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Transseptal puncture

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INTRODUCTION

The technique of transseptal puncture was developed to gain access to the left atrium (LA) for pressure measurement. Methods to measure left atrial pressure prior to the transseptal approach included direct left atrial puncture through the anterior chest wall, and transbronchial puncture via the left mainstem bronchus (1–8). These methods had obvious limitations. The transseptal approach was first described by Cope in 1959, using a 17-gauge solid needle introduced through polyethylene tubing via the right femoral vein (9). He employed the procedure in two patients and described left atrial and ventricular pressure measurement and angiography. In 1958 Ross et al., while working at the National Institutes of Health, were catheterizing the LA in patients with atrial septal defects. Ross was a fellow at the time. A visiting physician observed this procedure and asked whether Ross had considered using a needle to puncture the intact septum. This rapidly led to the development of a needle device for transseptal puncture via femoral cutdown in the animal laboratory (10). A few years later, when the Seldinger technique was introduced, a surgical resident working with Braunwald designed a catheter, the Brockenbrough catheter, through which the Ross needle could be placed percutaneously (11–13). The substitution of the Mullins sheath for the Brockenbrough catheter was the last major advance in the basic procedure. Subsequently, the transseptal puncture procedure has undergone only minor modifications (Fig. 1) (14,15).

Due to the technical challenges and the risks involved with transseptal puncture, pulmonary wedge pressure (PCW) measurement has been accepted as a surrogate for left atrial pressure assessment (16). PCW measurement remains the most common approach for estimation of the left atrial pressure in patients with heart failure and valvular heart disease. There are clear limitations to PCW, especially among patients with pulmonary hypertension (17–21). In the setting of pulmonary hypertension, elevated pulmonary artery pressure may "contaminate" the wedge pressure waveform and result in a significant overestimation of the PCW. Similarly, over-wedging may yield an underestimation.

Methods for retrograde catheterization of the LA via the left ventricle have been developed using specialized catheter shapes (22–24). Shirey and Sones described a multipurpose-type catheter that could be folded in the left ventricular apex and introduced into the left atrium (22). This approach is complicated by frequent ventricular ectopy, ventricular perforation, and inconsistent ability to cannulate the left atrium. Stefanadis et al. developed a guide catheter with a pull wire to flex the catheter tip backward from

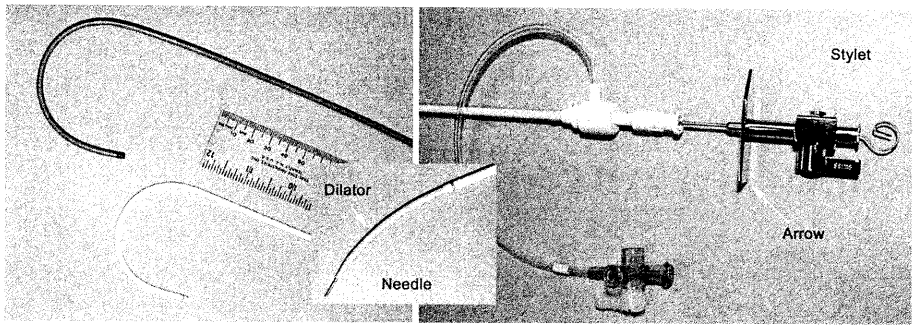

Figure 1 Mullins sheath and transseptal needle. The left panel shows 2 brands of 8-French Mullins sheaths. The curve helps direct the tip of the sheath toward the left ventricle after placement in the left atrium. The inset shows the tip of the transseptal needle protruding from the end of the dilator-sheath assembly. The right panel shows the hub of the dilator, sheath, and needle assembly. The large metal arrow indicates the orientation of the curve of the tip of the needle. A stylet is placed within the needle as the needle is passed through the dilator initially, to keep the tip of the needle from catching or perforating the transseptal dilator and sheath during insertion of the needle.

the left ventricle toward the LA, which allows introduction of a wire consistently and reliably into the left atrium (25). This device is not available in the United States and has not gained wide popularity for diagnostic purposes, being used only for retrograde, transarterial mitral balloon valvuloplasty.

Thus, transseptal puncture remains the gold standard for left atrial pressure assessment. It has clearly become more important in both electrophysiology and interventional cardiology as therapeutic procedures that require left atrial access become more common (21).

TECHNIQUE

The basic technique involves right femoral vein access. A 0.032 in. small guide wire is passed into the superior vena cava. A pigtail catheter is placed in the aortic root to better define the location of the aortic valve. A Mullins sheath and dilator are tracked over the wire into the superior vena cava and ideally angulated toward the left subclavian vein (Fig. 2). The wire is removed. A transseptal needle is introduced into the dilator. The needle contains a stylette that keeps the tip of the needle from catching on the body of the transseptal sheath dilator as the needle is advanced. The stylette must be withdrawn from the needle before the needle gets too close to the distal end of the transseptal dilator. The needle is positioned with its tip a few millimeters proximal to the distal end of the Mullins dilator, connected to a manifold and flushed (Fig. 2, inset). Right

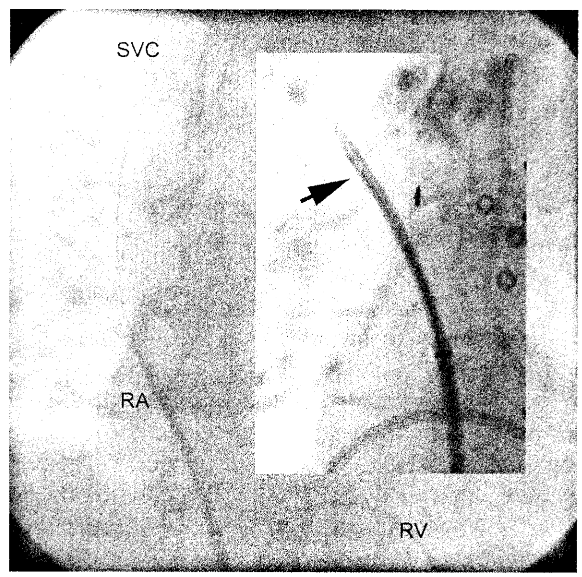

Figure 2 The initial step in the transseptal procedure is placement of the dilator and sheath in the superior vena cava (SVC). A 0.025 in. or 0.032 in. wire is placed in the SVC. The inset shows the tip of the transseptal needle placed just within the end of the dilator (*arrow*). *Abbreviations*: RA, right atrium; RV, right ventricle; SVC, superior vena cava.

atrial pressure is recorded from the tip of the needle. The needle and sheath/dilator assembly are pulled caudally through the superior vena cava (SVC) toward the right atrium (RA) as a unit. There is an indicator arrow on the hub of the needle that shows the direction of the angle of the needle. As the entire apparatus is pulled inferiorly from the SCV, the needle and Mullins sheath are rotated as a unit clockwise until the indicator arrow points inferiorly to between the 4 o'clock and 6 o'clock position (Fig. 3). The degree of rotation is less in structurally normal hearts, and progressively more in aortic stenosis and mitral valve disease. The fossa ovalis lies in the posterior aspect of the intra-atrial septum and is bounded superiorly by the limbus, an arch shaped outer muscular rim. Classic descriptions note two rightward movements as the needle is withdrawn from the SVC to the RA. The needle can be felt to move over the aortic knob, and then drop into the fossa ovalis (Fig. 4). The first movement over the aortic knob is often difficult to appreciate or absent. When the needle and dilator are in place on the fossa ovalis, it usually appears that the curve of the Mullins sheath will directly puncture the aorta. If the image intensifier is moved from an anteroposterior view to either a right or far left anterior oblique, it is possible to see that the needle is pointing posterior to the aorta (Fig. 5). A slight forward pressure on the needle will engage or catch on the limbus of the fossa ovalis. In many cases, the dilator will cross the intraatrial septum spontaneously at that point and the left atrial pressure will be seen. If this is not the case, pressure will damp as the needle tip contacts the interatrial septum. The transseptal needle is advanced out from the tip of the transseptal dilator. The needle must be advanced forcefully to avoid simply pushing the fossa away in front of it. The fossa ovalis comprises roughly 25% to 30% of the total septal area and is usually the thinnest portion of the septum. The diameter of the fossa can vary dramatically from patient to patient. This membrane consistency varies, however, usually becoming thicker and more fibrotic with age. The fossa may extremely thickened after prior cardiac surgery. When the needle enters the LA, left atrial pressure is recorded, and the dilator can be advanced into the LA and the needle withdrawn. Perforation of the LA posteriorly or anteriorly *with the needle alone* has rarely resulted in significant cardiac complications. It is typically the dilation with the sheath dilator or sheath itself that can cause significant cardiac compromise. If there is aortic or pericardial staining following what is presumed to be transseptal puncture, the needle must be removed and the dilator withdrawn and then the 0.032 in. J wire repositioned to the SVC and the process repeated. When the needle is clearly in the LA, the sheath can be advanced over the dilator and needle to secure access in the LA. Free back-bleeding of arterial blood should be noted from the hub of the Mullins dilator. Any air bubbles must be

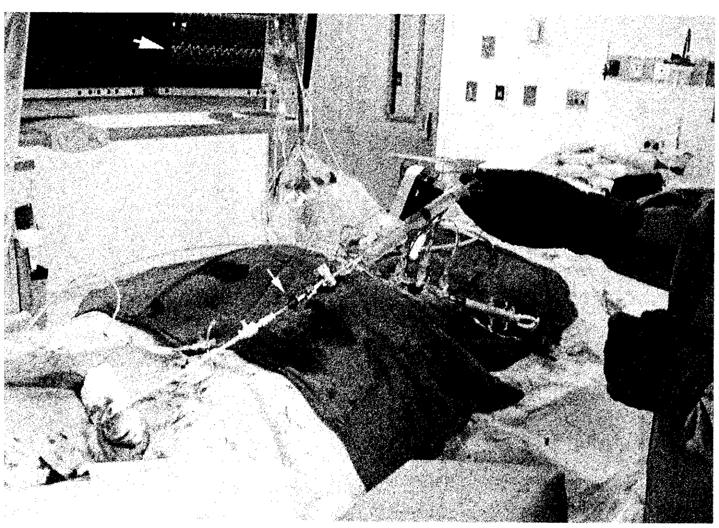

Figure 3 The arrow indicator (*lower arrow*) on the transseptal needle is oriented toward about 4 or 5 o'clock, relative to the patient. The patient's head is on the left side of the picture, and the feet are on the right. The transseptal needle is shown attached to a manifold for pressure measurement. In the upper left corner of the picture, *a second white arrow* shows the right atrial pressure, displayed on the monitor.

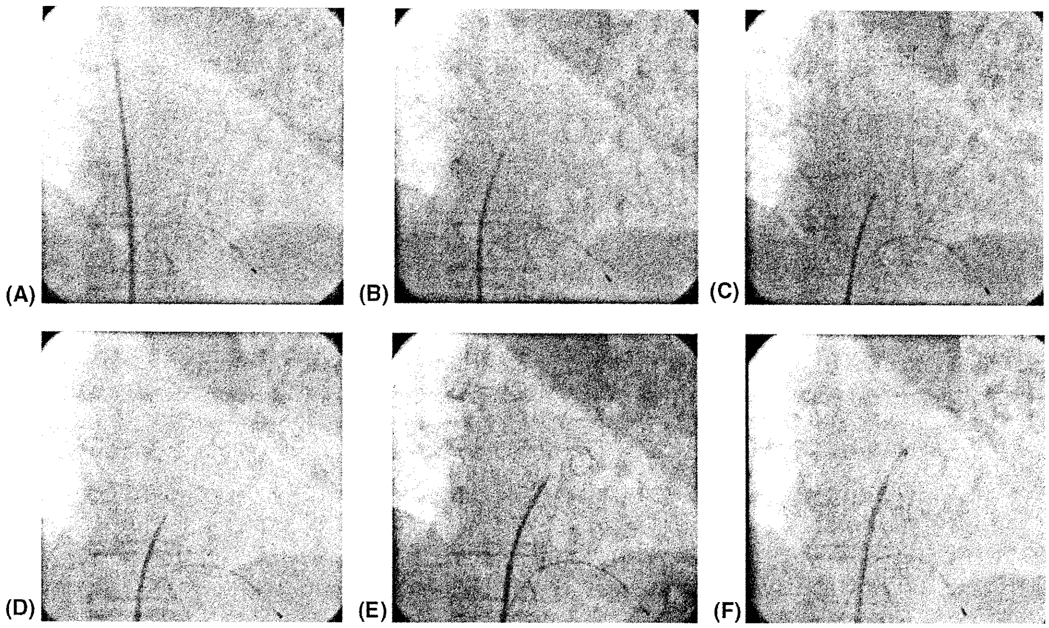

Figure 4 The basic steps in the transseptal procedure. (**A**) The sheath, dilator, and needle have been placed in the superior vena cava. (**B**) The sheath, dilator, and needle are pulled down inferiorly over the bulge of the aorta. (**C**) The assembly has engaged the fossa ovalis. The indicator arrow is rotated to between 4 and 6 o'clock relative to the patient. (**D**) The needle has been extended out of the dilator, through the fossa ovalis into the left atrium. Left atrial pressure should be seen on the monitor. (**E**) The dilator has been advanced over the needle into the left atrium. (**F**) A wire is advanced into the left upper lobe pulmonary vein, and the sheath advanced over the dilator. The sheath and wire are carefully removed to avoid aspiration of air, and the sheath system flushed. Heparin is administered at that point.

aspirated. Contrast injection can be used to verify the position of the Mullins sheath within the LA (Fig. 6). It is useful to pass a guidewire through the dilator just after the needle has been removed to stabilize forward advancement of both the dilator and the sheath. One of the disappointing modes of failure for this procedure is to successfully puncture the septum, but then have the tip of the dilator jump forward and perforate the left atrial free wall. Using a wire to help pass the dilator and sheath across the intra-atrial septum thus makes advancing the dilator safer. After successful puncture of the intra-atrial septum, heparin is given. The heparin dose depends on the purpose of the procedure. For a diagnostic procedure where the catheter time in the LA would be very brief, an arbitrary small dose of heparin might be used. For procedures such as valvuloplasty, activated clotting time between 200 and 300 seconds is desirable, depending on the procedure. Percutaneous mitral valve repair or longer electrophysiology procedures require activated clotting times $\geqslant$ 300 seconds.

The left femoral vein is usually not a successful approach, since the angulation of the left iliac vein as it joins the inferior vena cava will force the transseptal needle to move away from the intra-atrial septum. Only in patients who are very narrow hipped with a steep angle between the iliac vein and the inferior vena cava may left femoral access be likely to succeed.

Measurement of pressure through the transseptal needle is not a uniform practice. In our opinion, it is essential for the safest method for accessing the LA. If the needle is advanced and LA pressure is not detected, a number of possibilities exist. The needle may be buried in the tissue of the septum, having taken a tangential through the septum. It is possible that the free wall of the roof of the RA or the inferior

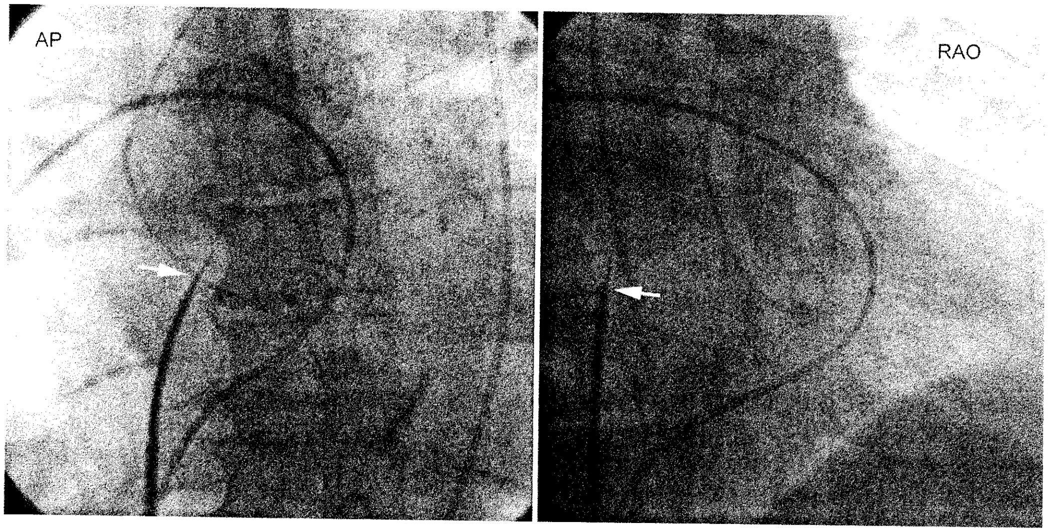

Figure 5 The *left panel* shows an anteroposterior (AP) view. The *arrow* points at the tip of the dilator, from which the needle is extended into the left atrium. The *right panel* shows a right anterior oblique (RAO) view. The *arrow* again indicates the tip of the dilator, from which the needle extends. The pigtail catheter is resting against the aortic valve. On the AP view it appears that the needle has transected the aorta, while on the 30° right anterior oblique view it is clear that the needle overlies the spine, and is thus posterior to the aorta and pigtail.

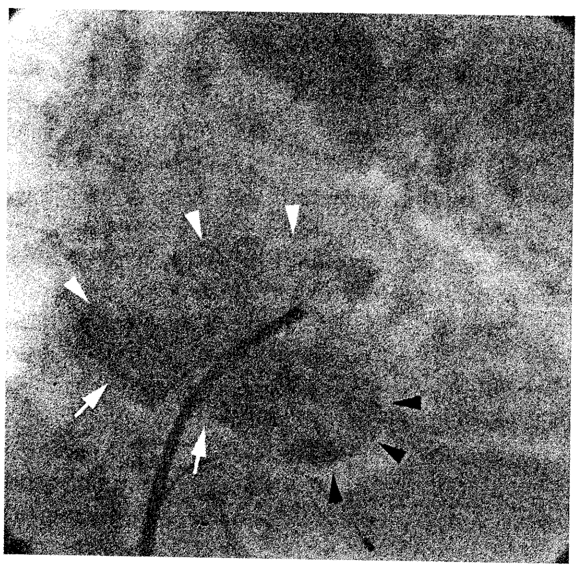

Figure 6 Contrast injection after successful transseptal puncture. The *white arrowheads* mark the upper border of the left atrium; the *white arrows* mark the intra-atrial septum; the *black arrowheads* show the mitral valve, closed in this angiographic frame.

border of the RA or LA has been perforated. It is also possible that the LA has been entered, but that a small thrombus has occluded the pressure lumen of the needle. In any of these eventualities, as long as the needle is withdrawn and the 8-French sheath is not advanced, and as long as the patient is not anticoagulated, the potential for pericardial tamponade is small. As long as the incorrect position of the needle is recognized and the attempt abandoned at that point, complications from needle perforations are infrequent. This emphasizes the need to have patients off of coumadin or heparin anticoagulation prior to beginning a transseptal puncture procedure.

FLUOROSCOPIC AND INTRA-CARDIAC ECHOCARDIOGRAPHY GUIDANCE

Since fluoroscopy only allows indirect assessment of the location of the fossa ovalis without good visual representation of these critical anatomic landmarks, advancement of the transseptal needle using only fluoroscopically-guided techniques can be frequently associated with unpredictable outcomes. The introduction of intracardiac echocardiography has added greatly to the safety and appreciation of the anatomic variability and location of fossa ovalis. Some centers routinely perform transesophageal echocardiography to facilitate transseptal catheterization. Transesophageal echocardiography can readily image the fossa ovalis and needle assembly, but requires a second operator, greater degrees of sedation, and is not practical for long procedures. More recently, intracardiac echocardiography has been employed to facilitate transseptal catheterization. With the introduction of this technology, a single operator can perform this procedure painlessly and continuously without sedation. Intracardiac echocardiography has permitted less experienced transseptal operators to adopt the procedure.

The classic approach to transseptal puncture uses fluoroscopic guidance coupled with tactile feedback from the dilator. The location of the puncture is "guestimated" based on the location of the aortic root as marked by a pigtail combined with bony landmarks. The variability of the puncture location is extreme. The classic fluoroscopic landmark for the puncture site is in the center of the spine, at the level of the aortic root. Depending on the patient's age, the relative amounts of right and left atrial dilatation, and spinal deformities, the puncture site may frequently be to the left or right of the center of the spine, sometimes by many centimeters. Tactile feedback from the transseptal needle is one of the most important descriptors of the location of the puncture. As the dilator is withdrawn from the SVC and felt to catch on the lumbus with a slight forward motion, a pulsatile motion can be felt in some cases. If fluoroscopy shows the needle pointing posterior and away from the aorta, the pulsatility represents the atrial "septal bounce," whereas if the needle is pointing at the aorta, it is the aorta that is being felt. Advancement of the needle will yield a left atrial pressure tracing, which confirms the left atrial location.

A variety of methods can be used to determine the location of the center of the intra-atrial septum. One of the simplest is right atrial contrast injection with filming of the levo phase. Contrast of 20 or 30 mL can be given as a bolus in the RA. A long acquisition time is required to be able to see the left atrial filling on the levo phase.

More recently, intravascular ultrasound has become the method of choice to clearly visualize the atrial septum to assist in transseptal puncture (26-31). Intracardiac echo (ICE) is widely available. A relatively simple ICE catheter is available which uses a single rotating crystal ultrasound transducer based on either 9-French 9 MHz rotating crystal or a 6.5-French 12.5 MHz ultrasound crystal (CVIS®, Boston Scientific, Sunnyvale, CA). This has the advantages of being compatible with standard coronary intravascular ultrasound consoles, and it is relatively inexpensive, costing about the same as a coronary IVUS catheter. It has the disadvantages of a limited depth of field, and it provides no more than a planar 2-dimensional view of the atrial septum. Nonetheless, in many cases it is adequate to demonstrate contact of the transseptal needle with the fossa ovalis. Accuson, a 64-element phased-array ultrasound system using a 10-French 9 MHz transducer (AcuNav®, Seimens Acuson, Mountain View, CA) that images in a sector field oriented in the plane of the catheter rather than a circumferential field of view intracardiac echo, requires a Siemens echo machine console, and the catheters are significantly more expensive than the simple Boston Scientific ultrasound. They have the advantage of a greater depth of field, image quality that appears basically equivalent to transesophageal echocardiography, and the availability of color Doppler as well. Accuson ICE is used widely in conjunction electrophysiology ablation procedures and with shunt closure procedures, because in addition to verifying catheter placement, it aids with device placement and assessment of post-procedure shunting.

When the transseptal dilator engages the fossa, it causes a pushing or tenting of the fossa from the RA into the LA (Fig. 7). It is important to note that the tip of the transseptal needle itself is often echolucent and tenting is the only reliable sign of proper engagement of the fossa ovalis. Simply seeing the echo shadow of the catheter close to the septum can be highly deceptive, since the body of the transseptal catheter may be transected by the plane of the ultrasound beam even when the tip of the needle is far away from the septum.

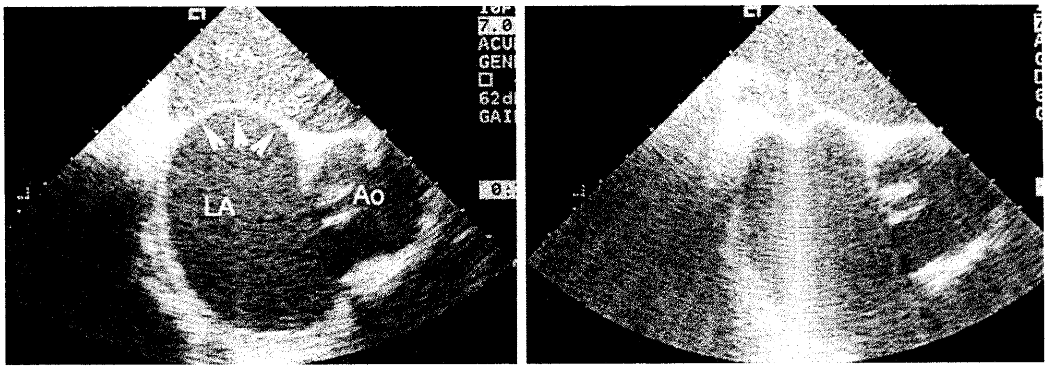

Figure 7 Intracardiac echo guidance for transseptal puncture. The left panel shows a baseline image. The arrowheads show the intra-atrial septum (IAS). In the *right hand panel* the transseptal needle has been engaged in the foramen ovale; the *arrow* shows tenting of the intra-atrial septum into the LA caused by forward pressure of the transseptal dilator. There is considerable shadowing in the left atrium from the transseptal apparatus. It is notable that the needle itself is not visible, but that the tenting is well displayed. The needle is either out of plane or, because of its relatively thin structure, is in this frame echolucent. *Abbreviations*: RA, right atrium; AO, aorta; LA, left atrium.

The electrophysiology approach

A totally venous access approach to transseptal procedures is now commonly utilized in experienced electrophysiology (EP) laboratories. Because EP catheters are placed in strategic anatomic locations defined by their recorded electrograms, EP recording equipment is required. It is our practice to begin by placing a His bundle and coronary sinus catheter to provide anatomic landmarks fluoroscopically (Fig. 8). A His bundle catheter *that is recording a His bundle* always identifies the most inferior aspect of the non-coronary cusp of the aorta. This obviates the need for an arterial puncture to place a pigtail catheter in the ascending aorta. A coronary sinus catheter properly placed along the artereovenous groove demarcates the widest portion of the LA parallel and just posterior to the mitral annulus. One must ensure that the coronary sinus catheter courses near the mitral annulus by seeing equal-amplitude atrial and ventricular electrograms exist throughout the course of the catheter. If not, the catheter may have inadvertently been placed in a posterolateral branch of the coronary sinus and should be repositioned prior to performing transseptal catheterization.

The fluoroscopic views are adjusted so the His bundle catheter is pointing directly at the image intensifier of the fluoroscopic camera. The right anterior oblique angulation is adjusted so the coronary sinus catheter intersects the His bundle catheter and its midpoint. Careful evaluation of the His bundle recording should be maintained to ensure an accurate anatomic reference relative to the inferior aspect of the aorta. The transseptal needle and sheath assembly are withdrawn in the LAO view as a *single unit* maintaining the position of the needle to the dilator from the SVC position to the RA with the needle usually oriented in the 4 o'clock psosition. If the coronary sinus catheter has been placed from a superior approach, care must be utilized to ensure that, during torquing of the sheath, the coronary sinus catheter is not twisted around the sheath and needle assembly.

As the needle/sheath assembly is withdrawn, an initial slight leftward jump of the assembly is noted as it enters the RA, and then a second movement leftward occurs as the catheter tip approaches the level of the His bundle catheter, which is below the superior limbus of the fossa ovalis. At this level the RAO view confirms that the catheter tip is posterior to the site of the His bundle recording and angled posterior and parallel to the projection of the coronary sinus

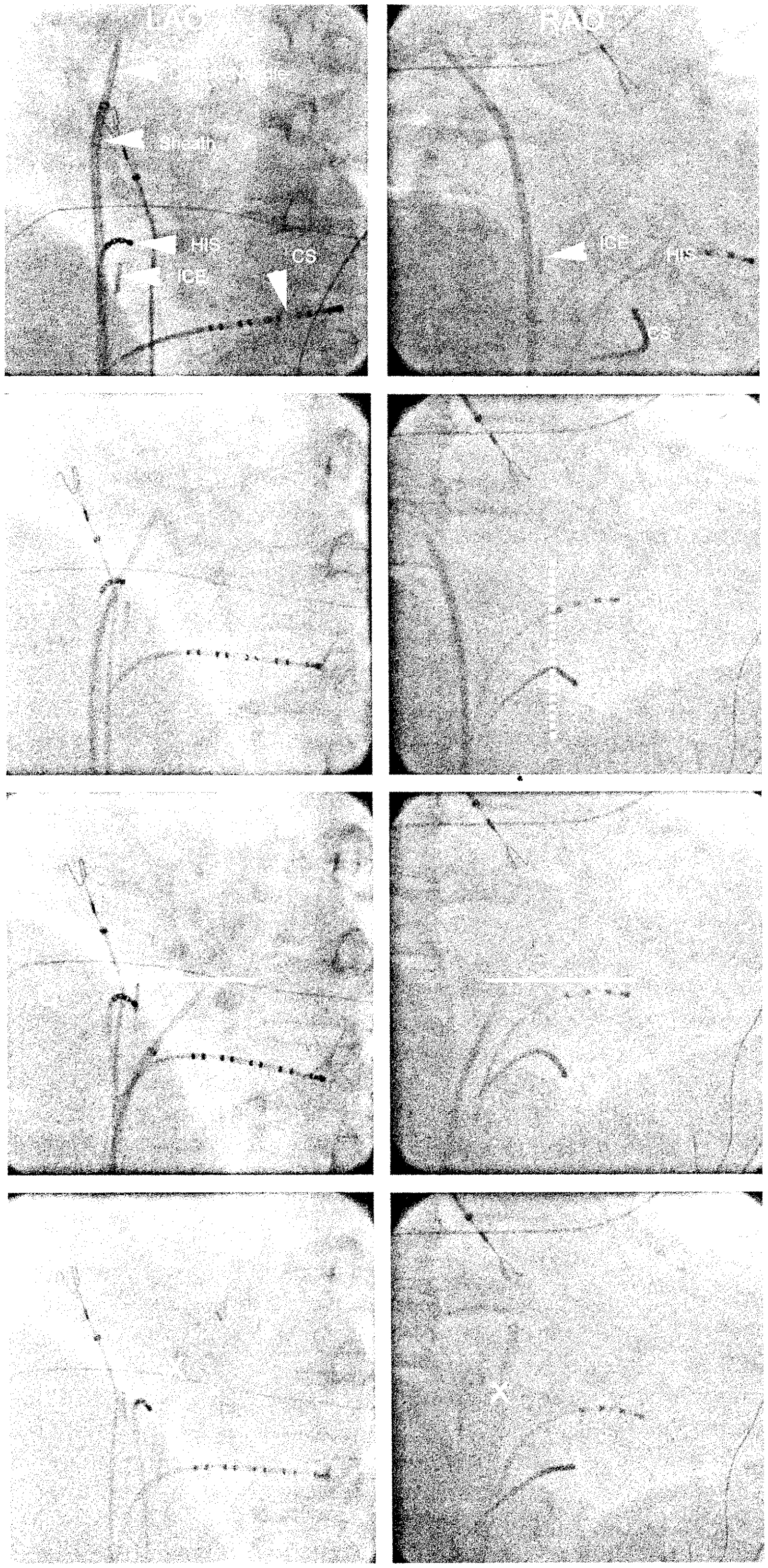

Figure 8 (**A**) RAO 40 and LAO 40 fluoroscopic images of the sheath, dilator, needle assembly positioned in the superior vena cava. Note the position of the His bundle catheter (His), coronary sinus catheter (CS), and intracardiac echocardiography catheter (ICE). (**B**) Angulation of the RAO camera is adjusted to 30 degrees so the proximal electrode of the His catheter is in the same vertical plane as the CS catheter (dashed white line in RAO view). Withdrawal of the sheath/dilator/needle (SDN) has entered the right atrium. Note the assembly is positioned too posteriorally in the RAO 30-degree view despite having the needle torqued to approximately a 4 o'clock position. (**C**) Proper positioning of the SDN position prior to transseptal puncture. Note the SDN assembly is oriented posterior to the His bundle catheter in the RAO view. Note that the electrograms of the His bundle must be seen to be able to use this catheter as a reliable anatomic landmark. Typically, the tip of the dilator is at the same level as the His bundle catheter (*solid white line*) and well to the left (posterior) of the His bundle catheter in the LAO view, and oriented posterior and parallel to the CS catheter in the RAO view. (**D**) Sheath position following transseptal crossing. Following transseptal puncture the dilator is advanced over the needle and dilator assembly into the left atrium. Only after the sheath is advanced into the left atrium should the needle and dilator be removed, because they provide support for the sheath to pass into the left atrium. The point of transseptal crossing is marked by an "x".

catheter. This angle ensures that the assembly is not pointing too posteriorally, in which case the needle may perforate the posterior wall of the LA, and not pointing too anteriorally, at which point the needle might enter the ascending aorta. Adjustments of angulation between 3 o'clock and 6 o'clock may be necessary, with enlarged left atria often requiring a more posterior (or 5 to 6 o'clock) angulation and vertically oriented hearts requiring a more anterior (3 to 4 o'clock) angulation of the needle.

When the angulation of the needle is confirmed, transseptal crossing is done in the LAO projection. The assembly is withdrawn. 25–.5 cm farther and then advanced to engage the limbus of the fossa ovalis. Patients with patent foramen ovale will have the dilator move toward the left atrium. If hemodynamics are utilized, the left atrial pressure recording can be recorded from the transseptal needle or the needle location can be confirmed by ICE or contrast injection. More commonly, however, the dilator does not pass spontaneously into the left atrium. Pressure measurements are usually damped when the needle and dilator are juxtaposed to the intra-atrial septum. When the transseptal needle is advanced to enter the LA, a tactile "pop" is felt. This can be confirmed by contrast injection or pressure recording from the tip of the needle. The dilator is then advanced over the needle assembly to enter the LA and, with the support of the needle, the sheath is advanced over the dilator into the LA. If there is any question about the location of the needle the dilator should not be advanced. Once the sheath is in the LA and has been flushed, heparin is given.

Thickened atrial septum

A septum thick enough to make puncture difficult may be encountered in older patients with lipomatous hypertrophy and after prior open heart surgery (31–36). Patients with prior valve surgery may develop endocardial thickening, and in some cases the fossa is sutured to prevent air embolism. Puncture may also be performed after atrial septal patching or repair for congenital heart disease. In all of these situations ICE is extremely helpful and puncture is often unsuccessful without ICE guidance (Fig. 9). The needle may be advanced tangentially into the septal tissue, so that even if the puncture location is correct, it is not possible to reach the LA. When the transseptal needle causes "tenting" of the septum, more force than is otherwise acceptable can be used to advance into the LA. Another method to cross a tough or thick septum is with radiofrequency perforation (37). This requires specialized equipment, and is best performed with ICE.

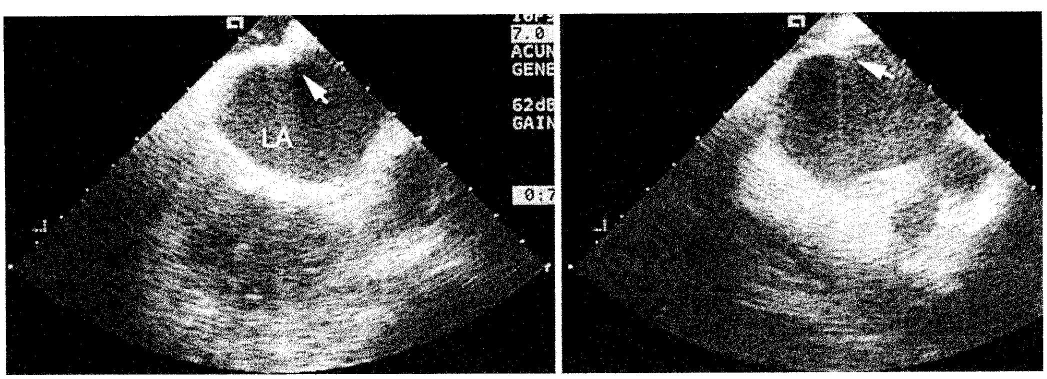

Figure 9 Intracardiac echo images from a patient with a markedly thickened intra-atrial septum. This patient had undergone prior resection of a right atrial myxoma from the right atrial free wall. The septum is almost 1-cm thick. The *left panel* shows tenting of the septum from a transseptal dilator marked by the *arrow*. With full extension of the needle, the left atrium could not adequately be entered. Forward pressure on the needle, more extreme than would be possible without echo guidance, was necessary to force the needle into the left atrium, and ultimately record left atrial pressure via the needle before advancing the dilator. The *right panel* shows the needle across the septum, marked by the *arrowhead*. *Abbreviation*: LA, left atrium.

Indications, contraindications, and complications

Indications

Indications for transseptal procedures include a variety of diagnostic uses, and an increasing array of therapeutic procedures (35–39). Diagnostic assessment of mitral and aortic valve disease, congenital lesions, and hypertrophic cardiomyopathy are the most frequent situations in which transseptal puncture is employed. Mitral stenosis is, of course, the most classic, and catheter-based mitral valve repair the most recent (39). Direct measurement of left atrial pressure combined with retrograde left ventricular pressure yields accurate assessment of the transmitral pressure gradient. It is also possible to pass a French Mullins sheath into the LA, and through this float a 7-French balloon tip catheter into the left ventricle (Fig. 10). Thus simultaneous left atrial and left ventricular pressure can be obtained via a single venous puncture without the need for arterial catheterization or retrograde crossing of the aortic valve. Similarly, this approach for left ventricular pressure measurement can be coupled with retrograde placement of a catheter in the central aorta for accurate assessment of the transaortic valve pressure gradient in aortic stenosis or hypertrophic cardiomyopathy. This method yields pressures recorded directly from either side of the valve and avoids all of the artifacts of pressure amplification and damping that are common in peripheral arterial sheath substitution for the central aortic pressure when assessing aortic valve stenosis.

In rare instances, the transseptal approach has been used to pass a catheter into the aortic root

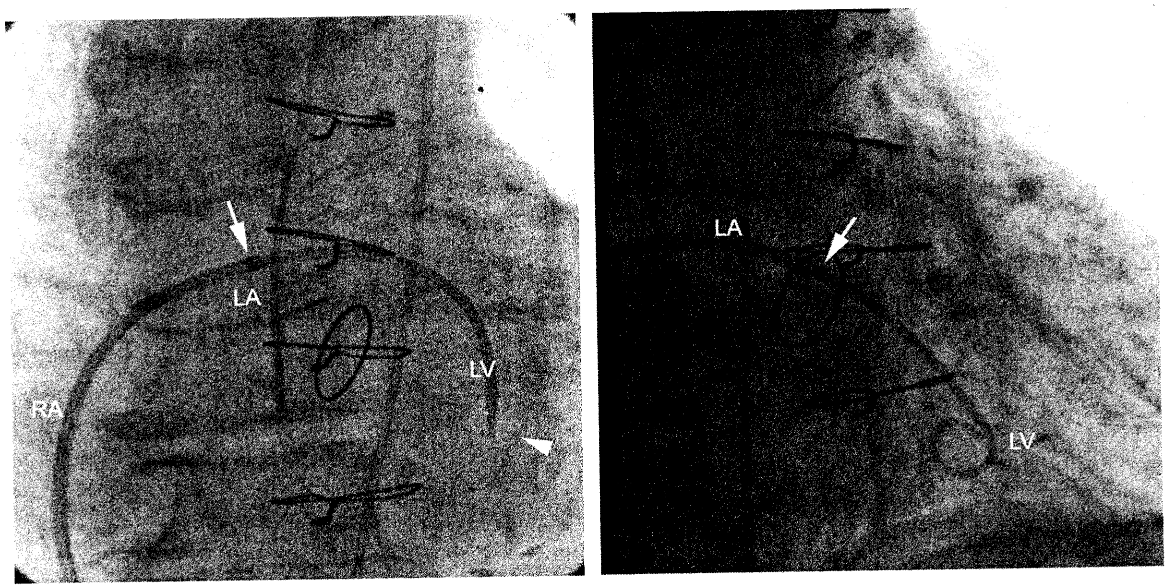

Figure 10 Catheterization of the left ventricle via the mitral valve after transseptal puncture. This is an excellent method to record a transaortic or transmitral valve pressure gradient. In this case, the patient has a Hancock bioprosthetic aortic valve replacement. A pigtail catheter sits in the sinus of Valsalva adjacent to the valve in the *left panel* (AP view). The *arrow* marks the tip of the Mullins sheath. A 7-French single lumen balloon catheter has been floated across the mitral valve into the left ventricle. The inflated balloon is marked by the *arrowhead*. In the *right hand panel* in a right anterior oblique view, a pigtail catheter has been substituted for the single lumen balloon catheter for ventriculography. Simultaneous recording of the left atrial and left ventricular pressures for evaluation of mitral stenosis, and of the left ventricular and aortic pressures for evaluation of the transaortic valve pressure gradient can be easily accomplished. A central aortic pigtail catheter is just visible in the upper left corner of this frame. *Abbreviations*: RA, right atrium; LA, Left atrium; LV, left ventricle.

for coronary arteriography. This can be accomplished in patients with limited access from the extremities. It, of course, requires a great deal of catheter manipulation and time to achieve selective or semiselective coronary arteriography.

The method for access of the aorta via the transseptal route is used increasingly for therapeutic procedures but also has diagnostic utility. A 8-French transseptal sheath is placed in the LA. A 7-French balloon catheter is floated into the left ventricle. The catheter can be curved in the left ventricular apex, or a curved wire can be introduced into the catheter to help it make the turn around the apex, and then the balloon catheter is floated across the aortic valve into the aortic root. This allows measurement sequentially of the entire right and left heart circulations, or passage of a guidewire from the RA, across the septum into the LA, through the left ventricle, into the aorta, and sometimes out through a femoral arterial sheath. This transcirculatory wire loop is sometimes called "flossing" the circulation (Fig. 11) (21,36).

Therapeutic uses for transseptal catheterization are increasing rapidly. Catheter ablation for left sided accessory pathways and atrial fibrillation in electrophysiology have become common procedures. Antegrade valvuloplasty of the mitral valve, and also of the aortic valve is accomplished using transseptal access. Paravalvular leak closure also frequently requires transseptal access either for delivery of a closure device, or for wire passage to ultimately allow retrograde delivery catheter placement. The variety of new percutaneous valve repair and replacement therapies require transseptal puncture as well. Mitral valve repair is predicated on left atrial access via the transseptal route. The E-valve procedure uses a 24-French venous cannula to access the LA, and then place a clip directly on the mitral leaflets. A great advantage of the transseptal route is the ability to place large catheters in the femoral vein, and then achieve left heart access. The obviates the need for large bore atrial sheaths in many instances. Antegrade aortic balloon valvuloplasty is accomplished using a 14-French venous sheath. This bears the challenges of arterial access and hemostasis using sheaths of that caliber via the arterial route, necessary of course for retrograde aortic valvuloplasty.

Contraindications

The most important contraindications to transseptal puncture include atrial thrombus or mass. Right atrial thrombus may form on pacemaker leads or inferior vena cava filters. It is unusual for right atrial thrombus to directly preclude transseptal puncture. Left atrial appendage thrombus is a more common problem (Fig. 12). In mitral stenosis patients who have not been on coumadin, left atrial appendage thrombi will often resolve in 2 to 4 months with coumadin therapy. For patients who have been on coumadin, the addition of antiplatelet therapy and more intense coumadin therapy is sometimes successful. Smoke, or spontaneous echo contrast, in the LA is not a contraindication to transseptal puncture. Rare cases of atrial septal thrombus are encountered and represent an important contraindication to transseptal puncture. In cases where left atrial appendage thrombus is seen on a baseline echo, and then appears in a stable concave, echo-dense (organized) configuration on a follow-up echo after prolonged anticoagulation therapy, it is sometimes safe to proceed with transseptal puncture. If the atrial appendage thrombus is well organized, there is little risk of embolization. Unfortunately it is prospectively very difficult to tell whether any fresh or mobile thrombus might exist on the surface of an echo-dense organized thrombus. Thus, left atrial appendage thrombus remains an important relative contraindication to this procedure.

Another strong relative contraindication to transseptal puncture is in patients who have abnormal coagulation or thrombocytopenia. Many patients present for transseptal catheterization having been on coumadin. Coumadin is typically discontinued 3 or 4 days before the catheterization procedure. A bridge using heparin or Lovenox® (Aventis, Bridgewater, NJ) is commonly employed. It is my practice to proceed with transseptal puncture only if the international normalized ratio (INR) is less than or equal to 1.7. After a hiatus off of coumadin therapy, patients will occasionally appear with an elevated INR and the procedure must be delayed. Platelet counts of 50,000 to 100,000 represent a degree of thrombocytopenia that imposes an important risk for tamponade if an

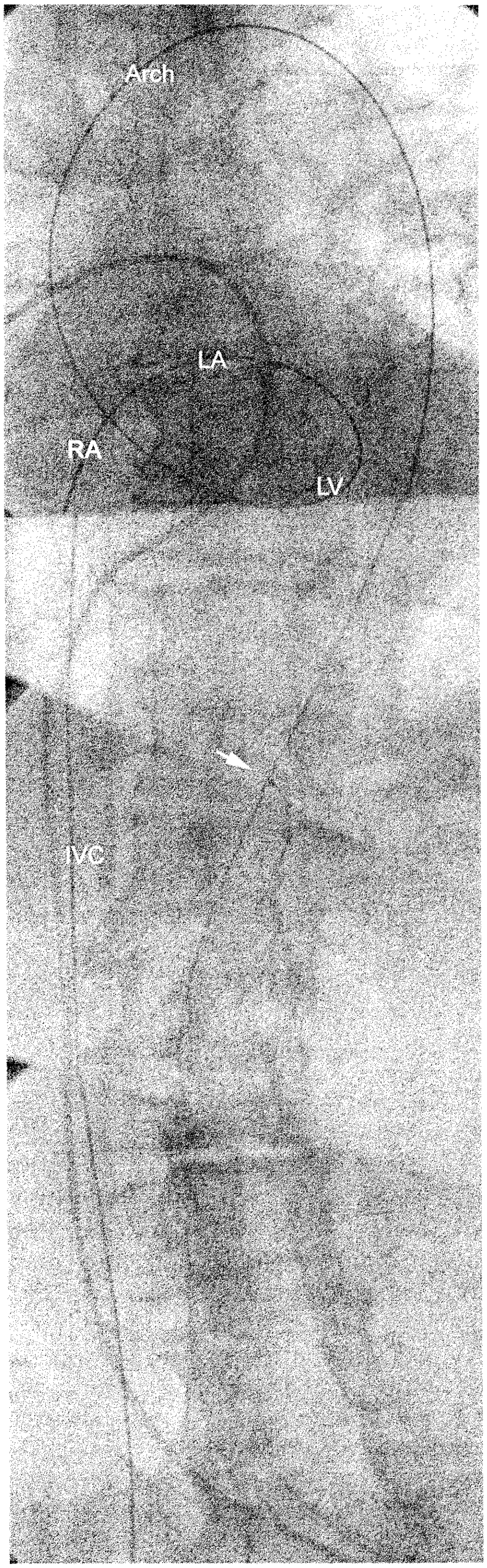

Figure 11 A guidewire has been placed via the transseptal route throughout the whole circulation. This is sometimes called "flossing" the circulation. The course of the wire involves introduction through a transseptal sheath via the inferior vena cava (IVC), right atrium (RA), left atrium (LA), across the mitral valve and into the left ventricle (LV), then out into the aortic arch and the descending aorta. In this example the wire has been snared in the descending aorta (*arrow*). The snare has been closed on the wire to provide stability for antegrade aortic balloon valvuloplasty. It is also possible to snare the wire and exteriorize it, which allows introduction of devices from either the arterial or venous limbs of the same wire. Importantly, when a wire loop like this is removed from the circulation it is critical to cover it with a diagnostic catheter so that friction of the wire does not lacerate the heart valves.

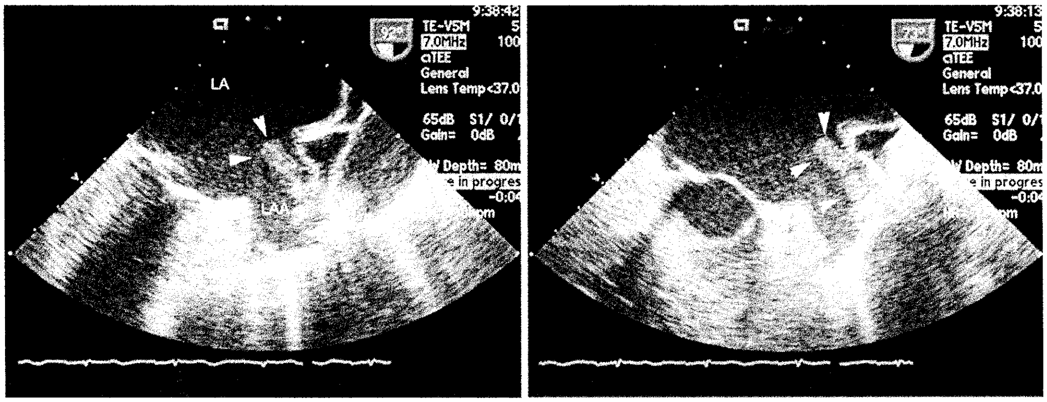

Figure 12 Transesophageal echocardiographic images showing left atrial thrombus. Atrial appendage thrombus is one of the most important contraindications to transseptal procedures. In the *left panel*, the arrowheads show a large thrombus. In the *right panel* in a second frame, the thrombus is seen to have a lobular or globular appearance. The thrombus extends out of the left atrial appendage (LAA) into the body of the left atrium (LA). Echocardiographic smoke is seen in the appendage and extending out into the body of the left atrium.

errant puncture results from the procedure. A platelet count over 100,000 can generally be regarded as acceptable for proceeding with a transseptal puncture.

Complications

Thromboemboli from the catheter, needle, or cardiac chambers may occur. Extreme care to flush and wipe the transseptal system frequently is needed to avoid thrombus formation on the transseptal needle. The stainless steel needle is metal and highly thrombogenic. In most reported series cardiac tamponade occurs in 0.5–2%, and stroke in <1% (41). Both cardiac perforation and thromboembolism can be fatal.

The vast majority of complications that arise from transseptal catheterization occur from inadvertent puncture of adjacent structures to the interatrial septum and fossa ovalis. Thus, anticoagulation is not given until the LA has been safely entered. The interatrial septum is bounded posteriorly by the pericardium. The aortic root lies superior and anterior to the fossa ovalis while the coronary sinus ostium lies inferior to the fossa ovalis and posterior to the tricuspid valve orifice. In pathologic hearts there is frequent distortion of the atrial and interatrial septum anatomy, which can significantly alter the proximity of these structures. The septum tends to lie more horizontal in patients with left atrial enlargement and can be more vertical in patients with aortic valve disease or a dilated aortic root. Varying degrees of kyphoscoliosis can also alter intrathoracic cardiac rotation. Also, prior open heart surgery can result in a thickened fossa ovalis because surgeons occasionally must over-sew the fossa in patients with a patent foramen ovale to ensure evacuation of air from the LA before coming off cardiopulmonary bypass. Cardiac perforation may result from perforation of the RA, perforation of the LA after successful transseptal puncture, and also by perforation through the inferior border of the RA across the transverse pericardial sinus and then into the LA. This latter route for perforation may not be recognized until the conclusion of the procedure, since the catheter will exit the RA and very quickly enter the LA, yielding a good left atrial pressure wave form. It is not until the catheter is removed that the puncture through the space between the RA and LA at the lower border can be recognized. After balloon mitral valvotomy procedures, it is my practice to leave the wire across the transseptal puncture after the catheters have been removed for about 5 minutes with continuous arterial pressure monitoring. This allows re-access to the puncture site and LA if a puncture across the transverse pericardial sinus has occurred.

The performance of transseptal puncture cannot reasonably be undertaken without readiness also to perform pericardiocentesis (42). When hypotension occurs during a transseptal procedure, it is fair to assume that it is due to cardiac perforation until proven otherwise. Pleuritic chest pain, shoulder pain, or new atrial fibrillation should also raise suspicion regarding potential perforation. The ready availability of echocardiography to help with both the confirmation of the diagnosis and the performance of pericardiocentesis is helpful. In the event that pericardiocentesis is necessary, it can almost always be accomplished using equipment already available on the catheterization table without a special pericardiocentesis set. A standard 18-gauge thin wall needle is adequate to reach the pericardial space in the vast majority of patients. While the traditional approach for pericardiocentesis involves directing the needle from the left subxiphoid angle toward the left shoulder, in the setting of acute pericardial tamponade, it is common for the effusions to be much smaller and a more vertical pathway is needed to reach the pericardial space. It is my usual practice when echocardiographic guidance is not available, to make a first pass with the needle angulated toward the mid part of the left clavicle. A standard pigtail catheter of any French size can be used for initial pericardial drainage. Once the blood pressure is stabilized, the pigtail catheter can be exchanged for a multihole pericardial drainage catheter. Generally, the drain should be left overnight, since continued bleeding from a perforation may occur. It is disappointing to create a perforation during a transseptal procedure, successfully drain the pericardium, and then have the patient tamponade some hours later from recurrent bleeding if the drain has been removed prematurely. The drain can be discontinued when there is less than 100 mL of drainage in a 24-hour period.

If perforation is recognized after administration of heparin, protamine should be used to reverse the anticoagulation. Protamine sulfate is itself a mild anticoagulant, but when given with heparin (which is strongly acidic) a stable, non-coagulating salt is created and inactivates the anticoagulant effect of heparin. On average 1 mg of protamine will reverse approximately 90 USP units heparin derived from beef lung or 115 USP units of heparin derived from porcine intestinal mucosa. Usually it is advised that no more than 50 mg of protamine be given over 10 minutes. Rapid administration of protamine can result in severe hypotension, anaphylactoid reactions, and respiratory compromise. In practice, administration of 5–10 mg of protamine at one time with frequent reassessment of the ACT will achieve reversal of anticoagulation with a minimum of complications. Typically no more than 100 mg of protamine should be administered acutely. Because protamine sulfate can cause anaphylaxis, medications should also be available to deal with this emergency as well. Anaphylactoid reactions are more common in diabetic patients who have taken NPH insulin, which contains protamine and sensitizes some of them to protamine.

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