalis. Once the correct position is confirmed, TSP should be done under left anterior oblique projection. The needle is slowly advanced from the tip of the assembly into the septum. The puncture across the septum into left atrium can be readily felt. Puncture of the left atrium can be confirmed by pressure transduction through the needle, aspiration of oxygenated blood, and injection of contrast [8].

Various morphologic changes in interatrial septum (elastic, aneurysmal, fibrosed, presence of septal occlude device) or surrounding structures (small or large atria, dilated aortic roots, thoracic spine deformities) pose unique challenge for successful TSP even for experienced physicians [10, 11]. TSP involving such cases not only increases the procedural difficulty but can also increase the risk of cardiac perforation. Use of special puncture needles and advanced imaging modalities has been found to reduce complications in such procedures [12•].

## Electrocautery

A brief application of electrocautery to the standard needle tip has been used successfully for difficult TSP. With the application of cautery to the needle, the need for the additional pressure when pushing the needle through the septum is typically avoided minimizing the risk of sudden lurching and perforating posterior part of left atrial wall. McWilliams et al. reported over 350 double transseptal punctures using electrocautery without major complications in 2009 [13]. Since then, several reports have demonstrated the safety and efficacy of electrocautery for TSP with difficult septal anatomy during left-sided arrhythmia ablation [14], MitraClip procedure [15], and corrections of congenital heart disease [16•]. Much cheaper than other special needles, electrocautery can also be used as a bail out procedure when conventional methods fail to gain transseptal access in 3 or > 3 attempts [17].

## Radio Frequency Needle

The risk of complication associated with TSP by conventional Brockenbrough needle is low with experienced operators. However, in difficult puncture involving thickened or scarred septum, complication rate is high. A radio frequency–powered transseptal needle has been shown to perform TSP safely and successfully without the need for significant mechanical force, in patients who have undergone prior TSP [18] or corrective procedures for congenital heart disease [19]. It was shown to result in successful puncture in atrial fibrillation (AF) ablation, left atrial appendage occlusion, and mitral clip procedure [20]. Radio frequency transseptal system (Baylis Medical, Montreal, Canada) uses the introduction of radio frequency catheter instead of the needle through the sheath and dilator to deliver energy for puncturing interatrial septum. The main advantage of radio frequency (RF) needle is negation of mechanical pressure potentially preventing excessive catheter movement and inadvertent injuries to surrounding structures [5]. Use of RF-powered needle for TSP for various procedures has consistently shown to result in shorter time to transseptal left atrium access and shorter fluoroscopy duration [21, 22]. However, in the hands of an experienced operator, no major clinically significant differences in procedural complications between the standard and RF needle approaches have been noted [23••]. A recent propensity score–matched analysis of 383 patients undergoing catheter ablation for AF showed lower risk of magnetic resonance imaging (MRI) detected asymptomatic acute cerebral embolism with RF needle compared to traditional Brockenbrough needle [24••]. Brockenbrough needle with or without stylet may be associated with formation of some visible and sub-visible particles during advancement of needle through the sheath and dilator, with the potential for causing embolic complications [25]. In vitro study suggested RF catheter decrease the formation of such particles. However, there are no published studies to appraise how such particles with different types of needle result in distinct clinical outcomes. CRYO-LATS, a randomized trial that is recruiting patients currently (NCT03199703) and comparing the effectiveness and safety of RF-powered TSP with conventional TSP for left atrial access in patients undergoing AF ablation, might be able to shed more light on this.

## Steerable Transseptal Needle

The steerable transseptal needle provides real-time adjustable deflection without the need to remove and reshape the needle. The distal curve of the steerable transseptal needle can be controllably adjusted, under fluoroscopy or echocardiography, to facilitate targeting the FO. It is capable of being inserted through a transseptal introducer. It has been used to target the intended puncture location in the interatrial septum without any complications in an initial series of 27 patients undergoing left-sided procedures [26••]. Further studies on this novel technique might be anticipated.

## Laser Puncture

Use of laser for septal procedures was described many years ago [27, 28]. However, it has failed to gather widespread interest from interventional cardiologists. The main advantage of laser is that it negates the need for application of large force. Laser is noted to require ten times less force than Brockenbrough needle to puncture a septum in an animal study [29]. The only available human study on laser puncture involves 45 subjects from Germany (43 for AF and 2 ventricular tachycardia) and shows the successful puncture in 93% at first attempt and remainder at second attempt [30••].

## Imaging Modalities

TSP is commonly performed with fluoroscopic guidance, contrast injection, and pressure monitoring. However, fluoroscopy can have limitations in demonstrating the detailed visualization of the FO especially in patients with anatomic abnormalities in aortic root and atrial septum. In many centers, additional imaging techniques are routinely employed such as transesophageal echocardiography (TEE) and intracardiac echocardiography (ICE). Small published series of ICE-guided punctures report no complications compared with 1% for those guided fluoroscopically [31–33]. TEE or ICE might be able to provide better information than fluoroscopy alone if complications such as atrial or aortic perforation, pericardial tamponade occur [34]. In addition, in hypovolemic states when left free wall tends to fall towards interatrial septum, ICE can help with prompt recognition of the condition and prevent left atrial free wall puncture [35]. A study from Japan showed that additional use of ICE shifted the puncture site of fossa ovalis in fluoroscopy-based left-sided ablation procedure in 89% of patients and did not lead to any complications [36]. A recent study from Sweden that analyzed 4690 consecutive transseptal perforation performed between 2000 and 2015 for left-sided arrhythmias did not find incremental role of TEE or ICE over fluoroscopic guidance [37]. It showed tamponade rate was high for operators' first 100 cases and decreased significantly after that (1.3% vs 0.4%, $P = 0.04$). Fluoroscopic-guided procedure might be adequate for an experienced operator if septal anatomy is normal. However, we believe that in the age of excellent adjunctive imaging like ICE and TEE, it is important to use these supportive modalities for improved safety of transseptal procedures especially in complicated cases. ICE can easily detect anatomic variants that can make the transseptal puncture more challenging, such as lipomatous hypertrophy of the interatrial septum or atrial septal aneurysm. In hypertrophied interatrial septum, ICE can help localize the thinner portion of fossa ovalis, while in aneurysmal dilatation ICE can help with controlling the needle direction and monitoring the space between bulging septum and left free wall [38••].

Recently, a new transseptal approach using non-fluoroscopic technique has been introduced. MediGuide (St. Jude Medical, St. Paul, MN, USA) incorporates a 3D non-fluoroscopic catheter tracking system onto prerecorded 2D cine images. After acquisition of cine images, the needle tip can be accurately tracked in a multidimensional fashion with MediGuide screen. The first prospective study evaluated the feasibility of this novel approach in 16 patients undergoing radio frequency ablation of AF [39•]. The study showed successful TSP with significant reduction in radiation exposure. Similarly, a recent study on 31 patients getting AF ablation demonstrated procedural success rate of 96.7% with minimal radiation exposure [40]. Table 1 shows a summary of currently used different types of devices for transseptal puncture.

## Considerations for Specific Interventions

While the fundamental process of obtaining a TSP remains the same, there are some variation in techniques and approaches for specific interventions based on the target structure within the heart and secondary changes in cardiac anatomy due to diseases. Some considerations associated a few commonly performed specific procedures needing TSP are presented here.

### AF Ablation

Pulmonary veins are posterior structure in left atrium. For pulmonary vein isolation (PVI), posterior TSP has been found favorable [41]. However, if complete mitral isthmus block is needed, then posterior access might not be a suitable approach especially in patients with enlarged LA. In such instances, anterior [42] or anteroinferior [43] TSP will allow easy ablation. A more anterior approach is preferable for cryoballoon technology [44].

Electrophysiologists performing radio frequency ablation generally do not prefer to access artery because of risk of bleeding with continuous anticoagulation. Therefore, instead of pigtail catheter, a catheter at the His bundle location can substitute as an anatomical landmark of aortic valve to guide septal puncture. TSP in the context of AF ablation has been shown to carry higher risk of tamponade from 1.2 to 6% [45–47]. The most common cause of cardiac perforation in AF ablation is due to misdirected TSP [48]. For AF ablation, two or more transseptal sheaths are often positioned in the left atrium that might require two or more TSPs which can theoretically increase the risk of complications. Instead of puncturing the septum a second time, it might be possible to slip in the guidewire and a second sheath by the side of the previous puncture in majority of the cases [49]. Single TSP for positioning two or more catheters in the left atrium for AF ablation has been found highly safe and successful. Fagundes et al. assessed the outcomes of the 1150 patients who underwent single TSP for AF ablation and found only 6(0.5%) required second puncture to place all catheters in left atrium [50]. Furthermore, in no patient was a residual septal atrial defect after the transseptal maneuvers detected during a mean follow-up of 14 months.

**Table 1** Comparison of different types of transseptal puncture methods

| Puncture methods | Brockenbrough needle | Electrocautery needle | Radio frequency needle | Steerable needle | Laser puncture |
|---|---|---|---|---|---|
| Design | Standard needle to mechanically puncture the septum<br>BRK series of needles are similar to Brockenbrough in different lengths | Brief application of electrocautery to standard needle tip is used to advance the needle | Radio frequency–powered transseptal needle<br>Allows the operator to cross the septum in controlled manner without using excessive force | Steerable needle provides real time adjustable deflection without need to remove the needle | Use of laser energy for septal puncture. Requires much less force than conventional technique |
| Use | Most commonly used in clinical practice | Used in difficult case where more pressure is required to cross septum | Helpful in repeat procedure and in anatomical atrial septal abnormalities | Used in difficult case to target the specific part of fossa ovalis | Used in difficult case which requires more pressure to cross the septum |
| Experience | Most experience and widely used | Commonly used | Commonly used | Limited experience | Limited experience |
| Cost | Cheap | Cheap | Expensive | Expensive | Expensive |

### LAA Ligation

Left atrial appendage is located in the anterior superior position of left atrium. Left atrial appendage occlusion, irrespective of the device, is best facilitated with a puncture of the superior region of FO so that the delivery sheath is coaxial with the appendage. Chicken-wing morphology with an early and severe bend constitutes one of the most difficult anatomical settings for transcatheter LAA occlusion. Such morphology of LAA might need a little posterior and inferior approach to allow for easier manipulation of the sheath [51]. After TSP, any wire should be advanced very cautiously and only under imaging guidance because even a soft wire can perforate the thin-walled LAA very easily [52].

### Percutaneous Mitral Valve Repair

It is important to realize that patients with long standing mitral valve disease may have developed some anatomical changes. Fossa ovalis can be located more inferiorly in such patients [8]. Within the FO, posterosuperior location is preferred to allow for a more tangential approach to the mitral valve to facilitate device delivery [53]. The largest experience of percutaneous mitral valve repair is with MitraClip which requires the introduction of 22-F device via septal puncture [54].

### Prior Septal Repair

Previous atrial septal defect/patent foramen ovale closure is not a contraindication to TSP but it calls for modification in the traditional approach of TSP. Most of the atrial occlusion device is located in the anterior superior location; therefore, puncture can be easily performed inferior or posterior to the device. ICE can be very helpful in accurately localizing the interatrial device and delineating the site for secondary puncture [5]. Successful puncture through the septal patch have been reported [55, 56]. However, such approach is limited by technical challenges and higher rate of failure.

## Conclusion

Transseptal puncture has regained much interest in interventional cardiology with expanding indications of its use for various structural heart diseases. It is very important for interventionalists to have sound knowledge of interatrial septum anatomy and surrounding structures to master the procedure. While routine normal TSP might be considered safe in the hands of the experienced operators, many cases involve difficult anatomies requiring use of different aids in successful puncture and prevention of complications. TSP for simple cardiac procedure with normal anatomy may not need more than fluoroscopy. However, in today's era of excellent adjunctive imaging ICE or TEE may be preferred for safe transseptal access. Newer puncture technique and imaging modalities that are being studied currently may potentially improve the procedural safety further.

## Compliance with Ethical Standards

**Conflict of Interest** Sharan Prakash Sharma, Rahul Nalamasu, Rakesh Gopinathannair, Chandrasekhar Vasamreddy, and Dhanunjaya Lakkireddy declare that they have no conflict of interest.

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

## References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance


1. Ross J, Braunwald E, Morrow AG. Transseptal left atrial puncture; new technique for the measurement of left atrial pressure in man. Am J Cardiol. 1959;3:653–5.
2. Ross J. Transeptal left heart catheterization: a new method of left atrial puncture. Ann Surg. 1959;149:395–401.
3. Alkhouli M, Rihal CS, Holmes DR. Transseptal techniques for emerging structural heart interventions. JACC Cardiovasc Interv. 2016;9:2465–80.
4. Joshi SD, Chawre HK, Joshi SS. Morphological study of fossa ovalis and its clinical relevance. Indian Heart J. 2016;68:147–52.
5. 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.
6. Sweeney LJ, Rosenquist GC. The normal anatomy of the atrial septum in the human heart. Am Heart J. 1979;98:194–9.
7. 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;47:1037–42.
8. 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;51:2116–22.
9. Earley MJ. How to perform a transseptal puncture. Heart. 2009;95:85–92.
10. Gul EE, Baranchuk A, Glover BM. A guide to transseptal access. Can J Cardiol. 2017;33:544–7.
11. Klimek-Piotrowska W, Hołda MK, Koziej M, Piątek K, Hołda J. Anatomy of the true interatrial septum for transseptal access to the left atrium. Ann Anat. 2016;205:60–4.
12.• Kataria V, Berte B, Vandekerckhove Y, Tavernier R, Duytschaever M. Modified transseptal puncture technique in challenging septa: a randomized comparison to conventional technique. Biomed Res Int. 2017;2017:2351925 **It shows modified transseptal techniques could allow effective, safe, and time-sparing transseptal puncture in patients when conventional technique fail**.

13. McWilliams MJ, Tchou P. The use of a standard radiofrequency energy delivery system to facilitate transseptal puncture. J Cardiovasc Electrophysiol. 2009;20:238–40.
14. Capulzini L, Paparella G, Sorgente A, de Asmundis C, Chierchia GB, Sarkozy A, et al. Feasibility, safety, and outcome of a challenging transseptal puncture facilitated by radiofrequency energy delivery: a prospective single-centre study. Europace. 2010;12:662–7.
15. Maisano F, La Canna G, Latib A, et al. Transseptal access for MitraClip® procedures using surgical diathermy under echocardiographic guidance. EuroIntervention. 2012;8:579–86.
16.• Gowda ST, Qureshi AM, Turner D, et al. Transseptal puncture using surgical electrocautery in children and adults with and without complex congenital heart disease. Catheter Cardiovasc Interv. 2017;90:E46–54 **This shows radio frequency current delivery using surgical electrocautery for transseptal puncture is a feasible and an effective option in patients requiring transseptal puncture for wide array of conditions**.
17. Abed HS, Alasady M, Lau DH, Lim HS, Sanders P. Approach to the difficult transseptal: diathermy facilitated left atrial access. Heart Lung Circ. 2012;21:108–12.
18. Smelley MP, Shah DP, Weisberg I, et al. Initial experience using a radiofrequency powered transseptal needle. J Cardiovasc Electrophysiol. 2010;21:423–7.
19. Esch JJ, Triedman JK, Cecchin F, Alexander ME, Walsh EP. Radiofrequency-assisted transseptal perforation for electrophysiology procedures in children and adults with repaired congenital heart disease. Pacing Clin Electrophysiol. 2013;36:607–11.
20. Radinovic A, Mazzone P, Landoni G, Agricola E, Regazzoli D, Bella PD. Different transseptal puncture for different procedures: optimization of left atrial catheterization guided by transesophageal echocardiography. Ann Card Anaesth. 2016;19:589–93.
21. Fromentin S, Sarrazin J-F, Champagne J, Nault I, Philippon F, Molin F, et al. Prospective comparison between conventional transseptal puncture and transseptal needle puncture with radiofrequency energy. J Interv Card Electrophysiol. 2011;31:237–42.
22. 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:e000428.
23.•• Sharma G, Singh GD, Smith TW, Fan D, Low RI, Rogers JH. Accuracy and procedural characteristics of standard needle compared with radiofrequency needle transseptal puncture for structural heart interventions. Catheter Cardiovasc Interv. 2017;89:E200–6 **This study shows that radio frequency needle compared to standard needle is associated with improved outcome when standard needle fails. It is associated with favorable procedural time and degree of septum tenting**.
24.•• Tokuda M, Yamashita S, Matsuo S, et al. Radiofrequency needle for transseptal puncture is associated with lower incidence of thromboembolism during catheter ablation of atrial fibrillation: propensity score-matched analysis. Heart Vessel. 2018;33:1238–44 **Interesting findings came from this study. It shows patients undergoing atrial fibrillation ablation with radio frequency needle for transseptal puncture had lower incidence of MRI-confirmed acute cerebral embolism**.
25. Feld GK, Tiongson J, Oshodi G. Particle formation and risk of embolization during transseptal catheterization: comparison of standard transseptal needles and a new radiofrequency transseptal needle. J Interv Card Electrophysiol. 2011;30:31–6.
26.•• Rogers JH, Stripe BR, Singh GD, Boyd WD, Fan D, Smith TWR. Initial clinical experience with the FlexPoint steerable transseptal needle in left-sided structural heart procedures. Catheter Cardiovasc Interv. 2018;92:792–6 **This study presents the initial experience of using steerable needle in 27 patients for transseptal puncture. With real-time adjustable deflection capability, steerable needle was used able to puncture the specific intended part of fossa ovalis without any complications**.
27. Bommer WJ, Lee G, Riemenschneider TA, Ikeda RM, Rebeck K, Stobbe D, et al. Laser atrial septostomy. Am Heart J. 1983;106:1152–6.
28. Galal O, Weber HP, Enders S, al Watban F, ElSayet RM, Duran C. Transcatheter laser atrial septostomy in rabbits. Int J Cardiol. 1993;42:31–5.
29. Elagha AA, Kocaturk O, Guttman MA, Ozturk C, Kim AH, Burton GW, et al. Real-time MR imaging-guided laser atrial septal puncture in swine. J Vasc Interv Radiol. 2008;19:1347–53.
30.•• Weber HP, Gerhardt MS. Side-selective Atrial Transseptal Laser Puncture. Available at: http://www.innovationsincrm.com/cardiac-rhythm-management/2013/december/524-side-selective-atrial-transseptal-laser-puncture#ref9. Accessed 8 Oct 2018. **Findings from this study show the feasibility of site-specific transseptal puncture by using laser energy. Conducted in 45 patients, the study does not report any major procedural complications.**
31. Daoud EG, Kalbfleisch SJ, Hummel JD. Intracardiac echocardiography to guide transseptal left heart catheterization for radiofrequency catheter ablation. J Cardiovasc Electrophysiol. 1999;10:358–63.
32. Hung JS, Fu M, Yeh KH, Wu CJ, Wong P. Usefulness of intracardiac echocardiography in complex transseptal catheterization during percutaneous transvenous mitral commissurotomy. Mayo Clin Proc. 1996;71:134–40.
33. Szili-Torok T, Kimman G, Theuns D, Res J, Roelandt JR, Jordaens LJ. Transseptal left heart catheterisation guided by intracardiac echocardiography. Heart. 2001;86:E11–111.
34. Citro R, Ducceschi V, Salustri A, Santoro M, Salierno M, Gregorio G. Intracardiac echocardiography to guide transseptal catheterization for radiofrequency catheter ablation of left-sided accessory pathways: two case reports. Cardiovasc Ultrasound. 2004;2:20.
35. Epstein LM, Smith T, TenHoff H. Nonfluoroscopic transseptal catheterization: safety and efficacy of intracardiac echocardiographic guidance. J Cardiovasc Electrophysiol. 1998;9:625–30.
36. Hanaoka T, Suyama K, Taguchi A, Shimizu W, Kurita T, Aihara N, et al. Shifting of puncture site in the fossa ovalis during radiofrequency catheter ablation: intracardiac echocardiography-guided transseptal left heart catheterization. Jpn Heart J. 2003;44:673–80.
37. Matoshvili Z, Bastani H, Bourke T, Braunschweig F, Drca N, Gudmundsson K, et al. Safety of fluoroscopy-guided transseptal approach for ablation of left-sided arrhythmias. Europace. 2017;19:2023–6.
38.•• Enriquez A, Saenz LC, Rosso R, et al. Use of intracardiac echocardiography in interventional cardiology: working with the anatomy rather than fighting it. Circulation. 2018;137:2278–94 **This comprehensive review provides findings about the emerging roles of intracardiac echocardiography in electrophysiology procedures including transseptal puncture**.
39.• Mansour M, Afzal MR, Gunda S, et al. Feasibility of transseptal puncture using a nonfluoroscopic catheter tracking system. Pacing Clin Electrophysiol. 2015;38:791–6 **This prospective observational study shows transseptal puncture can be successfully performed using non-fluoroscopic catheter tracking system (MediGuide) and that it results in significant reduction in radiation exposure**.
40. Ballesteros G, Ramos Ardanaz P, Neglia R, et al. Mediguide-assisted transseptal puncture without echocardiographic guidance. Pacing Clin Electrophysiol. 2017;40:545–50.
41. Ruisi CP, Brysiewicz N, Asnes JD, et al. Use of intracardiac echocardiography during atrial fibrillation ablation. Pacing Clin Electrophysiol. 2013;36:781–8.
42. Bazaz R, Schwartzman D. Site-selective atrial septal puncture. J Cardiovasc Electrophysiol. 2003;14:196–9.
43. Okubo K, Kuwahara T, Takigawa M, Tanaka Y, Nakajima J, Watari Y, et al. Impact of anteroinferior transseptal puncture on creation of

a complete block at the mitral isthmus in patients with atrial fibrillation. J Interv Card Electrophysiol. 2017;48:317–25.
44. Su W, Kowal R, Kowalski M, Metzner A, Svinarich JT, Wheelan K, et al. Best practice guide for cryoballoon ablation in atrial fibrillation: the compilation experience of more than 3000 procedures. Heart Rhythm. 2015;12:1658–66.
45. Ellis ER, Culler SD, Simon AW, Reynolds MR. Trends in utilization and complications of catheter ablation for atrial fibrillation in Medicare beneficiaries. Heart Rhythm. 2009;6:1267–73.
46. Cappato R, Calkins H, Chen S-A, Davies W, Iesaka Y, Kalman J, et al. Updated worldwide survey on the methods, efficacy, and safety of catheter ablation for human atrial fibrillation. Circ Arrhythm Electrophysiol. 2010;3:32–8.
47. Hsu L-F, Jaïs P, Hocini M, et al. Incidence and prevention of cardiac tamponade complicating ablation for atrial fibrillation. Pacing Clin Electrophysiol. 2005;28(Suppl 1):S106–9.
48. Calkins H, Kuck KH, Cappato R, Brugada J, Camm AJ, Chen SA, et al. 2012 HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for patient selection, procedural techniques, patient management and follow-up, definitions, endpoints, and research trial design: a report of the Heart Rhythm Society (HRS) task force on catheter and surgical ablation of atrial fibrillation. Developed in partnership with the European Heart Rhythm Association (EHRA), a registered branch of the European Society of Cardiology (ESC) and the European Cardiac Arrhythmia Society (ECAS); and in collaboration with the American College of Cardiology (ACC), American Heart Association (AHA), the Asia Pacific Heart Rhythm Society (APHRS), and the Society of Thoracic Surgeons (STS). Endorsed by the governing bodies of the American College of Cardiology Foundation, the American Heart Association, the European Cardiac Arrhythmia Society, the European Heart Rhythm Association, the Society of Thoracic Surgeons, the Asia Pacific Heart Rhythm Society, and the Heart Rhythm Society. Heart Rhythm. 2012;9:632–696.e21.
49. Naik N. How to perform transeptal puncture. Indian Heart J. 2015;67:70–6.
50. 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;18:1277–81.
51. Freixa X, Tzikas A, Basmadjian A, Garceau P, Ibrahim R. The chicken-wing morphology: an anatomical challenge for left atrial appendage occlusion. J Interv Cardiol. 2013;26:509–14.
52. Thakkar J, Vasdeki D, Tzikas A, Meier B, Saw J. Incidence, prevention, and management of periprocedural complications of left atrial appendage occlusion. Interv Cardiol Clin. 2018;7:243–52.
53. Urena M, Himbert D, Brochet E, Carrasco JL, Iung B, Nataf P, et al. Transseptal transcatheter mitral valve replacement using balloon-expandable transcatheter heart valves: A Step-by-Step Approach. JACC Cardiovasc Interv. 2017;10:1905–19.
54. Feldman T, Wasserman HS, Herrmann HC, Gray W, Block PC, Whitlow P, et al. Percutaneous mitral valve repair using the edge-to-edge technique: six-month results of the EVEREST phase I clinical trial. J Am Coll Cardiol. 2005;46:2134–40.
55. Chen K, Sang C, Dong J, Ma C. Transseptal puncture through Amplatzer septal occluder device for catheter ablation of atrial fibrillation: use of balloon dilatation technique. J Cardiovasc Electrophysiol. 2012;23:1139–41.
56. El-Said HG, Ing FF, Grifka RG, et al. 18-year experience with transseptal procedures through baffles, conduits, and other intra-atrial patches. Catheter Cardiovasc Interv. 2000;50:434–9 **discussion 440**.