CHAPTER 1

Procedural issues for electrophysiologic studies: vascular access, cardiac chamber access, and catheters

Before we can discuss the relationship between electrograms and ECGs and use this information to unravel the mechanisms for arrhythmias and to design therapies, it is important to understand how procedures are performed in the electrophysiology laboratory. In general there are two types of electrophysiologic procedures: (1) electrophysiologic studies and ablation that use temporarily placed catheters to evaluate and treat arrhythmias, and (2) implantation of “permanent” cardiac rhythm devices. This book focuses on electrophysiology procedures, and our discussion of implantable devices will be limited to basic electrograms and ECGs associated with pacing therapy.

The electrophysiologic test combines standard ECG recording and electrical signals acquired from within the heart (electrograms). Electrograms are acquired using specialized thin plastic catheters that have exposed metal electrodes at the tip, connected via insulated wires to plugs that in turn can be connected to a recording device on which the signal is displayed for analysis. The catheters are placed in different cardiac chambers, and electrical signals are recorded from direct contact with the myocardium. Since electrophysiologic testing is invasive and requires vascular access, it is usually performed in a specialized cardiac suite that has fluoroscopic equipment.

Vascular access

Electrophysiologic testing and ablation procedures usually require several points for venous access, depending on operator preference, arrhythmia complexity, and patient-specific considerations. At our institution two to five separate venous sheaths are placed, depending on the case, to allow independent movement of multiple catheters. More complex arrhythmias require more simultaneous mapping points and either more venous access points or catheters with more electrodes. Smaller adults and children provide less opportunity for placing multiple sheaths safely within a single vein. Requirement for equipment such as intracardiac echocardiography necessitates additional vascular access sites.

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The most commonly used sites for venous access are the femoral veins (Fig. 1.1). Cannulation of the femoral vein is performed by first identifying the inguinal ligament that travels from the iliac crest to the pubis. Fluoroscopically it is usually at the head of the femur. The vein should be cannulated below this landmark. The arterial pulse is palpated and a thin-wall needle is inserted at a 40° angle relative to the skin approximately 1 cm medial to the pulse. When the vein is cannulated, there will be free venous return with slight aspiration on the syringe. The syringe is removed and a guidewire is threaded through the hub of the needle into the vein. With the wire acting as a stable support, an intravascular sheath is threaded into the vein. In an adult the femoral vein can support up to three intravascular sheaths safely with minimal complications. If multiple sheaths are placed within the same femoral vein, the insertion sites are usually separated by 3–5 mm, with guidewires placed for all of the necessary access points before placing the sheaths.

Specialized long sheaths with specific shapes are often used in the electrophysiology laboratory to provide additional support and “directionality” to electrode catheters, particularly those used for ablation. At our laboratory,
standard-length smaller sheaths are placed (6 French, 10 cm) and are exchanged for longer sheaths as the case unfolds. In this way, specific sheath shapes can be chosen depending on the arrhythmia type and the patient’s specific anatomic characteristics.

Access from “above” has also been traditionally used in some laboratories, via the interval jugular vein or the subclavian vein. The right internal jugular vein provides a “straight line” down the superior vena cava and the right atrium. Although many laboratories still use these vascular access sites, because of patient comfort and the small but definite risk for pneumothorax, superior access sites are now generally used less frequently.

**Chamber access**

Correlation between fluoroscopic images and recorded electrograms is discussed in detail in Chapter 2. However, it is instructive at this time to discuss how different cardiac chambers and large veins can be reached during electrophysiologic testing. The right atrium is the easiest chamber to access, since venous return from both the inferior vena cava and superior vena cava feed directly into this chamber (Fig. 1.2). From the right atrium, catheters can be directed through the tricuspid valve to obtain recordings from the right ventricle.

Recording from the left atrium can be achieved by placing a catheter within the coronary sinus (Fig. 1.2). The coronary sinus travels near the mitral annulus and provides stable electrical signals from adjacent left atrial tissue and left ventricular tissue. Oftentimes access to the left atrium itself is required to allow...
Aortic knob
IAS
Mullins sheath/introducer

Figure 1.3 A 0.032 inch guidewire has been placed in the superior vena cava. The guidewire is then used to place a Mullins sheath/introducer into the superior vena cava. The dashed line shows the approximate course of the most septal portion of the superior vena cava and right atrium. In most cases, the Brockenbrough needle/Mullins sheath introducer will track along this course as it is slowly withdrawn. IAS, interatrial septum.

recording of electrical signals from other areas of the left atrium away from the mitral annulus

Obtaining vascular access to the left atrium is performed by puncturing a small hole through the interatrial septum. Many techniques have been developed for safe access to the left atrium, but all are a variation of the technique developed by Brockenbrough in the late 1950s. The following paragraphs describe in detail the technique used by the author for accessing the left atrium.

The Mullins sheath/introducer combination is placed in the superior vena cava at the level of the innominate vein (Fig. 1.3). After the introducer is flushed, the Brockenbrough needle is carefully inserted through the introducer. As the needle is advanced it will make two turns, one at the level of the iliac veins and the other at the level of the renal veins. The needle is advanced to a point 4–5 cm from the hub of the introducer with the inner stylet in place to prevent “snowplowing” of plastic within the lumen of the sheath. The stylet is removed and the needle is attached to a manifold that allows pressure monitoring, saline flush, and contrast injection. The Brockenbrough needle has a “pointer” that is in the same plane and direction as the needle curve. Depending on anatomy the “pointer” will be directed in the range of 4:30 to 5:30 o’clock, using a vertical clockface as a reference (Fig. 1.4). However, depending on the orientation of the heart within the body, if the interatrial septum is directed more posteriorly an orientation of 6:00 or even 8:00 is sometimes required, and if the interatrial septum is directed more anteriorly an orientation of 3:00 is required. The whole assembly (both the Mullins sheath/introducer set and the Brockenbrough needle) is slowly pulled back under fluoroscopic guidance in the AP projection. The sheath/needle assembly will make two leftward “jumps,” once at the superior vena cava/right atrium junction and then again as it falls into the fossa ovalis (Figs. 1.5, 1.6, 1.7).

At our laboratory access to the left atrium is always performed with the aid of intracardiac echocardiography using a “point and shoot” technique. Intracardiac echocardiography provides real-time information that supplements standard fluoroscopy and allows for safer entry into the left atrium. The tip of the intracardiac echocardiography catheter is placed at the fossa ovalis
Figure 1.4  Photograph showing the orientation of the Brockenbrough needle. In this case the patient has an interatrial septum that lies more posteriorly, so a needle position of approximately 5:00 is required. Through the left femoral venous sheath (LFV) an ultrasound catheter is placed.

Figure 1.5  Continuation of Fig. 1.3. The wire is removed and the Brockenbrough needle is placed in the Mullins sheath/introducer, and the entire apparatus is slowly withdrawn. At this point the sheath/introducer/needle combination is still in the superior vena cava.

Figure 1.6  Continuation of Fig. 1.5. The entire apparatus is now at the junction of superior vena cava and right atrium.
and the region is explored with gentle maneuvering, and frequently a patent foramen ovale will be noted as the intracardiac echocardiography catheter is advanced into the left atrium. The superior and posterior portion of the fossa ovalis is the most common region to be probe-patent. If the fossa ovalis is not patent, or if the operator wishes to access the left atrium at a different site than the patent foramen ovale (which can sometimes be too superior and posterior to allow for maneuvering the catheter), then puncture of the interatrial septum with the needle will be required. The tip of the intracardiac echocardiography catheter can be used as a guide for the exact point the needle should be placed (Figs. 1.8, 1.9). When the needle and echocardiography catheter are placed in the same position, the echocardiographic image and the pressure tracing are evaluated. If shadowing from the catheter tip is seen within the left atrium and a left atrial pressure tracing are recorded, the Mullins introducer has already entered the left atrium through a patent foramen ovale, and the needle can be removed and a guidewire placed in the left atrium. More commonly, tenting of the interatrial septum will be observed and the pressure tracing will be dampened (Fig. 1.9). The needle is carefully extended, and with a palpable
In the same patient as Fig. 1.8, as the needle or introducer is advanced, tenting of the interatrial septum (arrowheads) will be observed by intracardiac echocardiography. Artifact from the needle called shadowing can be seen within the left atrium. LA, left atrium; RA, right atrium; RSPV, right superior pulmonary vein.

The needle is extended into the left atrium. Arrows point to the exposed needle. A palpable “pop” will frequently be felt by the operator as the left atrium is entered.

“pop” the left atrium will be entered (Fig. 1.10). This is confirmed by evaluating the pressure tracing and injection of a small amount of contrast. With experience, when the “pop” is felt the operator will learn to quickly relax any forward pressure on the needle and introducer assembly to prevent the needle from puncturing the lateral wall of the left atrium. The needle is removed and a 0.032 inch guidewire is placed into the left atrium and used as a support to advance the sheath into the left atrium (Fig. 1.11). The sheath is then used as a “passageway” to place an electrophysiologic catheter into the left atrium (Fig. 1.12). Remember that any time the left atrium is catheterized, aggressive anticoagulation is required to reduce the risk of thromboembolic complications. The use of intracardiac echocardiography has made left atrial access much safer. In fact, at our laboratory most patients are fully anticoagulated when they undergo transseptal puncture because thrombus can form quickly on catheters in some patients.

The left ventricle can be accessed using the transseptal technique, or retrogradely through the aortic valve. From a transseptal approach it is usually very
simple to advance the catheter across the mitral valve to access the left ventricle. Sometimes advancing the sheath to the mitral annulus provides support for the catheter. For the retrograde approach the femoral artery is accessed and a catheter is prolapsed across the aortic valve. Choice of the transseptal or retrograde approach depends on the operator, and on the specific regions of interest within the left ventricle.

**Electrophysiologic catheters**

Once sheaths are placed, specialized electrophysiologic catheters are placed within the heart. At their simplest, electrophysiologic catheters are composed of thin wires attached to electrodes located at the tip and more proximal rings insulated by plastic. Catheters will vary by the number and location of electrodes. Since electrograms are usually recorded from two adjacent electrodes, the electrode number is even, usually four, eight, or ten, although catheters with more than 20 electrodes are also available. For adult cases, catheters from
Electrophysiology catheters often come in preformed shapes that allow the clinician to manipulate the catheter to desired locations. Two commonly used fixed curved are the Josephson curve and the Cournand curve. (Courtesy of Mike Repshar, Boston Scientific.)

5 to 7 French are used, with the size dependent on factors ranging from cost to catheter complexity (multielectrode catheters are usually larger).

Electrophysiology catheters also come in a variety of preformed shapes depending on the intended use (Fig. 1.13). The most common shape is the “Josephson” (named after Mark Josephson, a pioneer in electrophysiology who developed the shape to allow optimal recording and manipulation characteristics for the first endovascular electrophysiologic catheters), which has a gentle curve at the tip to allow the operator to twist the catheter and guide it to the desired location. Another commonly used shape is the Cournand curve (named for André Cournand, who shared the 1956 Nobel Prize for advances in cardiac catheterization), which has a more proximal curve and a longer tip. More complex shapes include catheters designed to enter into the coronary sinus, as well as circular and basket-shaped catheters for obtaining recordings from tubular structures.

Catheters with steering capabilities have been developed by all the manufacturers, and these were an important advance, allowing catheters to be carefully moved to different positions of the heart in a reliable way. To allow even more flexibility, catheters are available with different adjustable radii, while others can be curved in both directions at a 180° angle (bidirectional).

**Signal acquisition**

Once catheters are placed, they can be used to record electrical activity of the heart. The two traditional methods for recording electrical signals are “unipolar” and “bipolar” (Fig. 1.14). The term “unipolar” is a misnomer, since electrical recording always requires two electrodes. However, in unipolar recording only one electrode within the heart is used, with the second electrode being located outside the heart. The anode can be Wilson’s central terminal, which uses the sum of the extremity electrodes, an electrode located within the inferior vena, or a surface electrode. When unipolar recording is used in our laboratory, most commonly an inferior vena cava electrode is used, since this configuration is less susceptible to electronic “noise” from the environment.
Figure 1.14 Schematic showing recording differences between “bipolar” and “unipolar” recordings. In bipolar recordings, the voltage differences between two electrodes placed within the heart are measured. In this schematic bipolar recording from electrodes 1 and 2 leads to a signal that reflects local activation (small circle). In unipolar recording only one electrode is within the heart and the other electrode is located outside the heart (in this case an electrode in the inferior vena cava). This leads to electrical measurement over a larger area (large circle).

In electrophysiology laboratories, bipolar recording is most commonly used. Bipolar electrodes have less far-field activity since the signals cancel. This effect can be observed in Fig. 1.15. In this case unipolar signals from the proximal and distal electrodes from a catheter placed in the right atrium are shown. Notice that the unipolar signals have a broad lower-amplitude signal (other electrical equipment used in the electrophysiology laboratory). Since unipolar recording measures electrical activity over a larger distance, “far-field” activity is more commonly seen (Figs. 1.14, 1.15).
due to ventricular depolarization and repolarization (the waves that correspond with the QRS complex and T wave) since the signal is obtained from the electrode in the heart and Wilson’s central terminal. The broad signal from ventricular depolarization is called low frequency because it is characterized by a very slow change in signal amplitude and a broader base. In a bipolar signal, the far-field ventricular signal “cancels out” and it is easier to see the effects of depolarization in a smaller region of tissue. However, unipolar recording has an important role, particularly during ablation, since the signal of interest is obtained from only the tip electrode rather than a combined signal from a distal and proximal electrode.

Catheters are connected to a “junction box” that is in turn connected to a signal amplifier, and the signal is then displayed on a recording apparatus (usually high-resolution displays and a computer system that allows signals to be selected and adjusted by the user and recorded to a hard drive or other storage medium). Within the signal amplifier, electrical signals are amplified and filtered. High-pass filters allow frequencies higher than a certain cut-off to pass through while low-pass filters allow frequencies lower than a specified frequency to pass through. Think of high-pass and low-pass filters as “shutters” that allow desired frequencies to be recorded. Notch filters are designed to remove signals from a specific unwanted frequency. In clinical use a notch filter that removes signals with a 60 Hz frequency can be used to eliminate unwanted noise from the standard alternating current that is used to power equipment used within the electrophysiology laboratory (since 60 Hz is the frequency of the alternating current).

The effects of filtering are shown in Figs. 1.16 and 1.17 for atrial and ventricular signals respectively. In Fig. 1.16, a catheter is placed in the right atrium. The top tracing shows the electrogram recorded with the high-pass filter

![Figure 1.16](image-url)

**Figure 1.16** Effects of filtering on atrial electrograms. A catheter is placed in the right atrium. Notice that the electrogram coincides with the P wave and not the QRS complex. Noise from alternating current can be seen in the recording using 0.05–1000 Hz filtering that is removed with the use of a “notch” filter. Notice, however, that the electrogram morphology is also changed with the addition of the “notch” filter, because these signal components are lost in the atrial electrogram.
Figure 1.17 Effects of filtering on a ventricular electrogram. As the high-pass filter is increased from 0.05 to 30 Hz and finally 100 Hz, the low-frequency signal due to ventricular repolarization is gradually lost. When the low-pass filter is decreased from 1000 to 150 Hz the ventricular electrogram becomes significantly attenuated due to loss of ventricular signal content.

and low-pass filter set at 0.05 Hz and 1000 Hz respectively. Notice the regular undulating baseline due to “noise” from alternating current that is eliminated by using a notch filter (middle tracing), but the electrogram itself is also changed. In the bottom tracing the high-pass and low-pass filters are increased and decreased respectively to provide a smaller frequency recording “window,” resulting in significant changes in electrogram morphology. The significant change in electrogram morphology with different filtering is one of the reasons that while electrogram timing can be measured fairly consistently it is more difficult to evaluate electrogram morphology. Figure 1.17 shows the effects of filtering on ventricular signals. Electrograms from a bipolar electrode placed in the right ventricle are shown. Since the catheter is within the right ventricle the “sharp” high-frequency signals coincide with the QRS complex. When the filters are opened widely (0.05–1000 Hz), a high-frequency signal associated with ventricular depolarization is observed along with a lower-frequency signal due to ventricular repolarization that coincides with the T wave. Since T waves generally have a frequency of 0.05–10 Hz, as the high-pass filter is increased from 0.05 to 30 and finally 100 Hz, the wave due to ventricular repolarization becomes attenuated. The frequency of ventricular activity is usually between 50 and 150 Hz, with some additional higher-frequency components, so that as the low-pass filter is decreased, the ventricular signal becomes attenuated. These two figures illustrate the important effects of filtering on the electrograms that are recorded during electrophysiologic studies.