

# Emerging Applications for Transseptal Left Heart Catheterization

## Old Techniques for New Procedures

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Transseptal (TS) catheterization was introduced in 1959 as a strategy to directly measure left atrial (LA) pressure. Despite acceptable feasibility and safety, TS catheterization has been replaced by indirect measurements of LA pressure using the Swan-Ganz catheter. Today, TS puncture is rarely performed for diagnostic purposes but continues to be performed for procedures such as balloon mitral valvuloplasty, antegrade balloon aortic valvuloplasty, and ablation of arrhythmias in the LA. Thus, the “art” of TS puncture has been lost, except in centers that perform these procedures with regularity. Recently, there has been a renewed interest in the TS technique because of emerging therapeutic procedures for structural heart disease and atrial fibrillation ablation. Invasive cardiologists will have to refamiliarize themselves with the TS technique, newer TS devices, and advanced ultrasound imaging for guidance of the procedure. (*J Am Coll Cardiol* 2008;51:2116–22) © 2008 by the American College of Cardiology Foundation

Measurement of left atrial (LA) pressure is important in the evaluation of heart disease. Various direct methods, such as transbronchial, supraclavicular (1), and transseptal (TS) puncture (2–4), were developed in the 1950s to measure LA pressure. Despite acceptable feasibility and safety (1,2,5), these methods were replaced by indirect measurements of LA pressure with a Swan-Ganz catheter. Right heart catheterization with a balloon wedge catheter replaced TS left heart catheterization not only because of ease and safety, but because many hemodynamic parameters could be measured with a single catheter. Today, TS catheterization is rarely performed for diagnostic purposes unless the wedge pressure reading is in question or retrograde access to the left ventricle is not possible. Thus, the “art” of TS puncture has been lost by invasive cardiologists, except in centers that perform balloon mitral valvuloplasty and LA arrhythmia ablation with regularity.

With the introduction of new procedures for percutaneous structural heart disease therapy (6–8) and atrial fibrillation ablation (9) in the last 5 years, TS catheterization is increasingly necessary. This review focuses on the current

state of TS catheterization, with emphasis on updated techniques and emerging indications.

### TS Technique

Current TS technique has changed very little since the initial reports in 1959 (3,4). In brief, a needle is inserted into a catheter that is in contact with the right atrial (RA) septum at the level of the fossa ovalis. The needle is then advanced, puncturing the atrial septum and allowing access to the LA. The key to a successful procedure is a thorough understanding of the anatomy of the fossa ovalis and the surrounding landmarks.

### Anatomy of the Fossa Ovalis and Surrounding Structures

The intact atrial septum is formed from fusion of the septum primum and the septum secundum. Both septae extend from the roof of the atria toward the endocardial cushions. The septum primum, which is the LA septum, is absorbed superiorly, leaving the septum secundum, or the RA septum, to cover this superior defect (ostium secundum) and separate the atria. The area of fusion of the muscular, septum secundum and the thin portion of the septum primum is known as the limbus (10). The limbus is most pronounced superiorly and laterally, and forms the raised margin around the fossa ovalis (Fig. 1). Thus, the fossa ovalis appears as a depression in the interatrial septum when viewed from the RA (Fig. 1) and is composed primarily of

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thin fibrous tissue (10,11). Surrounding the fossa is the muscular septum, the thick portions of the septum secundum and primum composed primarily of atrial muscle. The fossa ovalis is either oval or circular with an average area of 1.5 to 2.4 cm<sup>2</sup> in the adult (11). It is located posteriorly, at the junction of the mid and lower third of the RA. In patients with dilated aortae and in those with mitral valve disease and a bulging LA, the fossa ovalis can be located more superiorly or inferiorly, respectively.

### Localization of the Fossa Ovalis

Localization of the fossa ovalis for TS puncture has traditionally been done by fluoroscopic imaging. A pigtail catheter is placed retrograde into the aortic root so that its tip marks the location of the aortic valve. The cardiac silhouette identifies the posterior and lateral borders of the atria (12). Several different angiographic projections are used to puncture the septum safely. In the anteroposterior projection, the fossa lies below the pigtail catheter in the mid RA silhouette (Fig. 2A). In the lateral projection, the fossa is usually halfway along the imaginary line from the pigtail catheter tip to the posterior border of the heart (Fig. 2B). In the right anterior oblique projection (40° to 50°), the outline of the atrial septum is en face. The fossa is posterior and 1 to 3 cm inferior to the pigtail catheter tip, but anterior to the RA silhouette (Fig. 2B). In difficult cases, an RA angiogram with delayed LA angiography can help visualize the septum (overlap area). "Tattooing" of the septum with a 1-ml contrast injection through the TS puncture needle can also help visualize the septum.

Echocardiographic visualization of the atrial septum has aided in the safety of TS catheterization (13). Transthoracic echocardiography (TTE) has limited utility, but transesoph-

ageal echocardiography (TEE) is more useful, particularly when visualizing a specific area of the fossa ovalis to be punctured. Superior/inferior localization is seen best in the bicaval view (90°), and anterior/posterior localization is seen best in the 4-chamber view (0°). Tenting (Fig. 3A) of the fossa ovalis (the thin septum) by the TS catheter tip indicates correct positioning, even if the needle or catheter cannot be visualized. Newer imaging modalities such as intracardiac echocardiography (AcuNav ICE, Siemens Medical Systems, Mountain View, California)

(12,14,15) have also been used with success. The role of 3-dimensional TEE has yet to be fully evaluated, although initial experience is positive (Fig. 3B). CardioOptics (Boulder, Colorado) manufactures a catheter that emits infrared light and can image through flowing blood in real time. This catheter may be useful in TS catheterization, allowing direct visualization of the fossa ovalis. Animal testing has been completed, and Phase I human trials are pending.

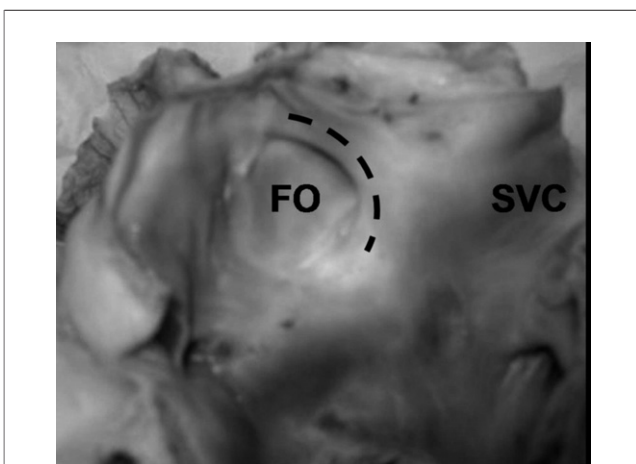
### Puncture of the Fossa Ovalis

Puncture of the fossa ovalis begins with insertion of the needle delivery catheter and dilator to the level of the superior vena cava from the right common femoral vein. The catheter has a 270° curve at the end that is straightened by the dilator, and is most commonly a Mullins TS introducer (Medtronic, Minneapolis, Minnesota). The radius of the end of the catheter is available in different sizes, allowing variable reach within the RA. The needle is then inserted into the dilator, and allowed to freely rotate as it is advanced. Passage of the needle is easier if the sheath and dilator is introduced from the right rather than left femoral vein because of tortuosity. Fluoroscopy is used to visualize the needle as it is advanced up to the tip of the dilator so as to avoid inadvertent passage out of the dilator and sheath.

The needle most commonly used is a Brockenbrough needle (Medtronic). This needle is an 18-gauge hollow tube that tapers distally to 21 gauge. The proximal end has a flange with an arrow that points to the position of the needle tip. With the needle tip just within the dilator, the entire assembly is rotated such that the needle points to a 4 o'clock orientation (ceiling of the room is 12 o'clock orientation, floor is 6 o'clock orientation) and withdrawn into the mid RA. Using the fluoroscopic projections as previously described, the dilator is then advanced to catch the limbus of the fossa ovalis. In the minority of patients in whom the limbus is not prominent, echocardiographic guidance is helpful. The sheath, dilator, and needle assem-

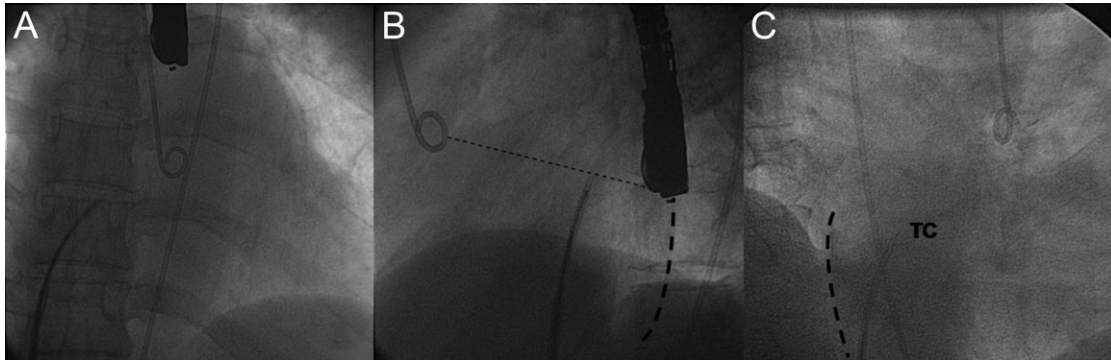
#### Abbreviations and Acronyms

<b>ASD</b>	= atrial septal defect
<b>EP</b>	= electrophysiology
<b>LA</b>	= left atrial/atrium
<b>PFO</b>	= patent foramen ovale
<b>PVL</b>	= paravalvular leak
<b>RA</b>	= right atrium/atrial
<b>RF</b>	= radiofrequency
<b>TEE</b>	= transesophageal echocardiography
<b>TS</b>	= transseptal
<b>TTE</b>	= transthoracic echocardiography



**Figure 1. Gross Examination of the FO From the Right Atrium**

Right atrial view of the atrial septum with limbic ledge seen superiorly (below dotted line) and depressed fossa ovalis (FO) inferiorly. SVC = superior vena cava.



**Figure 2** Fluoroscopic Views During Transseptal Puncture

(A) Transseptal puncture performed in the anteroposterior projection with fluoroscopic imaging. The pigtail catheter marks the location of the aortic valve, and the tip of the transseptal dilator engages the fossa ovalis inferiorly and medially to the aortic valve. (B) Transseptal puncture performed in the lateral fluoroscopic projection. The transseptal dilator engages the fossa ovalis in the lower third of the imaginary line (thin dashed line) connecting the pigtail catheter (aortic valve) and the posterior wall of the left atrium (heavy dashed line). (C) Transseptal puncture performed in the right anterior oblique projection with fluoroscopic imaging. The transseptal dilator (TC) engages the fossa ovalis posterior to the pigtail catheter (aortic valve) but anterior to right atrial silhouette (dashed line).

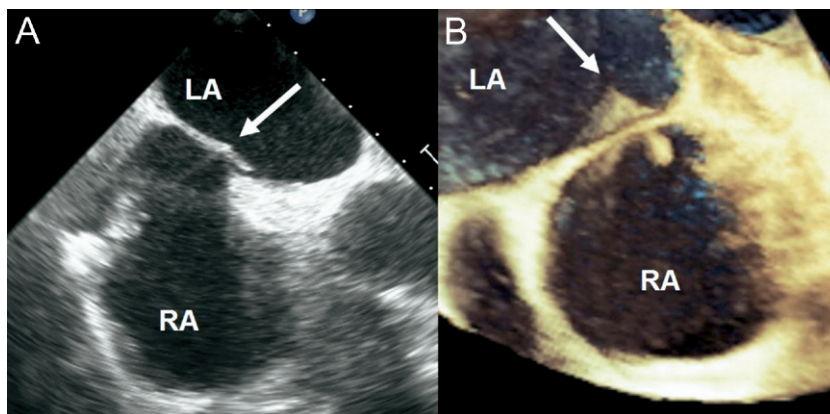
bly are advanced as a unit, tenting the fossa. The needle is then rotated to 3 o'clock to prevent posterior puncture and is fully advanced. Puncture into the LA can be confirmed by pressure transduction through the needle (Fig. 4), aspiration of oxygenated blood, and injection of contrast.

In 20% to 25% of adult patients, the fossa ovalis is probe patent (patent foramen ovale [PFO]) and may not require needle puncture (10,11). In approximately two-thirds of patients, the fossa is paper thin, and the catheter can be passed into the LA with gentle pressure and rotation of the dilator (10). Puncture is associated with a tactile feeling of the septum giving way. The dilator and sheath are then advanced over the needle (without advancing the needle) to avoid injury to the posterior LA wall. Some operators introduce a 0.014-inch angioplasty wire through the needle

into the LA and pulmonary vein to prevent inadvertent puncture of the LA free wall by the needle or dilator (16). Fortunately, serious morbidity or mortality after needle puncture of the LA free wall or aorta is uncommon if the sheath and dilator are not advanced. Overall, serious complications from TS catheterization are  $\leq 1\%$  (1,17,18). After successful puncture of the atrial septum, the patient should be immediately anticoagulated (heparin or direct thrombin antagonist) to minimize the risk of thromboembolism.

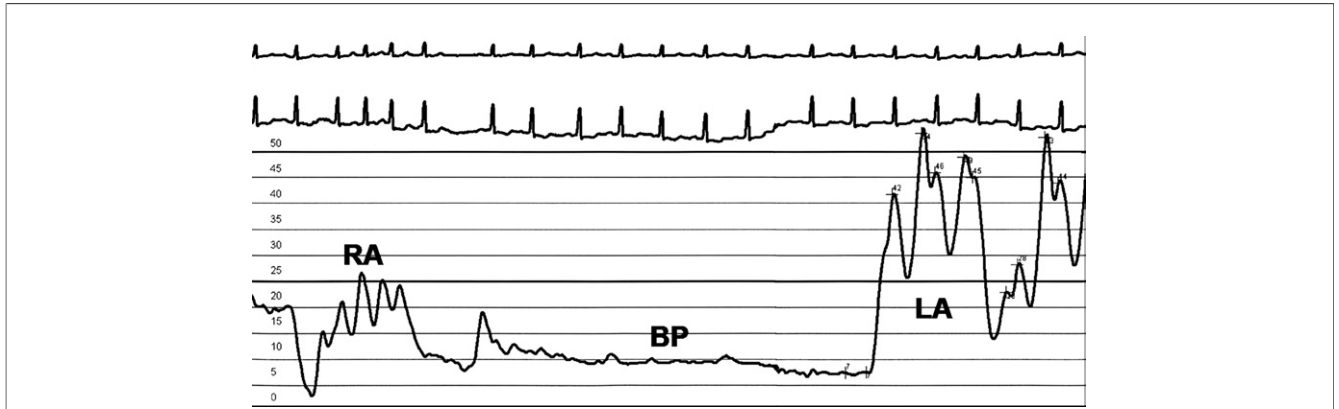
### Newer Methods for Atrial Septal Puncture

In an attempt to improve the TS technique, a new system that uses radiofrequency (RF) energy to puncture the septum (Radiofrequency Transseptal System, Baylis Medi-



**Figure 3** 2- and 3-Dimensional Echocardiographic Views During Transseptal Puncture

(A) 2-dimensional transesophageal echocardiographic imaging depicts tenting (arrow) of the atrial septum into the left atrium (LA).  
(B) 3-dimensional transesophageal echocardiographic imaging visualizes tenting (arrow) of the atrial septum. RA = right atrium.



**Figure 4** Pressure Tracing From Transseptal Needle During Transseptal Catheterization

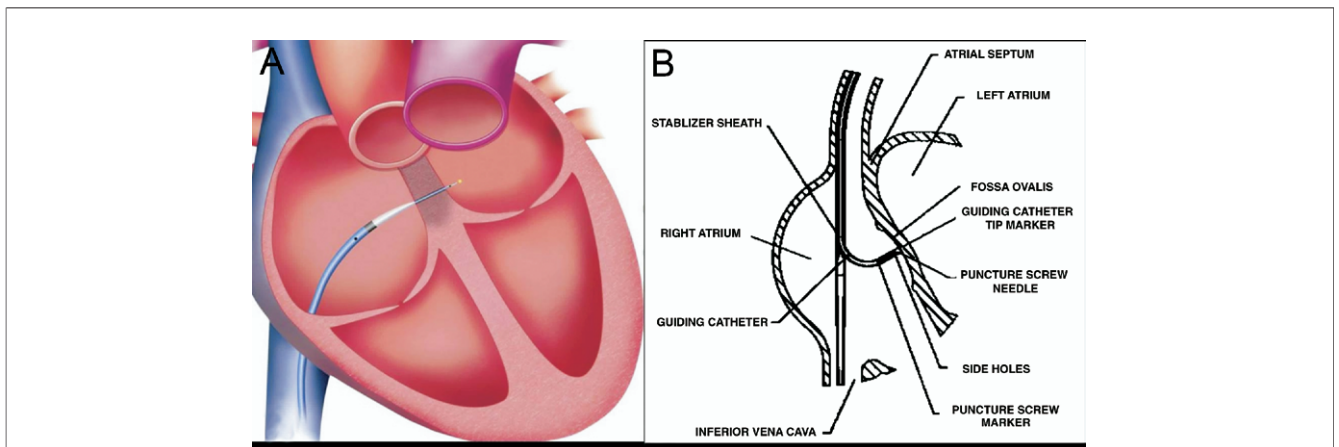
Right atrial (RA) pressure wave form becomes blunted (BP) as the needle engages the septum. After the needle passes through the septum, a left atrial (LA) pressure wave form is seen.

cal, Montreal, Canada) has been developed (19). Instead of a needle, an RF catheter is introduced into the dilator/sheath assembly (Fig. 5A). This catheter delivers 5 W energy for 2 to 5 s and can perforate the atrial septum after 1 to 4 pulses. It has been used in 5 patients undergoing balloon mitral valvuloplasty and was successful in 4. This technology may have an advantage in thick, scarred, calcified, or patched atrial septa, where excess force could result in unsuccessful puncture or in perforation of the LA free wall secondary to catheter momentum.

Another new technology that also may improve the safety of TS puncture is the excimer laser catheter (0.9-mm Clirpath X-80, Spectranetics, Colorado Springs, Colorado) (20-22). The laser catheter is inserted via a modified Mullins sheath and dilator (inner lumen compatible with a 0.038-inch wire) and can puncture the septum after a brief

(2 to 5 s) application of laser energy. The laser catheter requires less force (<10-fold) to cross the septum compared with the Brockenbrough needle, and can then be used as a rail over which the Mullins sheath and dilator can be advanced. Currently, only data from animal studies are available, although the technology seems promising and can be used “off the shelf” with existing deflectable guiding catheters (Morph catheter, Biocardia, San Francisco, California, and Naviport catheter, Cardima, Fremont, California).

In cases in which TS catheterization cannot be performed from the femoral vein, a new system has been developed for safe puncture of the LA from the internal jugular vein. The LA-Crosse system (St. Jude Medical, St. Paul, Minnesota) is composed of 3 parts: a stabilizer sheath, a guide catheter, and a flexible puncture screw (Fig. 5B). The stabilizer sheath is placed from the right internal jugular vein such



**Figure 5** New Transseptal Catheterization Techniques Using a Radiofrequency Catheter or an Internal Jugular Vein Approach

(A) A radiofrequency catheter is inserted into dilator and sheath and ablates a thickened atrial septum to cross into the left atrium (courtesy of Radiofrequency Transseptal System, Baylis Medical, Montreal, Quebec, Canada). (B) The LA-Crosse system uses a stabilizer sheath, a guide catheter, and a flexible puncture screw to safely cross the atrial septum from the right internal jugular vein (courtesy of St. Jude Medical, St. Paul, Minnesota).

that the distal end lies in the inferior vena cava and the side opening faces the mid RA. A guide catheter is advanced through the stabilizer sheath and out the side opening until its distal end is in contact with the fossa ovalis. The flexible puncture screw is then advanced through the guide catheter to its tip. When it contacts the atrial septum, the puncture screw is rotated and penetrates the atrial septum. Once LA pressure is measured through the end hole of the puncture screw, an Inoue guidewire is advanced into the LA. This system has been 100% successful in animal models guided by fluoroscopy, and can be used to perform multiple punctures in selective portions of the atrial septum. Additionally, introduction of catheters from the internal jugular vein through the superior vena cava and across the atrial septum may offer a more favorable trajectory than the femoral approach for transcatheter interventions on the mitral valve. Human evaluation is pending.

### Emerging Indications for TS Puncture

**TS catheterization in electrophysiology (EP).** The cardiac subspecialty of EP accounts for the single most common context in which TS punctures are performed in the U.S. Interest in the refinement and perfection of the TS technique has paralleled the dramatic increase in the number of ablative procedures performed for atrial fibrillation in the last 5 years (9,23). In addition to RF ablation for atrial fibrillation, TS puncture is routine for ablation of accessory pathways located along the mitral annular region, LA tachycardias and flutters, and less commonly for variants of atrioventricular nodal reentrant tachycardia. The TS route also provides a useful alternative to the retroaortic approach for ablation within the left ventricle and left ventricular outflow tract.

In most centers, TS puncture is performed under fluoroscopic biplanar guidance using methods described above. Additionally, a diagnostic catheter in the coronary sinus aids in the localization of the fossa ovalis. Often, EP procedures require 2 or more sheaths across the fossa ovalis. This can be accomplished by 2 separate TS punctures or a single pass with the Brockenbrough needle. In the latter case, the initial sheath, which is already across the atrial septum, can be withdrawn into the RA over a guidewire in the LA. A second sheath or ablation catheter can then pass through the previously created rent in the septum. The initial sheath is then reinserted over the guidewire. On occasion, patients require repeat TS procedures for atrial fibrillation ablation (24). If previous punctures have been performed, the fossa ovalis can become thickened and fibrotic. This can obscure the physical landmarks, prevent the characteristic leftward movement of the TS needle into the fossa, and require significant forward pressure for puncture with the needle. In this situation and in the case of prior aortic root surgery adjuncts to fluoroscopic visualization, such as intracardiac or TEE, are most useful.

**PFO and atrial septal defect (ASD) repair.** The second most common use for TS catheterization is percutaneous repair of ASD and PFO. Percutaneous ASD repair is a validated alternative to surgical repair (25), and is used primarily to prevent or reverse the untoward consequences of left-to-right shunting across the atrial septum (pulmonary hypertension, right ventricular failure). Alternatively, percutaneous PFO closure has been used to prevent the problems of right-to-left shunting, specifically secondary stroke prevention. Ongoing trials are also evaluating the role of PFO closure in migraine reduction.

In the majority of cases, the ASD and PFO can be crossed with the use of a multipurpose catheter and a J-wire without the need for TS puncture. In rare occasions, atrial septal aneurysms may “pocket” the catheter tip and wire, preventing the cannulation of a small ASD or PFO. In this situation and in the long-tunnel variant PFO, TS puncture has been used to place a catheter in the LA, and deploy a closure device to seal the defect (26,27). This technique requires echocardiographic guidance to puncture the septum as close to the defect as possible.

**Percutaneous mitral valve repair.** Percutaneous mitral valve repair strategies include leaflet repair, coronary sinus annuloplasty, and noncoronary sinus annuloplasty with or without myocardial reduction (6,7,28,29). The largest experience with repair strategies has been with percutaneous leaflet clipping in the treatment of primary mitral regurgitation. The MitraClip device (Evalve Inc., Menlo Park, California), requires the introduction of a 22-F device via TS puncture (8). The TS puncture should be performed under ultrasound guidance in order to pierce the septum superiorly and posteriorly. This high TS puncture allows adequate distance above the mitral valve plane for manipulation of the guiding and delivery catheter and to properly place the mitral valve clip.

The Ample PS3 System (Ample Medical, Foster City, California) also involves TS puncture. A T-bar implant is delivered to the posterior annulus via the coronary sinus. A TS puncture is performed to tether the T-bar to an Amplatzer (AGA Medical, Minneapolis, Minnesota) device anchored in the atrial septum.

**LA appendage closure.** The LA appendage is positioned in the anterior-superior portion of the LA, above the mitral valve. The Watchman device (Atritech Company, Plymouth, Minnesota) is a nitinol cage with a polyethylene membrane that can be implanted into the LA appendage of patients with atrial fibrillation to prevent stroke (30). For placement of this device, TS puncture is performed in the superior fossa ovalis so that the delivery sheath is coaxial with the LA appendage, and device deployment is facilitated.

**Percutaneous left ventricular assist device.** The Tandem-Heart Device (CardiacAssist, Pittsburgh, Pennsylvania) is a circulatory assist device (31–33) that retrogradely perfuses the aorta with oxygenated blood from the LA. After TS puncture, a 21-F cannula is advanced across the atrial septum from the femoral vein; the proximal end of the

venous cannula (inflow) is connected to a 15- to 18-F cannula in the iliac artery (outflow) via a rotary pump. The flow can be as high as 4.0 l/min and requires appropriate placement of the distal end of the LA cannula in the mid-posterior LA. Ultrasound guidance for placement of the LA catheter is recommended.

**Paravalvular leak (PVL) closure.** Paravalvular leak of mitral prostheses can be repaired percutaneously from a TS approach (34), particularly if the leak is along the lateral aspect of the LA. The TS puncture should be in the middle or inferior fossa ovalis to direct a right Judkins catheter to the lateral wall of the atrium at the level of the mitral valve. A PVL along the medial aspect of mitral prostheses is technically more difficult to repair because the acute angle needed to access the PVL. Such leaks might be approached from a TS puncture performed from the right internal jugular in the future. A TS puncture has also been performed to snare a wire from the left ventricle or LA when closing an aortic or mitral PVL.

**Other procedures.** The TS technique has been used in a variety of other procedures, including pulmonary vein stenosis intervention, antegrade VSD closure, stent implantation in the right internal carotid artery (35), and atrial septostomy. Indications for TS catheterization will increase as more interventions are performed for treatment of structural heart disease.

## Conclusions

Although once popular, TS catheterization has been shelved by all except electrophysiologists and a few interventionalists until recently. Today's invasive cardiologists will have to refamiliarize themselves with the technique as well as become involved with the newer TS devices and more advanced imaging. Training will remain an issue because of the number of cases and the lack of recent experience. Therefore, simulators and echocardiographic imaging should prove helpful. In the current era of catheter therapies for structural heart disease and EP, we will certainly see new and a resurgence of old techniques to aid in the success of forthcoming procedures.

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