Percutaneous Approach, Including Transseptal and Apical Puncture

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In contrast with the direct brachial technique (see Chapter 5), the percutaneous approach to left and right heart catheterization achieves vascular access by needle puncture (1), and thus obviates surgical isolation of the vessel during either the insertion or the subsequent withdrawal of the cardiac catheter. Once the needle has been positioned within the vessel lumen, a flexible guidewire is advanced through the needle and well into the vessel being accessed (2). This guidewire remains in an intravascular position as the needle is withdrawn and provides the means for introducing the desired catheter. Although most operators once inserted end-hole catheters directly over the guidewire, current practice is to first place an introducing sheath over the guidewire, and then to advance the catheter through this sheath (3),(4). This modification reduces patient discomfort and eliminates repetitive local arterial trauma during catheter exchanges, although it does increase the size of the puncture slightly (the outer diameter of the sheath is 1F size or 0.33 mm larger than the corresponding bare catheter). At the termination of the percutaneous catheterization procedure, the catheters and introducing sheaths are withdrawn, and bleeding from the puncture sites is controlled by the application of direct pressure.

Percutaneous entry via the femoral approach has become the dominant approach to cardiac catheterization. More than 85% of the procedures contained in the 1990 registry of the Society for Cardiac Angiography and Intervention were performed via this route (5). With appropriate skill and knowledge of regional anatomy, moreover, the same percutaneous techniques used for femoral artery and vein cannulation can be adapted to allow catheter insertion from a variety of other entry sites. Venous catheterization can thus be performed via the internal jugular, subclavian, or median antecubital vein, whereas arterial catheterization can be performed via the brachial, axillary, or radial arteries, or even the lumbar aorta.

CATHETERIZATION VIA THE FEMORAL ARTERY AND VEIN

Patient Preparation

After palpation of the femoral arterial pulse within the inguinal skin crease, a safety razor is used to shave an area approximately 10 cm in diameter surrounding this point. Although most catheterizations can be performed quickly and easily from a single groin, we have found it expedient to prepare both groins routinely. The right groin is generally used, since it is more easily accessed by the operator standing on that side of the table. If difficulties in catheter advancement force a switch to the other groin once the procedure has begun, however, having the left groin already prepared saves time and inconvenience. The shaved areas are scrubbed with a povidone-iodine/detergent mixture and then painted with povidone-iodine solution. The latter is blotted dry using a sterile towel and the patient is draped from clavicles to below the feet, leaving exposed only the sterile prepared groin areas. Most laboratories now use disposable paper drapes with adhesive-bordered apertures for this purpose, frequently packaged together with other disposable supplies (syringes, needles, bowls, and so on) in a custom kit available from any of several vendors.

Selection of Puncture Site

The adjacent femoral artery and vein(Fig. 4.1A,B) are the most commonly used vessels for percutaneous diagnostic cardiac catheterization (5). It is important to perform the punctures at the correct level (1 or 2 cm below the inguinal ligament) to facilitate vessel entry and avoid local vascular complications. To do so, some operators rely on the location of the inguinal skin crease to position the skin nicks through which puncture will be attempted (see later).
We prefer locating the skin nicks in reference to the inguinal ligament (which runs from the anterior superior iliac spine to the pubic tubercle), since the position of the skin crease can be misleading in obese patients. More recently, we have begun to confirm the appropriate localization of the skin nick by fluoroscopy, which should show the nick to overlie the inferior border of the femoral head (6)(Fig. 4.1C,D). Making the skin nicks at this level increases the chance that needle puncture will take place in the common femoral segment, rather than too high (above the inguinal ligament) or too low (in the superficial femoral or profunda branches of the common femoral artery). The femoral artery should be easily palpable over a several-centimeter span above and below the skin nick site. The femoral vein will lie approximately one fingerbreadth medial to the artery, along a parallel course.

**FIG. 4.1.**

Regional anatomy relevant to percutaneous femoral arterial and venous catheterization. **A:** Schematic diagram showing the right femoral artery and vein coursing underneath the inguinal ligament, which runs from the anterior superior iliac spine to the pubic tubercle. The arterial skin nick (indicated by X) should be placed approximately 3 cm below the ligament and directly over the femoral arterial pulsation, and the venous skin nick should be placed at the same level but approximately one fingerbreadth more medial. Although this level corresponds roughly to the skin crease in most patients, anatomic localization relative to the inguinal ligament provides a more constant landmark (see text for details). **B:** Corresponding radiographic anatomy as seen during abdominal aortography. **C:** Fluoroscopic localization of skin nick (marked by clamp tip) to the inferior border of the femoral head (ibfh). **D:** Catheter (open arrow) inserted via this skin nick has entered the common femoral artery (cf), safely above its bifurcation into the superficial femoral (sfa) and profunda branches. (For further details see Kim D, Orron DE, Skillman JJ, et al. Role of superficial femoral artery puncture in the development of pseudoaneurysm and arteriovenous fistula complicating percutaneous transfemoral cardiac catheterization. Cathet Cardiovasc Diagn 1992;25:91.)

Most difficulties in entering the femoral artery and vein-and most vascular complications-arise as the result of inadequate identification of these landmarks prior to attempted vessel puncture. Puncture of the artery at or above the inguinal ligament makes catheter advancement difficult and predisposes to inadequate compression, hematoma formation, and/or retroperitoneal bleeding following catheter removal. Puncture of the artery more than 3 cm below the inguinal ligament increases the chance that the femoral artery will have divided into its profunda and superficial femoral branches. Puncture in the crotch between these two branches fails to enter the arterial lumen, while puncture of either one of the branches increases the risk of false aneurysm formation or thrombotic occlusion due to smaller vessel caliber. Because the superficial femoral artery frequently overlies the femoral vein, low venous punctures may pass inadvertently through the superficial femoral artery, leading to excessive bleeding and possible arteriovenous fistula formation (6) (see Chapter 3).

**Local Anesthesia**

Adequate local anesthesia is essential for a successful catheterization. Inadequate anesthesia leads to poor patient cooperation and makes the time in the catheterization laboratory unpleasant for both patient and operator. Once the inguinal ligament and femoral artery have been identified, the femoral artery is palpated along its course using the three middle fingers of the left hand, with the uppermost finger positioned just below the inguinal ligament. Without moving the left hand, a linear intradermal wheal of 1% or 2% lidocaine is raised slowly by tangential insertion of a 25- or 27-gauge needle along a course overlying both the femoral artery and vein at the desired level of entry.

With the left hand remaining in place, transverse skin punctures are made over the femoral artery and vein, using the tip of a No. 11 scalpel blade. The smaller needle is then replaced by a 22-gauge 1.5-inch needle, which is used to infiltrate the deeper tissues along the intended trajectory for arterial and venous entry. As this needle is advanced, small additional volumes of lidocaine are infiltrated by slow injection. Each incremental infiltration should be preceded by aspiration so that intravascular boluses can be avoided. If the anesthetic track passes through the artery or vein, infiltration should be suspended until the tip of the needle has passed out of the back wall of the vessel and then continued to the full length of the needle or to the point where the needle tip contacts the periosteum. Approximately 10 to 15 mL of 1% xylocaïne administered in this fashion usually provides adequate local anesthesia. The patient should be warned that he may experience some burning as the anesthetic is injected, but that the medication will abolish any subsequent sharp sensations.
Once local anesthesia has been achieved, the small skin nicks can be enlarged and deepened, using the tips of a curved “mosquito” forceps. This procedure decreases the resistance that is encountered during subsequent advancement of the needle and subsequent vascular sheath, and increases the likelihood that any vascular bleeding will become manifest as oozing through the puncture rather than hidden in the formation of a deep hematoma.

**Femoral Vein Puncture**

If right heart catheterization is to be performed or secure venous access is desired (for administration of fluids and medications, or rapid placement of a temporary pacing catheter), the femoral venous puncture is usually performed prior to arterial puncture. With the left hand palpating the femoral artery along its course below the inguinal ligament, the needle is introduced through the more medial skin nick. Classically, the 18-gauge thin-walled Seldinger needle, which consists of a blunt, tapered external cannula through which a sharp solid obturator projects (Fig. 4.2) was used for both arterial and venous access. The needle should be grasped so that the index and middle fingers lie below the lateral flanges of the needle and the thumb rests on the top of the solid obturator as the needle is advanced along the sagittal plane angled approximately 45° cephalad. Although this needle can occasionally be advanced up to its hub, the tip of the needle will usually stop more superficially as it encounters the periosteum of the underlying pelvic bones. The periosteum is well innervated and may be quite tender if the initial lidocaine infiltration failed to reach this level. Accordingly, forceful contact with the periosteum is neither necessary nor desirable. If the patient experiences significant discomfort, some operators will remove the obturator from the Seldinger needle and infiltrate additional lidocaine into the deep tissues through the outer cannula.

**FIG. 4.2.**

Percutaneous needles and guidewire. **Top panel** shows a Seldinger needle (left) with its sharp solid obturator in place, a Potts-Cournand needle (center), which differs in the fact that its obturator is hollow and therefore allows the operator to see blood flashback as the artery is punctured, and an 18-gauge thin-wall needle (right) used for internal jugular vein puncture and now frequently also for arterial entry. These percutaneous needles are surrounded by an 0.038-inch, 145-cm J guidewire. **Bottom panel:** A Doppler-guided Smart Needle.

At this point, it is hoped that the Seldinger needle has transfixed the femoral vein. The obturator is removed, and a 10-mL syringe is attached to the hub of the cannula. The syringe and cannula are then depressed so that the syringe lies closer to the anterior surface of the thigh (Fig. 4.3) and the needle is more parallel (rather than perpendicular) to the vein. Gentle suction is applied to the syringe, and the whole assembly is slowly withdrawn toward the skin surface. In doing so, it is helpful to control the needle with both the left hand (which also rests on the patient's leg for support) and the right hand (which also controls the aspirating syringe). As the tip of the cannula is withdrawn into the lumen, venous blood will flow freely into the syringe.

**FIG. 4.3.**

Seldinger technique for venous puncture. A skin nick has been created overlying the desired vein, which is punctured through and through by a Seldinger needle with its solid obturator in place. In the center panel, the obturator is removed and the needle cannula is attached to a syringe. Depression of the syringe toward the surface of the skin tents the vessel slightly and facilitates axial alignment of the cannula at the moment that slow withdrawal brings the tip of the cannula back into the vessel lumen. This is recognized by the sudden ability to withdraw venous blood freely into the syringe, which is then removed from the needle cannula to permit advancement of the J guidewire (shown here with a plastic straightener in place). Once the guidewire has been advanced safely into the vessel, the needle cannula can be removed.

We and most laboratories, however, have switched away from the Seldinger needle, in favor of an 18-gauge “single-wall-puncture” needle that has a sharpened tip and lacks the inner obturator. Placement of a fluid-filled syringe on the needle's hub allows direct entry into the lumen of the vein, without the need to first exit the back wall and then pull back. Otherwise, the technique used after entry of the venous lumen has been achieved is identical. With the left
hand stabilizing the needle, the right hand is used to remove the syringe and to advance a 0.035- or 0.038-inch J
guidewire into the hub of the needle. The wire tip may be straightened by hyperextension of the wire shaft in the
right hand or by leaving the tip of the wire within the plastic introducer supplied by the manufacturer. The wire
should slide through the needle and 30 cm into the vessel with no perceptible resistance. Fluoroscopy should then
show the tip of the guidewire just to the left (patient's right) of the spine.

If difficulty is encountered in advancing the guidewire, it should never be overcome by force. Fluoroscopy may
simply reveal that the tip of the wire has lodged in a small lumbar branch; it can be drawn back slightly and
redirected or gently prolapsed up the iliac vein. When resistance to advancement is encountered at or just beyond
the tip of the needle, however, even greater care is required. This resistance may simply be caused by apposition of the
tip of the needle to the back wall of the vein, which can be corrected by further depression of the needle hub, with or
without slight withdrawal of the needle shaft. If this maneuver fails to allow free advancement of the wire, however,
the wire should be removed, and the syringe should be reattached to the needle hub to ensure that free flow of venous
blood is still present before additional wire manipulation is attempted; the wire should not be reintroduced unless free
flow is obtained. If it is necessary to withdraw the wire, this should always be done gently, since it is theoretically
possible for the wire to “snag” on the tip of the needle. Were this to occur, the needle and wire should be removed as
a unit. If the wire still cannot be advanced after these maneuvers, the needle should be withdrawn, and the puncture
site should be compressed for 1 to 3 minutes. The anatomic landmarks should be reconfirmed and puncture
reattempted. In some cases, puncturing the vein during a Valsalva maneuver may help by distending the femoral vein
and making clean puncture more likely.

After the wire has freely entered the vein, the needle is removed, leaving the wire well within the vein and secured at
the skin entry site by the left hand. The protruding wire is wiped with a moistened gauze pad, and its free end is
threaded into the lumen of a sheath and dilator combination adequate to accept the intended right-sided heart catheter.
All current sheaths are equipped with a backbleed valve and sidearm connector(Fig. 4.4)to control bleeding around
the catheter shaft and to provide a means of administering drugs or extra intravenous fluids during the right-sided
heart catheterization. The operator must make sure that he has control of the proximal end of the guidewire and that
it is held in a fixed position as the sheath and dilator are introduced through the skin. Insertion is eased if the sheath
and dilator are rotated as a unit while they are advanced progressively through the soft tissues. If excessive resistance
is encountered, it may be necessary to remove the dilator from the sheath and to introduce the dilator alone before
attempting to introduce the combination. If inspection shows that initial attempts have created significant burring at
the end of the sheath, a new sheath should be obtained.

FIG. 4.4.

Vascular sheaths. Center: An original sheath and dilator assembly (USCI “888”). In contrast to the original design,
modern arteriovenous introducers are equipped with backbleed valves and sidearm attachment. Top: A Cordis sheath.
Bottom: A USCI Hemaquet. Each device is inserted over a conventional guidewire as a unit, following which the
inner Teflon dilator is removed to permit catheter introduction. The sidearm sheaths also permit fluid infusion and an
additional site for pressure monitoring with the catheter in place.

Once the sheath is in place, the wire and dilator are removed, and the sheath is flushed by withdrawal of blood and
injection of heparinized saline solution. In our laboratory we usually infuse the sidearm of the venous sheath from a
1-L bag of normal saline solution, connected via a sterile length of intravenous extension tubing, to maintain sheath
patency and provide a carrier for drug administration by the nurse. Although drug administration can also take place
via a peripheral intravenous line, the side arm of the sheath avoids any concerns about how quickly volume can be
administered or whether infiltration of the peripheral line might jeopardize drug delivery in an emergency. Even if
right heart catheterization is not planned, the femoral sheath makes it easy to place a right heart catheter or a
temporary transvenous pacemaker lead if hemodynamic instability or bradyarrhythmia ensue.

**Catheterizing the Right Heart from the Femoral Vein**

A right (as well as a left) heart catheterization is needed to obtain a “full” profile of the hemodynamic state. Only the
right heart catheterization can provide data regarding mean left heart filling pressure (the pulmonary capillary wedge,
rather than just the post-a wave left ventricular end-diastolic pressure), detect pulmonary arterial hypertension, measure the cardiac output, and detect left-to-right intracardiac shunts. Leaving the right heart catheter in the pulmonary artery during the procedure also gives an ongoing measure of changes in the hemodynamic state as fluid and contrast loading take place, various medications (nitrates, diuretics, etc.) are given, and episodes of ischemia develop and are treated. For these reasons, our practice was once to perform a right heart catheterization in every patient who came to the cardiac catheterization laboratory.

In contrast, the 1990 Society for Cardiac Angiography and Intervention (SCA&I) survey showed that the practice was to perform right heart catheterization in only 28% of procedures (5). This practice has likely fallen further, after several standard-setting and regulatory agencies ruled that a left heart catheterization alone is adequate for most patients undergoing evaluation for coronary artery disease. The time (<5 minutes), added expense (<$100), and added risk (<1/10,000) of right heart catheterization are small, but so is the added information. We now skip the right heart catheterization in patients with a primary diagnosis of coronary artery disease, unless they have symptoms of congestive heart failure, noninvasive evidence of depressed left ventricular function or associated valvular disease, or recent myocardial infarction. In such patients, however, we still believe that the quantitation of overall hemodynamic function provided by right heart catheterization justifies performance of this low-risk adjunctive part of the overall catheterization evaluation.

FIG. 4.5.

Right-sided heart catheters used from the femoral approach. **Left:** Woven Dacron Goodale-Lubin, Courmand catheters. **Center:** Swan-Ganz catheter. **Right:** Newer balloon catheters, including the PWP pressure measurement catheter and the Baim-Turi catheter with bipolar pacing electrodes (USCI).

If right heart catheterization is to be performed, the desired right heart catheter (Fig. 4.5) is flushed, attached to the venous manifold, introduced into the sheath, and advanced up the inferior vena cava. Although conventional woven Dacron (Goodale-Lubin or Courmand) catheters provide excellent torque control, their inherent stiffness makes them poorly suited for routine use in a training laboratory. We therefore for a time used 7F Swan-Ganz catheters to exploit their ease of passage, low risk of injury to the right-sided heart chambers, and ability to perform thermodilution measurements of cardiac output. Unfortunately, such soft catheters have poor frequency response (see Chapter 7), do not adequately transmit the torque required for easy catheterization of the right-sided heart from the femoral approach, and accept only 0.021-inch guidewires. To bridge this gap, we have begun using a stiffer, balloon-tipped catheter [PWP monitoring catheter (USCI, Billerica, MA)] that combines the safety of the Swan-Ganz catheter with the catheter control and frequency response previously found only in the woven Dacron catheters. The larger lumen diameter and stiffer wall of this catheter (compared with the traditional Swan-Ganz design) improve frequency response and allow the passage of conventional 0.035- and 0.038-inch-diameter guidewires when necessary. When temporary pacing is desired, this catheter is also available with bipolar pacing capacity (Baim-Turi, USCI).

Deviation of the catheter tip from its paraspinous position during advancement from the leg suggests entry into a renal or hepatic vein, which can be corrected by slight withdrawal and rotation of the catheter. Once the catheter is above the diaphragm and within the right atrium, it is rotated counterclockwise to face the lateral wall of the right atrium(Fig. 4.6). Additional counterclockwise rotation and gentle advancement allow passage of the catheter tip into the superior vena cava, which is contiguous with the posterolateral wall of the right atrium. In contrast, anterior orientation of the catheter tip at this point may result in its entrapment in the right atrial appendage and inability to reach the superior vena cava. Alternatively, the tip of the catheter can be withdrawn to the inferior vena cava, and a 0.035-inch J guidewire can be introduced to bridge the straight line path from the inferior to the superior vena cava, along the back wall of the right atrium. Once in position, a baseline superior vena caval blood sample is obtained for measurement of oxygen saturation and comparison with the subsequently measured pulmonary arterial blood oxygen saturation, to screen for unsuspected left-to-right shunts. The catheter is then flushed with heparinized saline solution and withdrawn to the right atrium for pressure measurement.

FIG. 4.6.
Right heart catheterization from the femoral vein, shown in cartoon form. **Top Row:** The right heart catheter is initially placed in the right atrium (RA) aimed at the lateral atrial wall. Counterclockwise rotation aims the catheter posteriorly and allows advancement into the superior vena cava (SVC). Although not evident in the figure, clockwise catheter rotation into an anterior orientation would lead to advancement into the right atrial appendage (RAA), precluding SVC catheterization. **Center row:** The catheter is then withdrawn back into the right atrium and aimed laterally. Clockwise rotation causes the catheter tip to sweep anteromedially and cross the tricuspid valve. With the catheter tip in a horizontal orientation just beyond the spine, it is positioned below the right ventricular outflow (RVO) tract. Additional clockwise rotation causes the catheter to point straight up, allowing for advancement into the main pulmonary artery and from there into the right pulmonary artery (RPA). **Bottom row:** Two maneuvers useful in catheterization of a dilated right heart. A larger loop with a downward-directed tip may be required to reach the tricuspid valve and can be formed by catching the catheter tip in the hepatic vein (HV) and advancing the catheter quickly into the right atrium. The reverse loop technique (bottom right) gives the catheter tip an upward direction, aimed toward the outflow tract.

To advance a catheter from the femoral vein to the pulmonary artery, the tip of the catheter is positioned in the lower portion of the right atrium, directed toward its lateral border. If a balloon flotation catheter is being used, the balloon is inflated at this point. Clockwise rotation is applied, which causes the catheter tip to sweep the anterior and anteromedial wall of the right atrium, along which the tricuspid valve is located (see Fig. 4.6). As the catheter tip passes over the tricuspid orifice, slight advancement causes it to enter the right ventricle, where pressure is again recorded. If the right atrium is enlarged, greater curvature of the catheter may be necessary (i.e., a large J loop). Such a loop may be formed by bending the tip of the catheter against the lateral right atrial wall or by engaging in the ostium of the hepatic vein (just below the diaphragm). This larger loop can then be rotated clockwise in the atrium as described earlier, causing the tip of the catheter to enter the right ventricle. Right ventricular pressure is then recorded.

Simple advancement of the catheter in the right ventricle causes the tip to move toward the apex of that chamber and usually does not result in catheterization of the pulmonary artery. To achieve this latter end, the catheter must be withdrawn slightly so that its tip lies horizontally and just to the right (patient's left) of the spine. In this position, clockwise rotation causes the tip of the catheter to point upward (and slightly posteriorly) in the direction of the right ventricular outflow tract(Fig. 4.6). The catheter should be advanced only when it is in this orientation to minimize the risk of ventricular arrhythmias or injury to the right ventricle. Advancement may be facilitated if performed as the patient takes a deep breath. If these maneuvers fail to achieve access to the pulmonary artery due to enlargement of the right atrial and ventricular chambers, the catheter may be withdrawn to the right atrium and formed into a large "reverse loop," which allows the tip of the catheter to cross the tricuspid valve in an upward orientation more likely to enter the outflow tract (Fig. 4.6, bottom right). When manipulated appropriately, the catheter tip should cross the pulmonic valve and advance to a wedge position without difficulty. Having the patient take a deep breath and cough during advancement is often of assistance in achieving a wedge position. Alternatively, a small amount of air may be released from the balloon to decrease its size and facilitate wedging in a smaller, more distal branch of the pulmonary artery. Catheters advanced from the leg are more likely to seek the left pulmonary artery, whereas catheters advanced from above tend to seek the right pulmonary artery as they make a continuous counterclockwise curve through the right heart chambers. If needed, either pulmonary artery can be catheterized by appropriate manipulation or careful introduction of a curved J guidewire, although we generally do not like to extend guidewires into the thin-walled pulmonary arteries unless absolutely necessary. Following measurement of the wedge pressure, the balloon (if a balloon-tip catheter is being used) is deflated, and the catheter is withdrawn into the more proximal left or right pulmonary artery. There, pulmonary arterial pressure is measured and another blood sample for measurement of oxygen saturation is obtained. If a more simultaneous "snapshot" of the hemodynamic state is desired, these “entry” pressures can be rerecorded during a right-sided heart pullback. For practical reasons, we now tend to rerecord only the wedge pressure (simultaneous with the left ventricular pressure) and pulmonary artery pressure, coincident with the measurement of the cardiac output. We then leave the right heart catheter in the proximal pulmonary artery for the duration of the case, allowing continuous monitoring of the pulmonary artery diastolic pressure as an index of volume status and ischemic left ventricular dysfunction.

Attempts to perform right heart catheterization occasionally result in entry into other structures. If a woven Dacron catheter is advanced in the right atrium with a posteromedial orientation, it may cross a patent foramen ovale and enter the left atrium. This is sometimes hard to detect by catheter position alone because the catheter appearance in the left atrium or ventricle may be indistinguishable (in the anteroposterior view) from its course during usual right
Unsuspected anatomic abnormalities frequently can be detected by an unusual catheter course or position. The course of a catheter passed from the femoral vein to the inferior vena cava (IVC), right atrium (RA), coronary sinus (CS), and up into an anomalous left superior vena cava (LSVC). The catheter crossing from the pulmonary artery (PA) to the descending aorta (Ao) by way of a patent ductus arteriosus. The catheter entering an anomalous pulmonary vein draining into the right atrium.

FIG. 4.7.

Unsuspected anatomic abnormalities frequently can be detected by an unusual catheter course or position. **Upper left panel:** The course of a catheter passed from the femoral vein to the inferior vena cava (IVC), right atrium (RA), coronary sinus (CS), and up into an anomalous left superior vena cava (LSVC). **Upper right panel:** The catheter crossing from the pulmonary artery (PA) to the descending aorta (Ao) by way of a patent ductus arteriosus. **Bottom panel:** The catheter entering an anomalous pulmonary vein draining into the right atrium.

In patients with elevated right heart pressures, prior placement of an inferior vena caval filter or umbrella, those undergoing specialized procedures (endomyocardial biopsy, coronary sinus catheterization), or those in whom prolonged postprocedure monitoring with a balloon-flotation catheter is desired, the **right internal jugular vein** offers an excellent alternative to the femoral vein. The technique for jugular puncture is described in Chapter 20, and the method of advancing the right-sided heart catheter to the pulmonary artery is identical to that described for the brachial approach in Chapter 5. On occasion, percutaneous right heart catheterization is performed from the subclavian or median basilic vein using a similar technique.

**Femoral Artery Puncture**

The common femoral artery is punctured by inserting the Seldinger or single-wall-puncture needle through the more lateral skin nick. Again, the needle is inserted at approximately 45° along the axis of the femoral artery as palpated by the three middle fingers of the left hand. The experienced operator may feel the transmitted pulsations as the tip of the needle contacts the wall of the femoral artery. With the Seldinger needle it is customary to advance the needle completely through the artery until the periosteum is encountered. The obturator is then removed, and the hub of the needle is depressed slightly toward the anterior surface of the thigh. Arterial pressure makes it unnecessary to attach a syringe to the cannula, so that both hands can be used to stabilize the needle as it is slowly withdrawn. When the needle comes back into the lumen of the femoral artery as evidenced by vigorous pulsatile flow of arterial blood, a 0.035- or 0.038-inch J guidewire should then be advanced carefully into the needle.

If a single wall puncture is desired, the operator may prefer a Potts-Cournand needle(Fig. 4.2), in which the obturator has a small lumen that transmits a flashback of arterial blood as the vessel is entered, or the same single-wall-puncture needle described for venous entry. When the femoral pulse is difficult to palpate or numerous needle insertions have been fruitless, it may be easiest to utilize the 18-gauge SmartNeedle (CardioVascular Dynamics, Irvine CA; see Fig. 4.2, bottom panel). The obturator of this device contains a Doppler crystal that helps aim the needle tip toward the center of the arterial lumen. Pulsatile arterial flow has auditory characteristics that distinguish it clearly from the more continuous venous flow signals detected from the adjacent femoral vein.

Whichever needle is used to enter the arterial lumen, the guidewire introduced through the needle should move freely up the aorta [located to the right (patient's left) side of the spine on fluoroscopy] up to the level of the diaphragm. When difficulty in advancing the guidewire is encountered at or just beyond the tip of the needle and is not corrected by slight depression or slight withdrawal of the needle, the guidewire should be withdrawn to ensure that vigorous
arterial flow is still present before any further wire manipulation is attempted. If flow is not brisk or if the wire still cannot be advanced, the needle should be removed and the groin should be compressed for 5 minutes. The operator should verify the correctness of the anatomic landmarks and attempt puncture of the femoral artery. If the second attempt is unsuccessful in allowing wire advancement, a third attempt on the same vessel is unwise, and an alternative access site should generally be selected.

If wire motion is initially free but resistance is encountered after several centimeters (particularly if the patient complains of any discomfort during wire advancement), extensive iliac disease or subintimal position of the wire is possible. The wire should be pulled back slightly under fluoroscopic control and the needle should be removed as the left hand is used to stabilize the wire and control arterial bleeding. After the wire is wiped with a moist gauze pad, a small (5F) dilator can be cautiously introduced to a point just below where wire movement became difficult. The wire is then withdrawn from the dilator, which is aspirated to ensure free flow of blood and flushed carefully. A small bolus of contrast medium (either a low-osmolar agent or ionic contrast diluted to half strength, to avoid local discomfort) is then injected gently under fluoroscopic monitoring. This should disclose the anatomic reason for difficult wire advancement—generally either iliac tortuosity, stenosis, or dissection. Problems advancing the wire above the aortic bifurcation may also suggest the presence of an abdominal aortic aneurysm (7), which warrants use of soft-tip guidewires and extreme care to avoid perforation or dislodgment of cavitary thrombus or debris. If contrast injection through the small dilator reveals that subintimal wire passage has occurred, retrograde left heart catheterization should be relocated to the other femoral artery or to the brachial or radial artery and the patient should be observed for signs of progressive dissection or arterial compromise, both of which are fortunately rare with retrograde guidewire dissections. If the problem turns out to be more tortuosity or stenosis (Fig. 4.8A), a more specialized guidewire (e.g., a steerable peripheral guidewire such as a Wholey, or a hydrophilic-coated guidewire such as the Terumo Glidewire) may be carefully reintroduced through the dilator in an attempt to reach the descending aorta. In an era when the obstructing lesion can be quickly and effectively treated by angioplasty or stent placement (see Chapter 27), iliac stenosis is no longer a firm indication to abandon retrograde left heart catheterization!

**FIG. 4.8.**

**A:** Entry of the right femoral artery was straightforward, but guidewire advancement stopped in the iliac system.

**Left:** Contrast injection through a 5F dilator shows severe iliac stenosis with extensive cross-pelvic collaterals. This was crossed with a Terumo Glidewire to allow completion of the diagnostic angiography and a right coronary artery angioplasty (not shown).

**Center:** Injection in the abdominal aorta shows the proximal extent of the iliac stenosis.

**Right:** Iliac stenosis then dilated and treated by placement of a Palmaz-Schatz iliac stent, with restored antegrade iliac flow.

**B:** Retrograde left heart catheterization in a patient with previous aortic-bifemoral grafting (left) entry of the graft hood has resulted in passage of the wire into the “blind” native iliac. In a RAO projection, the more anterior pathway to the central aorta (Ao) via the graft can be seen overlying the native iliac, with the bifurcation of the common femoral artery into the profunda and superficial femoral artery (SFA) just below.

In an aging population with diffuse atherosclerotic disease, the question of performing left heart catheterization via a prosthetic (e.g., aortobifemoral) graft arises frequently (8),(9). This is not an ideal approach because the graft wall is tough (making sheath insertion difficult), such grafts may contain diffuse atherosclerotic or thrombotic debris, and graft closure or serious graft infection may occur. The graft should be identified as a separate structure from the adjacent native femoral artery and punctured using a front-wall approach. Even if the graft hood is punctured correctly, the guidewire may pass through the anastomosis and into the native femoral artery rather than proximally up the graft (8). In that event, contrast injections through a small dilator in a right anterior oblique (RAO) projection (right leg) and the use of special steerable guidewires may be required to remain within or cross into the graft lumen, and thereby reach the descending aorta (Fig. 4.8B). A vascular introducing sheath should always be used to avoid excessive friction during catheter movement, or excessive traction on catheter tips during withdrawal, but may require the use of serial dilators for passage of the sheath through the tough graft wall. This approach via a vascular graft can thus be used with care, particularly when other alternatives (e.g., brachial, axillary, or radial artery) are themselves less than desirable. Some operators choose to administer prophylactic antibiotics [Kefzol (Eli Lilly, Indianapolis, IN) 1 g every 8 hours for 24 hours] when accessing a prosthetic graft.

**Catheterizing the Left Heart from the Femoral Artery**
Once the guidewire has been advanced to the level of the diaphragm and the needle has been removed, the operator's left hand is used to stabilize the wire and control arterial bleeding while the wire is wiped with a moistened gauze pad to remove any adherent blood. If the catheter is to be introduced directly into the artery, the soft tissues are predilated by brief introduction of a Teflon arterial dilator one F-size smaller than the intended catheter, before inserting the left heart catheter itself. Essentially all left heart catheterizations from the femoral approach, however, are now performed using an appropriate-sized vascular sheath (e.g., a 7F sheath for a 7F catheter) that is equipped with a backbleed valve and sidearm tubing as described earlier. The 15-cm length sheath is commonly used for diagnostic catheterization but can only reach the mid-iliac. In the presence of severe tortuosity, it may be preferable to use the 23-cm-length sheath designed for interventional procedures, which is sufficiently long to enter the distal aorta above the bifurcation. This helps to improve the torque responsiveness of diagnostic catheters under those circumstances.

The chosen sheath is introduced over the guidewire (the proximal end of which is held in a straightened, fixed position) with a rotational motion, following which the guidewire and dilator are removed and the sheath is aspirated, flushed, and connected to a pressurized flush system [Intraflo II (30 mL/hr), Abbot Critical Care, North Chicago, IL] to avoid clot formation in the sheath. Alternatively, this sidearm can be connected to a manifold for monitoring arterial pressure at a separate site (e.g., during passage of a pigtail catheter across a stenotic aortic valve). This sheath should be “power” flushed immediately after each catheter is introduced or withdrawn, by briefly activating the Intraflow device.

Classically, once the sheath had been inserted, the guidewire was removed. The desired left heart catheter was then flushed and loaded with a 145-cm J guidewire and its nose was introduced into the backbleed valve of the sheath. The soft end of the guidewire was then advanced carefully through the catheter, out the end of the sheath, and to the level of the diaphragm before the catheter itself was advanced. One concern, however, is that readvancement of the guidewire out the end of the sheath can cause vascular injury if severe iliac tortuosity or disease is present. We therefore adopted a modified technique in which a short-exchange length (175 cm) Newton J (Cook, Bloomington, IN) is placed through the access needle and its tip is left at the diaphragm as the dilator is removed from the sheath and the left heart catheter is inserted. This obviates the need to renegotiate complex iliofemoral anatomy with the guidewire.

Once the catheter has been advanced to the desired level (either above the diaphragm or into the ascending aorta), the guidewire is removed, so that the catheter can be connected to the arterial manifold and double-flushed (withdrawal and discarding of 10 mL of blood, followed by injection of heparinized saline solution). All subsequent left heart catheters are then introduced by reinserting this wire to the level of the diaphragm (allowing one catheter to be removed and the second to be reintroduced safely), rather than withdrawing the first catheter completely and then inserting the second catheter and wire through the sheath de novo. Of course if the left heart catheterization is being performed without the aid of a sheath, the operator must leave the tip of the wire in the abdominal aorta during the removal of the first catheter and the introduction of a second catheter to retain access to the vessel. These “over-the-wire” catheter exchanges are facilitated by extending the back end of the wire straight down the patient's leg and holding it fixed there to ensure that the wire remains in constant position within the aorta as the newer catheter is advanced.

A Word About Heparin

As described in Chapter 3, early catheterizations from the femoral artery had a higher incidence of major complications than catheterization from the brachial artery. One difference was that brachial catheterization utilized systemic heparinization to avoid thrombosis in the smaller brachial artery with a potentially occlusive catheter in its lumen. When systemic heparinization was adopted in femoral procedures, the rates of complications became equivalent. On this basis, the practice of full intravenous heparinization (5,000 U) immediately after the left-sided sheath was inserted, became a standard way to provide therapeutic anticoagulation that lasted at least 40 minutes in most patients. Lesser amounts of heparin (2,500 to 3,000) may also be used, particularly in smaller patients. If it is decided to perform catheter-based coronary intervention, larger heparin doses (usually 10,000 U, or 70 to 100 U/kg) are required, which will require further supplementation if a smaller heparin dose has been administered for the immediately preceding diagnostic procedure. This type of higher heparin dosing is routinely monitored by an activated clotting time (ACT) machine in the cardiac catheterization laboratory, and titrated to an ACT of roughly 300 seconds (10). If it is planned to use an intravenous IIb/IIIa receptor blocker, lower levels of heparin...
anticoagulation (ACT 250 to 275) may be desired to prevent excessive bleeding risk. Given the limitations of heparin (see Chapter 3), other anticoagulant agents, including low-molecular-weight heparins and other direct-acting thrombin antagonists, are being explored for cardiac catheterization procedures.

While the use of heparin is mandatory for interventional or prolonged diagnostic procedures, many laboratories have abandoned the use of systemic heparinization for simple diagnostic catheterizations, where the complications are extremely low with or without heparin (11). For this issue to be decided scientifically, more than 100,000 patients would have to be randomized to undergo diagnostic catheterization with and without systemic heparinization. Absent such trial data, we are now less likely to use systemic heparinization for simple procedures but still feel that systemic heparinization is appropriate for more prolonged or complex diagnostic catheterizations, cases where a guidewire will be required to cross a stenotic aortic valve, and (absolutely) for all percutaneous coronary interventions.

If systemic heparinization is used, its effects must be reversed at the termination of the left heart catheterization and associated angiography. This is usually accomplished by the administration of protamine (1 mL = 10 mg of protamine for every 1,000 IU of heparin) (12). The operator should be watchful for potential adverse reactions to protamine, characterized by hypotension and vascular collapse, as discussed in Chapter 3. Protamine reactions appear to be more common in insulin-dependent diabetics and patients with previous protamine exposure, who are more likely to have elevated levels of IgG or IgE antiprotamine antibodies (13). Although severe protamine reactions in these patients are uncommon, we prefer delaying sheath removal for approximately 1 hour in insulin-dependent diabetics to allow heparin to wear off without protamine administration. This is also our practice in patients with unstable symptoms, threatening anatomy, where there is a concern that abrupt reversal of the heparin effect may trigger thrombosis.

**Catheter Selection**

The initial left heart catheter in most cases is a pigtail catheter with multiple side holes (Fig. 4.9). This catheter usually can be flushed in the descending aorta and then advanced to the ascending aorta without difficulty. If left ventricular and femoral arterial (sheath side arm) pressures are being monitored (as in catheterization to evaluate aortic stenosis), the rough equality of central aortic and femoral arterial pressure should be confirmed at this time (Fig. 4.10) (3,4,14). The systolic peak in the femoral waveform may be slightly delayed and accentuated compared with the ascending aortic pressure trace, but the diastolic and mean pressures should be virtually identical. A greater difference in mean pressure between the catheter and the sheath may be seen in a patient with an extensively diseased iliac artery and may require the use of a longer sheath, as described earlier. For the highest-pressure fidelity, the sheath size should be one F larger than the intended left heart catheter (e.g., a 6F pigtail advanced through a 7F sheath). Alternatively, catheters can be advanced from separate arterial entry sites to record left ventricular and ascending aortic pressure, or a specially designed 8F pigtail with separate end lumens and a side-hole lumen may be used to perform such pressure recordings (15).

**FIG. 4.9.**

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Left heart catheters used from the femoral approach. **Left to right:** Pigtail, 145° angled pigtail, and Teflon Gensini catheter (no longer in common use). All three catheters have an end hole to allow placement over a guidewire and multiple side holes to minimize the tendency for catheter whipping or intramyocardial injection during power injection of contrast.

**FIG. 4.10.**

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Central aortic pressure (Ao) measured through a 7.3F pigtail catheter (Cook) and femoral artery (FA) pressure measured from the sidearm of an 8F arterial sheath (Cordis, Miami Lakes, FL). Only minimal damping of the femoral artery pressure is seen, blunting its systolic overshoot, which frequently exceeds central aortic systolic pressure (see Chapter 9). With larger (7.5F and 8F) catheters, more damping may occur in the sidearm pressure. Catheter and sidearm are connected to small-volume-displacement transducers without intervening tubing.
Crossing the Aortic Valve

After measurement of the ascending aortic pressure, the pigtail catheter is advanced across the aortic valve and into the left ventricle. If the aortic valve is normal and the pigtail is oriented correctly, it will usually cross the valve directly. In many cases, however, it may be necessary to advance the pigtail down into one of the sinuses of Valsalva to form a secondary loop (Fig. 4.11). As the catheter is withdrawn slowly, this loop will open to span the full diameter of the aorta, at which point a very subtle further withdrawal will often cause the pigtail to fall across the valve.

**FIG. 4.11.**

Crossing the aortic valve with a pigtail catheter. **Top row, left:** Although a correctly oriented pigtail catheter will frequently cross a normal aortic valve directly, it may also come to rest in the right or noncoronary sinus of Valsalva. **Top row, center:** Further advancement of the catheter enlarges the loop to span the aortic root and positions the catheter. **Top row, right:** Slow withdrawal causes the catheter to sweep across the aortic orifice and fall into the left ventricle. **Bottom row, left:** To cross a stenotic aortic valve, the pigtail catheter must be led by a segment of straight guidewire. Increasing the length of protruding guidewire straightens the catheter curve and causes the wire to point more toward the right coronary ostium; reducing the length of protruding wire restores the catheter curve and causes the wire to point more toward the left coronary. Once the correct length of wire and the correct rotational orientation of the pigtail catheter have been found, repeated advancement and withdrawal of both the catheter and guidewire as a unit will allow the wire to cross the valve. **Bottom row, center:** In a dilated aortic root, an angled pigtail provides more favorable wire positions. **Bottom row, right:** In a small aortic root, a Judkins right coronary catheter may be preferable.

If significant aortic stenosis is present, the pigtail must be advanced across the valve with the aid of a straight 0.038-inch guidewire. Approximately 6 cm of the guidewire is advanced beyond the end of the pigtail catheter, and the catheter is withdrawn slightly until the tip of the guidewire is leading (Fig. 4.11). The position of the tip of the guidewire within the aortic root can then be controlled by rotation of the pigtail catheter and adjustment of the amount of wire that protrudes. Less wire protruding directs the wire tip more toward the left coronary ostium, whereas more wire protruding directs the wire more toward the right coronary ostium. With the wire tip positioned so that it is directed toward the aortic orifice, the tip of the wire usually quivers in the systolic jet. Wire and catheter are then advanced as a unit until the wire crosses into the left ventricle. If the wire buckles in the sinus of Valsalva instead of crossing the valve, the catheter-wire system is withdrawn slightly and readvanced with or without subtle change in the length of protruding wire or the orientation of the pigtail catheter. Alternatively, some operators prefer to leave the pigtail catheter fixed and move the guidewire independently in attempts to cross stenotic aortic valves. In either case, the wire should be withdrawn and cleaned and the catheter should be double-flushed vigorously every 3 minutes despite systemic heparinization. If promising wire positions are not obtained, the process should be repeated using a different catheter: an angled pigtail or left Amplatz catheter if the aortic root is dilated or a Judkins right coronary catheter if the aortic root is unusually narrow (16). Other catheters have been proposed for this purpose (17), but we have found these standard catheters to suffice in virtually all cases.

When the tip of the guidewire is across the aortic valve, additional wire should be inserted before any attempt is made to advance the catheter itself. Otherwise the catheter may be diverted into a sinus of Valsalva, causing the wire to flip out of the left ventricle. The straight wire should be advanced carefully, since there is a potential (admittedly small in the hypertrophic left ventricle of a patient with aortic stenosis) to perforate the left ventricular wall if the guidewire is advanced further when it has become trapped in an endocardial surface feature. Once the catheter is in the left ventricle, the wire is immediately withdrawn and the catheter is aspirated vigorously, flushed, and hooked up for pressure monitoring, so that a gradient can be measured even if the catheter is rapidly ejected from the left ventricle or must be withdrawn because of arrhythmia. When using a left Amplatz catheter to cross a stenotic valve, however, we prefer to cross the valve with a full-exchange-length (260-cm) guidewire. Once the tip of this wire has entered the left ventricle, it is left in position as the Amplatz catheter is removed, and a conventional pigtail catheter is substituted before an attempt is made to measure left ventricular (LV) pressure.

The same approach applies to retrograde catheterization across a porcine aortic valve prosthesis, although it is more
common to use a J-tip guidewire to help avoid the area between the support struts and the aortic wall. Ball valves (Starr-Edwards, Baxter-Healthcare, Santa Ana, CA) can be crossed retrograde with this approach, but use of a small (4F or 5F) catheter will minimize the amount of aortic regurgitation resulting from catheter interference with diastolic ball seating. Tilting disc valves (Bjork-Shiley, Shiley, Inc., Irvine, CA; St. Jude Medical, St. Paul, MN; Sulzer Carbomedics, Austin, TX), however, should not be crossed retrograde because of the potential for producing torrential aortic regurgitation, catheter entrapment, or even disc dislodgement, if the catheter passes across the smaller (minor) orifice. Although safe passage through the major orifice may be possible under careful fluoroscopic control (18), we still prefer a transseptal or even apical puncture approach (see later) when it is necessary to enter the left ventricle in a patient who has a tilting disc valve in the aortic position.

Control of the Puncture Site Following Sheath Removal

After the effect of heparin (if used) has been reversed by Protamine or has been allowed to wear off (to an ACT < 160 seconds), the arterial catheter and sheath are removed. The standard way to control the puncture site and promote the formation of a hemostatic plug is to apply firm manual pressure. This is best done using three fingers of the left hand that are positioned sequentially up the femoral artery beginning at the skin puncture. With the fingers in this position, there should be no ongoing bleeding into the soft tissues or through the skin puncture. It should be possible to apply sufficient pressure to obliterate the pedal pulses and then release just enough pressure to allow them to barely return. This pressure is then gradually reduced over the next 10 to 15 minutes, at the end of which time pressure is removed completely. The venous sheath is usually removed 5 minutes after compression of the arterial puncture has begun, with gentle pressure applied over the venous puncture using the right hand. To avoid tying up the catheterization laboratory during this period, the patient is usually taken to a special “holding room” in the catheterization laboratory or back to his hospital bed before the sheaths are removed. If such relocation is to be performed prior to sheath removal, it is important that the sheaths be secured in place (suture, or at least tape) to prevent them from being pulled out during transport.

After procedures using larger arterial sheaths (i.e., PTCA or balloon valvuloplasty), or performed in the setting of thrombolytic agents or IIb/IIIa receptor blockers, more prolonged compression (30 to 45 minutes) is typically required. To avoid fatigue of the operator or other laboratory personnel performing compression, we typically use a mechanical device such as the Compressar (Instromedix, Beaverton, OR) or FemoStop (USCI, Billerica, MA)] to apply similar local pressure. These devices can be equally or even more effective in prolonged holds (19), but we still prefer manual compression for removal of smaller (6F and 7F) sheaths or in patients with peripheral vascular disease or prior peripheral grafting surgery that makes it important to avoid compressive occlusion or flow restriction that may cause arterial occlusion. In every case, however, it should be emphasized that a trained person must be in attendance throughout the compression to ensure that the device is providing adequate control of puncture site bleeding and is not compromising distal perfusion.

After compression has been completed, the puncture site and surrounding area are inspected for hematoma formation and active oozing, and the quality of the distal pulse is assessed before application of a bandage.

It is our policy to keep the patient at bedrest with the leg straight for 4 to 6 hours following percutaneous femoral catheterization (20), with a sandbag in place over the puncture site for the first few hours after catheter removal. In patients at higher risk for rebleeding (those with hypertension, obesity, or aortic regurgitation), application of a pressure bandage in addition to the sandbag may be of value. Although the patient should be instructed not to move the leg for several hours following the catheterization procedure, the patient does not have to lie flat during this time. Elevation of the head and chest to 30° to 45° by the electrical or manual bed control, without muscular effort by the patient, will greatly increase the patient's comfort and will not increase the risk of local bleeding. The only reason to insist that the patient lie completely flat is if there is significant orthostatic hypotension. Before ambulation and again before discharge, the puncture site should be reinspected for recurrent bleeding, hematoma formation, development of a bruit suggestive of pseudoaneurysm or A-V fistula formation, or loss of distal pulses.

FIG. 4.12.

Schematic diagrams of various new devices for the closure of femoral arterial punctures. A: The Vasoseal. B: The AngioSeal (Kensey-Nash) device. C: The Prostar suture device. D: The Duet device. (See the text for details.)
Puncture Closure Devices

The technique described earlier relies on manual or mechanical pressure for initial control of arterial bleeding and then on local hemostasis for ongoing plugging of the arterial puncture site. The potential for ongoing bleeding (with formation of hematoma, false aneurysm, or arteriovenous fistula) has already been described in Chapter 2 and tends to be more common with interventional procedures that require larger sheath size or more aggressive postprocedure antithrombotic therapy. This has prompted the development of a variety of new devices that seek to provide more positive closure of the arterial puncture site (Fig. 4.12). The simplest device (Vasoseal, Datascope, Paramus, NJ) applies a collagen plug in the skin track apposed to outer wall of the femoral artery (21). In randomized trials, this device shortens the time to hemostasis (from 17 to 4 minutes) and ambulation (from 19 to 13 hours), without clear benefit in terms of hematoma formation or the need for vascular surgery compared with manual compression. In diagnostic catheterization, it can also accelerate time to ambulation to 1 to 2 hours (22). Next in complexity is the AngioSeal hemostatic puncture closure device (Sherwood, Davis & Geck), which positions a rectangular absorbable “anchor” made of absorbable suture material against the inside wall of the artery and uses an attached suture to winch a small collagen plug down against the outside of the artery (23). In a randomized trial of mostly diagnostic procedures (24), the AngioSeal reduced the time to hemostasis (2.6 versus 15.3 minutes) and ambulation (1 hour versus 4 to 6 hours) compared with manual compression, with a modest decrease in hematoma formation. The Duett device (25) differs in that it uses a liquid procoagulant mixture (thrombin and collagen) that is injected into the soft-tissue track leading from the outside of the artery to the skin. A compliant balloon-on-a-wire is first positioned and inflated within the artery, pulled into contact with the end of the same sheath that was used for the catheterization, and pulled back against the inside of the puncture site to tamponade bleeding. The sheath is then withdrawn roughly 1 cm further so that its end lies outside the vessel lumen, and the sheath sidearm is used to inject the procoagulant into the soft-tissue tract leading to the outside of the artery. While each of these devices places a great deal of faith in the pro-coagulant properties of its collagen component, the approach of Perclose (Redwood City, CA) relies on the use of a sheathlike device to perform suture-mediated closure of the arterial puncture site. This device has undergone several design changes to improve the ease of delivery, but it still relies on the passage of fine nitinol needles through the margins of the arterial puncture and out through the skin tunnel, where they can be tied to provide surgical hemostasis (26). It shortens the time from the end of the procedure to hemostasis (19 minutes versus 243 minutes) and ambulation (106 minutes for diagnostic and 232 minutes for interventional procedures, versus 4 to 6 hours and 6 to 12 hours, respectively), with a comparably low incidence of major complications (27). If no venous sheath has been placed, some laboratories even allow immediate ambulation after a successful suture-mediated closure.

Given this array of new devices, groin closure devices are being used in most cases in some laboratories. Others, under less pressure to provide early ambulation and same-day discharge, restrict it to patients with an increased risk of bleeding with manual compression or other conditions (back pain, trouble voiding) that make prolonged bedrest undesirable. As these devices continue to evolve and the demand for early ambulation offsets the moderate cost ($100 to $300) of a closure device, they may ultimately replace prolonged local manual or mechanical pressure in the control of postprocedure bleeding from the femoral artery. The conversion to puncture-sealing devices will be accelerated if they can consistently reduce the 1% to 2% incidence of hemorrhagic complications at the arterial puncture site that constitute one of the most common morbidities associated with catheterization from this route. Of course, the success of these puncture-sealing approaches rests on the premise that a single, accurate, front-wall puncture of the common femoral artery has been performed and that favorable conditions prevail within the vessel and the surrounding soft tissue. Each also requires a modest level of skill and training on the part of the operator, and the realization that difficulties encountered in performing a clean closure once the sheath has been removed and wire access has been given up, may increase rather than decrease the incidence of complications requiring vascular surgery or transfusion. In an era of increasingly sophisticated catheter-based therapies, it seems likely that an effective device for definitive closure of the femoral artery puncture site will replace the 50-year-old practice of pressing on the puncture site until the bleeding stops!

Contraindications to Femoral Approach to Left Heart Catheterization

As discussed in Chapter 1, the choice of catheterization approach (femoral or brachial) is usually a function of operator, institution, and patient preference. Because of technical ease, however, data from the 1990 SCA&I registry shows that 83% of diagnostic (and 96% of interventional) catheterizations are performed via the femoral approach.
In patients with peripheral vascular disease (femoral bruits or diminished lower extremity pulses), abdominal aortic aneurysm, marked iliac tortuosity, prior femoral arterial graft surgery, or gross obesity, however, catheter insertion and manipulation may present technical challenges even for experienced operators. Recognition of these relative contraindications may favor the use of the percutaneous axillary, brachial, radial, or even translumbar aortic approaches (see later). Each laboratory should thus have one or more operators skilled in these alternative percutaneous routes, particularly if no operators skilled in the brachial cutdown approach (see Chapter 5) are available.

Beyond the limitations of access to the central arterial circulation, one important parameter in the selection of a percutaneous access site is the ability to obtain hemostasis after catheter removal. In the femoral arterial entry technique, this is usually obtained easily after removal of a percutaneous arterial catheter, but patients with a wide pulse pressure (e.g., severe aortic incompetence or systemic hypertension), gross obesity, or ongoing anticoagulation have more problems with bleeding after femoral catheterization than do patients without these factors, particularly if a groin closure device is not used. The vascular complications of percutaneous retrograde arterial catheterization are usually not life-threatening and have already been discussed in Chapter 3. In the final analysis, however, there are relatively few patients who absolutely cannot be catheterized from the femoral approach.

ALTERNATIVE SITES FOR LEFT HEART CATHETERIZATION

The techniques described earlier for percutaneous insertion of a femoral catheter also can be used successfully from the axillary, brachial, or radial arteries, or even the lumbar aorta, with the use of an introducing sheath. In certain cases, access to the left heart may be gained by transseptal puncture from the right atrium to the left atrium, or even by direct percutaneous entry via the left ventricular apex. Although these other access sites may utilize the similar needle puncture, guidewire advancement, and sheath insertion skills outlined earlier for the femoral approach, the operator wishing to use one of the alternative percutaneous routes must master the local anatomy, details of maximal allowable catheter size, limitations on catheter selection, techniques for achieving postprocedure hemostasis, and range of complications that may ensue from bleeding or thrombosis at that anatomic location. Individuals interested in mastering one or more of these approaches are referred to the growing body of literature.

Percutaneous Entry of the Axillary, Brachial, Radial Arteries, and Lumbar Aorta

Axillary puncture has long been used as an alternative to femoral entry by the vascular radiologist (32). The patient's hand is brought behind his or her head to expose the axillary fossa, in which the artery can be felt to course. Using local anesthesia and needle puncture and guidewire techniques like those described earlier, the axillary artery is entered over the head of the humerus. The left axillary artery is generally preferred to allow use of preformed Judkins catheters and avoid the brachiocephalic trunk. Effective control of the puncture site after catheter removal is critical, since accumulation of even modest amounts of hematoma around the artery can cause nerve compression (33).

The brachial artery is, of course, readily approached by surgical cutdown (see Chapter 5) but may also be approached using percutaneous (needle and guidewire) techniques (34). The antecubital fossa is prepared and anesthetized as for the cutdown approach. A 21-gauge arterial needle, a special 0.021 heavy-duty guidewire, and a 5F or 6F sheath (MicroPuncture set, Cook) can be used to gain access, after which traditional percutaneous catheter techniques are used. Working from the right brachial artery, Amplatz coronary curves are preferred (see Chapter 11). At the end of the procedure, the sheath is removed, and the area is compressed manually. Alternatively, proximal occlusion can be obtained by inflation of a blood pressure cuff, while a gauze pad and a clear intravenous infusion pressure bag is inflated to above systolic pressure over the puncture site (35). Pressure is then released gradually over 20 to 25 minutes. Comparisons of this percutaneous brachial technique to brachial cut-down show a shorter procedure time (without the need for dissection or repair) and no increase in complications, although surgical repair may be needed occasionally (36). This represents a viable approach for outpatient catheterization or an excellent alternative for access in a patient with difficult femoral or iliac anatomy when a Sones-trained angiographer is not available.
The radial artery was previously viewed as a site for placement of monitoring lines in the coronary care unit, rather than an access route for cardiac catheterization. Largely through the efforts of champions like Kiemeneij, however, this has been adapted to the performance of diagnostic angiography and many types of percutaneous coronary intervention (including stent placement) (37),(38). The small caliber of this vessel makes the use of small (5F or 6F) catheters mandatory in most patients. In some patients (mostly males) who have larger-caliber radial arteries, 7F or 8F sheaths can be used (39). Liberal use of lidocaine, nitroglycerin, or a calcium channel blocker through the sheath sidearm may be required to control local spasm that might render the procedure painful and catheter manipulation difficult. Controlling bleeding from the catheterization site at the end of the procedure usually is not difficult, and several “wrist-band” compression devices are available. Obviously, patients can get up and walk immediately after a radial arterial procedure. Although bleeding is not a problem, radial artery thrombosis occurs in roughly 5%, usually without clinical sequelae in patients for whom a preprocedure Allen test has confirmed adequate perfusion of the hand from the ulnar artery even while the radial artery is compressed firmly. The rapid (immediate) ambulation, availability of stents and other devices that can be used through current large-lumen guiding catheters, and paucity of entry-site complications (40) have made the percutaneous radial the preferred (or the preferred alternative to the femoral artery) approach in many laboratories.

Percutaneous puncture of the lumbar aorta is a technique that has been used by radiologists to study patients with extensive peripheral vascular disease since the early 1980s and was then adapted to the performance of coronary angiography (41). More recently, this approach has even been used for coronary stent placement (42), although the fact that the procedure must be done with the patient prone complicates angiographic views and limits resuscitative efforts. The inability to apply direct pressure over the arterial entry site (the posterior wall of the aorta) also limits aggressive anticoagulation. Because of these negative factors, direct aortic puncture should be considered a last resort for vascular entry.

**Transseptal Puncture**

With refinements and improvements in techniques for retrograde left heart catheterization, the use of transseptal puncture for access to the left atrium and left ventricle (43),(44) had become an infrequent procedure in most adult cardiac catheterization laboratories (45). In these laboratories, transseptal puncture was reserved for situations in which direct left atrial pressure recording was desired (pulmonary venous disease), in which it was important to distinguish true idiopathic hypertrophic subaortic stenosis (IHSS) from catheter entrapment, and in which retrograde left-sided heart catheterization had failed (e.g., due to severe peripheral arterial disease or aortic stenosis) or was dangerous because of the presence of a certain type of mechanical prosthetic valve (e.g., Bjork-Shiley or St. Jude valves). The infrequency with which the procedure was performed made it difficult for most laboratories to maintain operator expertise and to train cardiovascular fellows in transseptal puncture and gave the procedure an aura of danger and intrigue. With the advent of percutaneous mitral valvuloplasty (Chapter 26) and the availability of improved equipment, however, transseptal catheterization has again become a relatively common procedure (46).

The goal of transseptal catheterization is to cross from the right atrium to the left atrium through the fossa ovalis. In approximately 10% of patients, this maneuver is performed inadvertently during right heart catheterization with a woven Dacron catheter because of the presence of a probe-patent foramen ovale, but in the remainder, mechanical puncture of this area with a needle and catheter combination is required to enter the left atrium. Although puncture of the fossa ovalis itself is quite safe, the danger of the transseptal approach lies in the possibility that the needle and catheter will puncture an adjacent structure (i.e., the posterior wall of the right atrium, the coronary sinus, or the aortic root). To minimize this risk, the operator must have a detailed familiarity with the regional anatomy of the atrial septum(Fig. 4.13). As viewed from the feet with the patient lying supine, the plane of the atrial septum runs from 1 o’clock to 7 o’clock. The fossa ovalis is posterior and caudal to the aortic root and anterior to the free wall of the right atrium. The fossa ovalis is located superiorly and posteriorly to the ostium of the coronary sinus and well posterior of the tricuspid annulus and right atrial appendage. The fossa ovalis itself is approximately 2 cm in diameter and is bounded superiorly by a ridge-the limbus.

**FIG. 4.13.**

Regional anatomy for transseptal puncture. **Upper left:** The position of the fossa ovalis is shown relative to the
superior vena cava (SVC), aortic root (Ao), coronary sinus (CS), and tricuspid valve (TV). **Upper right:** A cross-section through the fossa (looking up from the feet) demonstrating the posteromedial direction of the interatrial septum (bold line) and the proximity of the lateral free wall of the right atrium. **Bottom row:** The appearance of the transseptal catheter as it is withdrawn from the SVC in a posteromedial orientation. As the catheter tip slides over the aortic root (bottom left, dotted position) it appears to move rightward on to the spine. Slight further withdrawal leads to more rightward movement into the fossa (solid position). **Bottom row, center:** Puncture of the fossa with advancement of the catheter into the left atrium. **Right:** Advancement into the left ventricle with the aid of a curved tip occluder. (Redrawn from Ross J Jr. Considerations regarding the technique for transseptal left heart catheterization. *Circulation* 1966;34:391.)

This anatomy can be distorted somewhat by the presence of aortic or mitral valve disease (47). In aortic stenosis, the plane of the septum becomes more vertical, and the fossa may be located slightly more anteriorly. In mitral stenosis, the intraatrial septum becomes flatter with a more horizontal orientation, and the fossa tends to lie lower. Combined with the fact that the septum (and fossa) may then bulge into the right atrium, this makes detailed familiarity with the anatomy even more important when transseptal catheterization is attempted in patients with advanced valvular heart disease. In such patients, intraprocedural transthoracic (48), transesophageal (49), or intracardiac (50) ultrasound may aid in identifying the optimal location for puncture of the intraatrial septum. Alternatively, several algorithms using fluoroscopic landmarks determined by right and left atrial angiography, or the position of a pigtail catheter in posterior (noncoronary) aortic sinus of Valsalva, have been developed to aid localization of the best site for transseptal puncture (51),(52)(Fig. 4.14).

**FIG. 4.14.**

Fluoroscopic landmarks for localizing the fossa ovalis. **Left panel:** As described by Inoue, right atrial injection can be used to locate the upper corner of the tricuspid valve (point A), which is marked on the TV monitor. **Right panel:** Continued filming during the levophase fills the left atrium. A horizontal line is drawn from point A to the back wall of the left atrium, defining point B. That line is divided in half, and a vertical line is dropped to the floor of the left atrium, defining point C. The location of the fossa (x) is along this vertical line, approximately one vertebral body height above point C. When the borders of the left atrium are visible fluoroscopically, the position of a pigtail catheter in the noncoronary sinus of Valsalva can be substituted for point A, allowing localization of the ideal puncture site without contrast injection (see reference 40). A similar localization scheme (not shown) has been proposed in the 40° RAO projection by Croft and associates (reference 39), using the aortic pigtail and the posterior border of the left atrium. Puncture is made 1 to 3 cm below the midpoint of a line connecting the posterior wall of the aorta to the back wall of the left atrium.

Transseptal catheterization is performed only from the right femoral vein. We use a 70-cm curved Brockenbrough needle (USCI, Billerica, MA) that tapers from 18 gauge to 21 gauge at the tip(Fig. 4.15).The needle is introduced via a matching Brockenbrough catheter or 8F Mullins sheath and dilator combination (53) (USCI) that has been inserted to the superior vena cava over a flexible 0.032-inch, 145-cm J guidewire. Once the wire has been removed and the catheter has been flushed, the Brockenbrough needle is advanced through the catheter, with an obturator (Bing stylet) protruding slightly beyond the tip of the needle to avoid abrasion or puncture of the catheter wall during needle advancement. As the needle and its stylet are advanced through the catheter, the patient may experience a slight pressure sensation due to distortion of the venous structures by the rigid needle. During needle advancement, it is thus essential to allow the needle and its direction indicator to rotate freely so that it may follow the curves of the catheter and venous structures; the hub of the needle should never be grasped and rotated at this point. The progress of the needle tip should be monitored fluoroscopically, looking for any sign of perforation of the catheter by the needle. The stylet is then removed at the diaphragm and the needle hub is connected to a pressure manifold using a stop-cock with a short length of tubing and is carefully flushed. The needle is then advanced to lie just inside the tip of the catheter or sheath, as indicated by measurements made by comparing the distance between the needle flange and the catheter hub, with similar measurements made with a sterile ruler before insertion(Fig. 4.16).Alternatively, current high-quality fluoroscopy can be used to visually monitor advancement of the needle to the catheter tip. **FIG. 4.15.**
Equipment for transseptal puncture. **Left:** The Brockenbrough needle. **Left center:** Bing stylet. These can be used in conjunction with the following. **Right center:** Traditional Brockenbrough catheter. **Right:** Mullins sheath/dilator system.

**FIG. 4.16.**

The Brockenbrough system with the needle and stylet inserted into the catheter. Ruler measurement of the distance from the catheter hub to the needle flange is shown with the tip of the stylet at the tip of the catheter (position 1) and with the stylet withdrawn and the needle tip extended to the tip of the catheter (position 2). (Redrawn from Ross J Jr. Considerations regarding the technique for transseptal left heart catheterization. *Circulation* 1966;34:391.)

The superior vena caval pressure should then be recorded through the needle, with the needle rotated so that the direction indicator points anteriorly. Under continuous fluoroscopic and pressure monitoring, the needle and catheter are then held in constant relationship as they are withdrawn slowly, using both hands. The direction indicator is firmly controlled with the right hand and used to rotate the needle clockwise during this withdrawal from the superior vena cava, until the arrow is oriented posteroomedially (4 o’clock when looking from below). As the tip of the catheter enters the right atrium, it moves slightly rightward (toward the patient’s left). The needle and catheter are maintained in their posteroomedial orientation, and they continue to be withdrawn slowly. As the catheter tip slips over the bulge of the ascending aorta, it again moves rightward to overlie the vertebrae in the anterior projection. Further slow withdrawal maintaining the 4 o’clock orientation will be associated with a third rightward movement as the catheter tip “snaps” into the fossa ovalis. This is confirmed by the fact that advancement will cause the catheter tip to flex slightly (rather than move back up the atrial septum) if its tip is lodged in the fossa. Clear fluoroscopic evidence of fossa engagement is thus essential to successful transseptal puncture.

If the foramen is patent, the catheter may actually cross into the left atrium spontaneously at this point, as indicated by a change in atrial pressure waveform and the ability to withdraw oxygenated blood from the needle. Otherwise, the catheter is advanced slightly to flex its tip against the limbus at the superior portion of the foramen ovale. Once the operator is satisfied with this position, she or he advances the Brockenbrough needle smartly so that its point emerges from the tip of the catheter and perforates the atrial septum. Successful entry into the left atrium should be confirmed by both the recording of a left atrial pressure waveform and the withdrawal of oxygenated blood or the demonstration of the typical fluoroscopic appearance of the left atrium during a contrast puff through the needle. Once the operator is confident that the needle tip is across the interatrial septum, the needle and catheter are advanced as a unit, a short distance into the left atrium, taking care to control their motion so that the protruding needle does not injure left atrial structures. When the catheter is across the atrial septum, the needle is withdrawn, and the catheter is double-flushed vigorously and connected to a manifold for pressure recording.

The main risk during transseptal catheterization is inadvertent puncture of adjacent structures (the aortic root, coronary sinus, or posterior free wall of the right atrium) rather than the fossa ovalis. As long as the patient is not anticoagulated and perforation is limited to the 21-gauge tip of the Brockenbrough needle (i.e., perforation is recognized and the catheter itself is not advanced), this is usually benign. However, if the 8F catheter itself is advanced into the pericardium or aortic root, potentially fatal complications may occur, underscoring the need for the operator to monitor closely the location of the transseptal apparatus by fluoroscopic, pressure, and oxygen saturation at each stage of the procedure. Damped pressure waveform during attempted septal puncture may indicate puncture into the pericardium or simply incomplete penetration of a thickened interatrial septum. Injection of a small amount of contrast through the needle can be useful in this case by staining the atrial septum, and allowing confirmation of an appropriate position in the left anterior oblique (LAO) and RAO projection before more forceful needle advancement is attempted. If the initial attempt at transseptal puncture is unsuccessful, the operator may wish to repeat the catheter positioning procedure by removing the transseptal needle from the catheter, withdrawing the catheter slightly, and reinserting the 0.032-inch guidewire into the superior vena cava. In general, one should never attempt to reposition the catheter-needle combination in the superior vena cava in any other way, since perforation of the right atrium or atrial appendage is a distinct possibility during such maneuvers.

Once the catheter is safely in the left atrium, additional manipulation may be required to enter the left ventricle. If the tip of the catheter has entered an inferior pulmonary vein (as evident by its projection outside the posterior heart
Apical left ventricular puncture. In this patient with Björk-Shiley aortic and mitral valve prostheses, percutaneous puncture of the left ventricular apex was performed to allow left ventricular pressure measurement and contrast ventriculography using a 4F angiographic pigtail catheter shown entering the LV apex. This catheter was advanced into the left ventricle over a 0.035-inch guidewire, following apical puncture with an 18-gauge thin-wall needle. (See the text for details.)

The technique for transseptal catheterization using the Mullins sheath (53) is similar, except that care must be taken to advance both the dilator and the 8F sheath into the left atrium without injuring the opposite left atrial wall. Slight counterclockwise rotation and repeated puffs of contrast to define location of the catheter tip may be helpful in this regard. Once the sheath is secure in the left atrium, the needle and dilator are withdrawn and the sheath is flushed carefully. Either a specially curved pigtail catheter (in patients with a normal mitral valve) or a CO2-inflated balloon flotation catheter (in patients with mitral stenosis) may then be inserted through the sheath and passed into the left ventricle. The current Mullins sheath designs have a sidearm connection and backbleed valve, allowing ongoing measurement of left atrial pressure around the left ventricular catheter.

Complications of transseptal catheterization are generally infrequent (“needle tip” perforation, less than 3%; tamponade, less than 1%; and death, less than 0.5%) in experienced hands. This is supported by experience in 1,279 cases from the Massachusetts General Hospital (54), 597 cases from Los Angeles (47), and 500 cases from Taiwan (52). The excellent results in these large series indicate that the technique for transseptal puncture has not been lost (or may even have improved) since its first wave of popularity in the 1960s and 1970s! Because serious complications can occur and are significantly more common early in an operator's experience or in high-risk patients, however, performance of this procedure should be limited to a few operators at each site who can do enough annual procedures to perfect their technique. This is particularly true in patients with distorted anatomy due to congenital heart disease, marked left or right atrial enlargement, significant chest or spine deformity, inability to lie flat, ongoing anticoagulation, or left atrial thrombus/tumor, in whom the technique should generally be avoided.

FIG. 4.17.

Apical left ventricular puncture. In this patient with Björk-Shiley aortic and mitral valve prostheses (arrow, upper left), percutaneous puncture of the left ventricular apex was performed to allow left ventricular pressure measurement and contrast ventriculography using a 4F angiographic pigtail catheter shown entering the LV apex (arrow, lower right). This catheter was advanced into the left ventricle over a 0.035-inch guidewire, following apical puncture with an 18-gauge thin-wall needle. (See the text for details.)

**Apical Left Ventricular Puncture**

Historically, a variety of direct puncture techniques were used to enter the cardiac chambers before the introduction of percutaneous left and right heart catheterization. These techniques included transbronchial (55) and transthoracic (56) approaches to the left atrium, the suprasternal puncture technique of Radner (57), and apical left ventricular puncture (58),(59). Of these, only the last has survived, albeit as an infrequent (roughly one per year in our laboratory) way to measure left ventricular pressure in a patient where retrograde and transseptal catheterization of the LV are precluded by the presence of mechanical aortic and mitral prostheses.

The site of the apical impulse is located by palpation and confirmed by fluoroscopy of a hemostatic clamp placed at the intended puncture site. Alternatively, the true left ventricular apex can be located using echocardiography (60) and may be found to lie significantly more laterally than the palpated “apical” impulse in patients with right ventricular enlargement. After liberal local anesthesia, an 18-gauge needle (like that used for internal jugular puncture) is introduced at the apex and directed along the long axis of the left ventricle. This is accomplished by aiming the needle tip roughly toward the back of the right shoulder. Contact with the left ventricular wall can usually be felt as a
distinct impulse (and the onset of ventricular premature beats). Sharp advancement of the needle at this point will cause its tip to enter the left ventricular cavity, with pulsatile ejection of blood.

In the technique of Semple (59), an outer Teflon catheter was then advanced over the puncture needle and into the left ventricle (sometimes out through the aortic valve as well). We, however, have preferred the technique in which a 0.035-inch 65-cm-long J guidewire is advanced through the needle and into the left ventricle under fluoroscopic guidance. This allows the advancement of a 4F dilator followed by a 4F pigtail catheter to allow pressure measurement and/or left ventricular angiography (Fig. 4.17).

One series describes excellent results of apical puncture in 102 patients (61). Major complications (tamponade or pneumothorax) occurred in 3%, although tamponade was not seen at all in postoperative patients (who have adhesive pericardium). Other complications of apical puncture can include hemothorax, intramyocardial injection, ventricular fibrillation, as well as pleuritic chest discomfort (approximately 10%) and reflex hypotension due to vagal stimulation (approximately 5%). We thus reserve this technique for patients in whom it is essential to enter the left ventricle and in whom neither retrograde nor anterograde (transseptal) entry of the left ventricle is feasible.