1

**Historical Perspective and Present Practice of Cardiac Catheterization**

William Grossman

University of California, San Francisco, School of Medicine; Division of Cardiology, University of California, San Francisco Medical Center, San Francisco, California 94143

It is difficult to imagine what our concepts of heart disease might be like today if we had to construct them without the enormous reservoir of physiologic and anatomic knowledge derived from the past 60 years’ experience in the cardiac catheterization laboratory. As Andre Cournand remarked in his Nobel lecture of December 11, 1956, “the cardiac catheter was... the key in the lock” (1). By turning this key, Cournand and his colleagues led us into a new era in the understanding of normal and disordered cardiac function in humans.

According to Cournand (2), cardiac catheterization was first performed (and so named) by Claude Bernard in 1844. The subject was a horse, and both the right and left ventricles were entered by a retrograde approach from the jugular vein and carotid artery. In an excellent review of the history of cardiac catheterization, angiography, and interventional cardiology, Mueller and Sanborn (3) describe and cite references for experiments by Stephen Hales and others whose work antedates that of Claude Bernard, and the interested reader is referred to their review for details (3). Although he may not have been the first to perform cardiac catheterization, Claude Bernard’s careful application of scientific method to the study of cardiac physiology using the cardiac catheter demonstrated the enormous value of this technical innovation. An era of investigation of cardiovascular physiology in animals then followed, resulting in the development of many important techniques and principles (e.g., pressure manometry, the Fick cardiac output method) which awaited direct application to the patient with heart disease.

Werner Forssmann usually is credited with being the first person to pass a catheter into the heart of a living person - himself (4). At age 25, while receiving clinical instruction in surgery at Eberswalde, near Berlin, he passed a catheter 65 cm through one of his left antecubital veins, guiding it by fluoroscopy until it entered his right atrium. He then walked to the radiology department (which was on a different level, requiring that he climb stairs), where the catheter position was documented by a chest roentgenogram (Fig. 1.1). During the next 2 years, Forssmann continued to perform catheterization studies, including six additional attempts to catheterize himself. Bitter criticism, based on an unsubstantiated belief in the danger of his experiments, caused Forssmann to turn his attention to other concerns, and he eventually pursued a career as a urologist (5). Nevertheless, for his contribution and foresight he shared the Nobel Prize in Medicine with Andre Cournand and Dickinson Richards in 1956.

**FIG. 1.1.**

Left ventricular (LV), aortic (Ao), and pulmonary capillary wedge (PCW) pressure tracings from a patient without valvular heart disease, illustrating the definition and measurement of diastolic filling period (DFP) and systolic ejection period (SEP). See text for discussion.

Forssmann's primary goal in his catheterization studies was to develop a therapeutic technique for the direct delivery of drugs into the heart. He wrote (4):

If cardiac action ceases suddenly, as is seen in acute shock or in heart disease, or during anesthesia or poisoning, one is forced to deliver drugs locally. In such cases the intracardiac injection of drugs may be life saving. However, this may be a dangerous procedure because of many incidents of laceration of coronary arteries and their branches leading to cardiac tamponade, and death... Because of such incidents, one often waits until the very last moment and valuable time is wasted. Therefore I started to look for a new way to approach the heart, and I catheterized the right side of the heart through the venous system.

Others appreciated the potential of Forssmann's technique as a diagnostic tool. In 1930, Klein reported 11 right-sided heart catheterizations, including passage to the right ventricle and measurement of cardiac output using the Fick principle (6). The cardiac outputs were 4.5 and 5.6 L/min in two patients without heart disease. In 1932, Padillo and coworkers reported...
Further developments came rapidly, and highlights include the following:

- Retrograde left-sided heart catheterization was first reported by Zimmerman (24) and by Limon-Lason (25) in 1950.
- The percutaneous technique developed by Seldinger in 1953 was soon applied to cardiac catheterization of both the left and right heart chambers (26).
- Transseptal catheterization was first developed in 1959 by Ross (27) and Cope (28) and quickly became accepted as a standard technique.
- Selective coronary arteriography was reported by Sones in 1959 and was perfected to a remarkable excellence over the ensuing years (29), (30). This technique was modified for a percutaneous approach by Ricketts and Abrams (31) in 1962 and Judkins (32) in 1967.
- In 1970, Swan and Ganz introduced a practical balloon-tipped, flow-guided catheter technique that enabled the application of catheterization outside the laboratory (33).

INTERVENTIONAL CARDIOLOGY

In the last 25 years, investigators have focused once again on the therapeutic potential of the cardiac catheter. In 1977, Grünzig introduced the technique of percutaneous transluminal coronary angioplasty (PTCA) (34), (35). In the ensuing years, catheter-based coronary revascularization has been applied widely. With rapidly evolving technology and expanding indications, PTCA and its "offspring" (e.g., stents, atherectomy) first rivaled and have now surpassed coronary bypass surgery as the dominant therapeutic modality for coronary artery disease. The development of percutaneous coronary intervention stimulated other innovations such as balloon valvuloplasty and devices to close intracardiac shunts, which together have made "interventional cardiology" a new field in cardiovascular medicine. The history of interventional cardiology has been summarized by Spencer King in an excellent review (36), and the interested reader is referred there for further details. In a sense, cardiac catheterization has returned to its roots, because, as mentioned earlier, Werner Forssmann's original intention had been to use the catheter as a tool for therapy, not diagnosis.

At approximately the same time that Grünzig was developing balloon angioplasty in Zurich, investigators in Germany and Los Angeles were administering the thrombolytic agent streptokinase through catheters placed selectively in the coronary arteries of patients early in the acute phase of transmural myocardial infarction. This new catheter-based therapy, which was viewed as radical at the time, produced angiographic findings that confirmed beyond any doubt the role of acute coronary thrombosis in the genesis of myocardial infarction. When investigators found that similar therapeutic benefit could be achieved by intravenous administration of the thrombolytic agent, the intracoronary direct-infusion technique all but died out except for a few special indications. However, catheter-based therapy for acute coronary thrombosis has undergone a renaissance in the last 10 years with the demonstration that PTCA/stenting in this setting produces results that are comparable or superior to those achieved with thrombolytic therapy (37), (38).

It is clear as we enter the 21st century that interventional cardiology—by virtue of its new technologies, potent adjunctive drug therapies (e.g., blockers of the platelet IIb/IIIa receptor), expanding indications, and improving results—has blossomed. In many ways, interventional cardiology, rather than purely diagnostic techniques, has become the dominant discipline within the broad field of cardiac catheterization. Although the emphasis in the field (and in this textbook) is now appropriately on the dynamic field of catheter-based intervention, the basic principles of catheter insertion, hemodynamic measurement, high-quality angiography, and integration of catheterization findings with both the clinical scenario and the findings of noninvasive tests are not just historical curiosities: they are the foundations on which all current interventional techniques are built, and from which future evolution of cardiac catheterization will proceed.

INDICATIONS FOR CARDIAC CATHETERIZATION
As performed today, cardiac catheterization is a combined hemodynamic and angiographic procedure undertaken for diagnostic and often therapeutic purposes. As with any invasive procedure, the decision to perform cardiac catheterization must be based on a careful balance of the risk of the procedure against the anticipated benefit to the patient. A summary of the indications for cardiac catheterization is given in Table 1.1 and discussed in the following paragraphs.

Cardiac catheterization usually is recommended to confirm the presence of a clinically suspected condition, define its anatomic and physiologic severity, and determine the presence or absence of associated conditions when a therapeutic intervention is planned in a symptomatic patient. The most common indication for cardiac catheterization today arises in the patient with an acute coronary ischemic syndrome in whom an invasive therapeutic intervention (PTCA, stent, or coronary artery bypass graft surgery) is contemplated. The patient with an acute coronary ischemic syndrome has most commonly experienced recent rupture of an atherosclerotic plaque within a coronary artery. Exposure of plaque contents to flowing blood leads to platelet deposition and coronary thrombosis, which, in turn, leads to transmural ischemia if the thrombus is completely obstructing, or to unstable angina if it causes only partial or intermittent occlusion. The goal of cardiac catheterization in such patients is to identify the culprit artery and restore vessel patency by PTCA/stent placement. The diagnostic part of the catheterization procedure may reveal other features (e.g., multivessel or left main coronary artery disease, severe associated valvular disease) that provide critical information for the decision to proceed with open-heart surgery.

Is cardiac catheterization necessary in all patients being considered for cardiac surgery? Although few would disagree that consideration of heart surgery is an adequate reason for the performance of catheterization, clinicians differ about whether all patients being considered for heart surgery should undergo preoperative cardiac catheterization. In this regard, it should be emphasized that the risks of catheterization are small compared with those of embarking upon cardiac surgery in a patient for whom an incorrect clinical diagnosis or the presence of an unsuspected additional condition greatly prolongs and complicates the planned surgical approach. The operating room is not a good place for surprises; by providing the surgical team with a precise and complete road map of the course ahead, cardiac catheterization can permit a carefully reasoned and maximally efficient operative procedure. Furthermore, information obtained by cardiac catheterization may be invaluable in the assessment of crucial determinants of prognosis, such as left ventricular function, status of the pulmonary vasculature, and patency of the coronary arteries. For these reasons, my colleagues and I recommend cardiac catheterization for almost all patients for whom heart surgery is contemplated.

Other major therapeutic considerations besides heart surgery may depend on the information afforded by cardiac catheterization and angiography. For example, the decision for pharmacologic intervention with heparin and/or a thrombolytic agent in suspected acute pulmonary embolism, or with high doses of a beta-blocker and/or calcium antagonists in suspected hypertrophic subaortic stenosis, might well be considered of sufficient magnitude to warrant confirmation of the diagnoses by angiographic and hemodynamic investigation before the initiation of therapy. A clinical diagnosis of primary pulmonary hypertension made by echocardiography usually requires cardiac catheterization (a) to confirm the diagnosis and (b) to assess potential responsiveness to pharmacologic agents, such as epoprostenol (39).

A second broad indication for performing cardiac catheterization is diagnosis of obscure or confusing problems in heart disease, even when a major therapeutic decision is not imminent. A common instance of this indication is presented by the patient with chest pain of uncertain cause, about whom there is confusion regarding the presence of obstructive coronary artery disease. Both management and prognosis of this difficult problem are greatly simplified when it is known, for example, that the coronary arteries are widely patent. Another example within this category might be the symptomatic patient with a suspected diagnosis of cardiomyopathy. Although some may feel satisfied with a clinical diagnosis of this condition, the implications of such a diagnosis in terms of prognosis and therapy (e.g., long-term bed rest, chronic anticoagulant therapy) are so important that I believe it is worthwhile to be aggressive in ruling out potentially correctable conditions (e.g., hemochromatosis, pericardial effusive-constrictive disease) with certainty, even though the likelihood of their presence may appear to be remote on clinical grounds.

Research

On occasion, cardiac catheterization is performed primarily as a research procedure. Although research is conducted to some degree in many of the diagnostic and therapeutic studies performed at major medical centers, this is quite different from catheterization for the sole purpose of a research investigation. Such studies should be carried out only under the direct supervision of an experienced investigator who is an expert in cardiac catheterization, using a protocol that has been carefully scrutinized and approved by the Committee on Human Research at the investigator's institution, and after a thorough explanation has been made to the patient detailing the risks of the procedure and the fact that the purpose of the investigation is to gather research information.
Contraindications

If it is important to carefully consider the indications for cardiac catheterization in each patient, it is equally important to discover any contraindications. Over the years, the concept of contraindications has been modified by the fact that patients with acute myocardial infarction, cardiogenic shock, intractable ventricular tachycardia, and other extreme conditions have tolerated catheterization and coronary angiography surprisingly well. At present the only absolute contraindication to cardiac catheterization is the refusal of a mentally competent patient to consent to the procedure.

A long list of relative contraindications must be kept in mind, however, and these include all intercurrent conditions that can be corrected and whose correction would improve the safety of the procedure. Table 1.2 lists these relative contraindications. For example, ventricular irritability can increase the risk and difficulty of left heart catheterization and can greatly interfere with interpretation of ventriculography (see Chapter 12); if possible, ventricular irritability should be suppressed medically before or during catheterization. Hypertension increases predisposition to ischemia and/or pulmonary edema and should be controlled before and during catheterization. Other conditions that should be controlled before elective catheterization include intercurrent febrile illness, decompensated left-sided heart failure, correctable anemia, digitalis toxicity, and hypokalemia. Allergy to a radiographic contrast agent is a relative contraindication to cardiac angiography, but proper premedication can substantially reduce the risks of a major adverse reaction, as discussed in Chapter 3.

Anticoagulant therapy is more controversial as a contraindication. As pointed out in Chapters 4 and 11, heparin may lower the incidence of thromboembolic complications during coronary angiography (40). It is important to distinguish anticoagulation with oral anticoagulants (e.g., warfarin) from that with heparin. Heparin anticoagulation can be reversed rapidly during catheterization if necessary (e.g., in the case of perforation of the heart or great vessels or uncontrolled bleeding from femoral or brachial sites). Reversal of the prolonged prothrombin time of oral anticoagulation before or during cardiac catheterization represents a more complex problem. I strongly oppose acute reversal of oral anticoagulation with parenteral vitamin K because of the occasional induction of a hypercoagulable state, which has been known to result in thrombosis of prosthetic valves or thrombus formation within cardiac chambers, arteries, or veins. If reversal of oral anticoagulation is required, we favor administration of fresh-frozen plasma. For patients chronically anticoagulated with an oral agent, we routinely recommend discontinuation of the oral anticoagulants 48 hours before cardiac catheterization, with heparin given during these 48 hours for patients who have a strong indication for continuous anticoagulation (e.g., mechanical cardiac valve prosthesis). I prefer to have the international normalized ratio (INR) less than 2.0, or the prothrombin time less than 18 seconds, and no heparin administration for 4 hours before the catheterization. If anticoagulant therapy cannot be interrupted at all, we prefer heparin for the reasons just mentioned.

**FACTORS INFLUENCING CHOICE OF APPROACH**

Of the various approaches to cardiac catheterization, certain ones have only historical interest (transbronchial approach, posterior transthoracic left atrial puncture, and suprasternal puncture of the left atrium). In this book only the following are discussed in detail: (a) catheterization by percutaneous approach from various sites (including femoral or radial arteries, transseptal catheterization, and apical left ventricular puncture) and (b) catheterization by direct surgical exposure of the brachial artery and vein.

The great vessels and all cardiac chambers can be entered in almost all cases by either the direct exposure or percutaneous approaches (or a combination of both). Each method has its advantages and disadvantages, its adherents and detractors. In reality, the methods are not mutually exclusive but rather complementary; ideally, the physician performing cardiac catheterization should be well versed in both methods.

**Advantages of the Percutaneous Femoral Approach**

The percutaneous femoral approach is clearly the dominant technique in cardiac catheterization today, presenting a broad set of advantages and indications. The femoral approach does not require arteriotomy and arterial repair and can be performed repeatedly in the same patient at intervals, whereas the brachial arteriotomy approach can rarely be repeated safely more than two or three times; infection and thrombophlebitis at the catheterization site are rare; surgical (suture) closure of the skin is not necessary; and the approach is readily adaptable to a variety of other entry vessels (e.g., internal jugular vein, axillary artery, radial artery). Larger-caliber devices (i.e., valvuloplasty balloons or intraaortic counterpulsation catheters) can be introduced into the femoral artery but not usually into the smaller brachial artery. The femoral approach is clearly the method of choice in a patient with absent or diminished radial and brachial pulsations or when the direct brachial approach has been unsuccessful. In the occasional patient with tight aortic stenosis in whom
retrograde catheterization has proved impossible, percutaneous transseptal catheterization of the left atrium and ventricle is helpful; in the rare instance in which retrograde arterial and transseptal catheterization have not succeeded in gaining entry into the left ventricle (or are contraindicated by the presence of disc mitral and/or aortic prostheses or left atrial thrombus), percutaneous transthoracic puncture of the left ventricle may be considered (see Chapter 4).

Advantages of the Percutaneous Radial Approach

In recent years, percutaneous technique using the radial, brachial, or ulnar arteries as entry sites has been applied to retrograde left heart catheterization, coronary angiography, PTCA, and even stent placement. This approach is becoming increasingly popular and has been demonstrated to have advantages of cost and patient comfort. A study by Mann and colleagues reported on the use of percutaneous transradial catheterization for stent placement in patients with acute coronary syndromes. A total of 144 patients with acute coronary syndromes were randomly assigned to either a femoral or a radial approach. Stenting from the radial approach allowed earlier hospital discharge and was associated with decreased hospital charges and fewer bleeding complications. Not all patients assigned to the radial approach strategy were able to have radial artery catheterization. Six of the 74 had a negative Allen test or Doppler examination, or both, suggesting an incomplete palmar arch, so that radial catheterization was thought to be contraindicated; accordingly, they were included in the femoral approach group. In three additional patients, the radial artery was not successfully cannulated, and these patients also crossed over to the femoral approach group.

Advantages of the Brachial Approach

Much less common today, the direct exposure approach usually utilizes cutdown on the brachial artery and basilic vein at the elbow (see Chapter 5). In general, the percutaneous radial approach has all the advantages of the direct brachial approach and few of its disadvantages. Nevertheless, the brachial cutdown approach is still used by a few centers and is worthy of some comment. The brachial approach may have advantages in a patient with severe peripheral vascular disease involving the abdominal aorta, iliac, or femoral arteries; suspected femoral vein or inferior vena caval thrombosis; or coarctation of the aorta. The brachial or radial approach may also have advantages in the very obese patient, in whom the percutaneous femoral technique may be technically difficult and where hard to control breathing occurs after catheter removal. Another advantage occasionally cited for the direct brachial approach is use of a single left heart catheter (Sones catheter) for left ventriculography and coronary angiography.

DESIGN OF THE CATHETERIZATION PROTOCOL

Every cardiac catheterization should have a protocol—a carefully reasoned, sequential plan designed specifically for the individual patient. Although this protocol may exist only in the mind of the operator, it is often helpful to prepare a written protocol and post it in the catheterization suite so that all personnel in the laboratory understand exactly what is planned and can anticipate the needs of the operator.

Certain general principles should be considered in the design of a protocol. First, hemodynamic measurements should precede angiographic studies whenever possible, so that crucial pressure and flow measurements may be made as close as possible to the basal state. A separate arterial monitor line (which may be just the sidearm of the arterial sheath) can be helpful; when complications develop (and they do, no matter how skilled the operator), this second transducer allows continuous monitoring of arterial pressure. Second, pressures and selected oxygen saturation values should be measured and recorded in each chamber “on the way in,” that is, immediately after the catheter enters and before it is directed toward the next chamber. If problems should develop during the later stages of a catheterization procedure (atrial fibrillation or other arrhythmia, pyrogen reaction, hypotension, or reaction to contrast material), the investigator will be glad to have measured pressures and saturations this way, rather than waiting until the time of catheter pullback. Third, measurements of pressure and cardiac output should be made as simultaneously as possible. A simple routine for recording pressure during the cardiac output measurement can be learned by the laboratory personnel and performed efficiently in every case.

Beyond these general guidelines, the protocol reflects individual patient differences. With regard to angiography, it is important to keep in mind Sutton’s law (when asked why he robbed banks, Willie Sutton is reported to have replied, “Because that’s where the money is”) and order the contrast injections in relation to the most important diagnostic considerations in a given patient.

PREPARATION AND PREMEDICATION OF THE PATIENT
It goes without saying that the emotional as well as the “medical” preparation of the patient for cardiac catheterization is the responsibility of the operator. It is our firm obligation to fully explain the proposed procedure in such terms that the patient can give truly informed consent. We always tell the patient and his or her family that there is risk involved and the extent of the risk, depending on the specific procedure and the patient’s clinical situation. If appropriate, we reassure patient and family that we do not anticipate any special problems. Our consent form lists the specific risks and informs the patient that “There is a less than 1% risk of serious complications (stroke, heart attack, or death).” If the patient and family want to know more about these risks, they will ask for details. We do not understate the discomfort involved or the duration of the procedure-doing so risks one’s credibility. We have been satisfied with this overall approach and can heartily recommend it. A study of psychologic preparation for cardiac catheterization (47) found that patients who received careful psychologic preparation had lower levels of autonomic arousal both during and after cardiac catheterization than did control subjects.

Once the question of indications and contraindications has been dealt with and the patient’s consent obtained, attention can be directed toward the matter of medications. As mentioned earlier, we prefer to have the INR less than 2.0 (prothrombin time less than 18 seconds) and no heparin administered for 4 hours. One exception is the patient with unstable angina, in whom a therapeutic heparin infusion may be continued until arterial entry and then supplemented by 3,000 to 5,000 additional units. For these patients, “front-wall” arterial puncture is particularly important, as discussed in Chapter 4. For patients receiving chronic anticoagulation therapy, we discontinue oral anticoagulants the day before hospitalization (or 48 hours before study for outpatient catheterizations), and on admission we begin intravenous heparin, which is stopped within 4 hours of the catheterization. Heparin and oral anticoagulants are re instituted after the catheterization, and heparin is stopped once adequate prolongation of prothrombin time has been achieved.

The question of administering antibiotics prophylactically is raised occasionally, and some laboratories administer them routinely before catheterization. We do not administer antibiotics prophylactically before cardiac catheterization, and we know of no controlled studies to support their use.

A wide variety of sedatives has been employed for premedication. We no longer routinely order premedication to be given before the patient is sent to the catheterization laboratory. Instead, we assess the patient’s state of alertness and need for sedation once he or she is on the catheterization table. At that time, we usually administer midazolam (Versed, Roche Laboratories, Nutley, NJ) 1 mg IV and/or fentanyl 25 to 50 mg IV.

It is our practice to have the patient fasting (except for oral medications) after midnight, but some laboratories allow a light tea and toast breakfast without ill effects. Complete vital signs should be recorded before the patient leaves the floor (for inpatients), or shortly after arrival at the ambulatory center (for outpatients), so that the procedure may be aborted if a change has occurred since the patient was last seen.

For a typical inpatient, our precatheterization orders might be the following:

1. To Cardiac Catheterization Laboratory at 7:30 a.m. tomorrow by stretcher; patient to be in hospital gown.
2. Fasting after midnight except for regularly scheduled oral medications.
3. Have patient urinate before leaving for Cardiac Catheterization Laboratory.
4. Record complete vital signs before patient leaves for Cardiac Catheterization Laboratory.

This list is only a general procedure guide and obviously would be modified as the details of specific situations require.

THE CARDIAC CATHETERIZATION FACILITY

A modern cardiac catheterization laboratory requires an area of 500 to 700 ft², within which is housed a conglomerate of highly sophisticated electronic and radiographic equipment. Reports of the Inter-Society Commission for Heart Disease Resources on optimal resources for cardiac catheterization facilities appeared in 1971, 1976, and 1983. The most recent American College of Cardiology/American Heart Association (ACC/AHA) Guidelines for Cardiac Catheterization Laboratories (48) were published in 1991. In this report, a variety of issues were dealt with, including the following:

1. Traditional versus nontraditional settings for a cardiac catheterization laboratory; location within a hospital versus a freestanding facility
2. Ambulatory cardiac catheterization: indications and contraindications
3. Ethical issues related to self-ownership of laboratories, self-referral of patients, and advertising
4. Optimal annual caseload for physicians and for the laboratory
5. Safety issues during conduct of the procedure (e.g., sterile technique, heparin)
6. Physical arrangements and space requirements
7. Radiation safety and radiologic techniques.

The report (48) provides detailed discussion of these issues. Certain points, however, are worth discussing here.

**Location Within a Hospital Versus a Freestanding Facility**

The issue of whether cardiac catheterization laboratories should be hospital-based, freestanding, or mobile has been the subject of much debate(48-50). There are many potential concerns about performance of cardiac catheterization in a freestanding facility, and the available data from such facilities are limited. Mobile cardiac catheterization laboratories may be either freestanding or hospital-based (as is the case for mobile magnetic resonance imaging and other mobile diagnostic units), so mobile and freestanding units should not be equated automatically. In its 1991 report, the ACC/AHA Task Force “generally found that in freestanding catheterization laboratories, access to emergency hospitalization may be delayed, and appropriate oversight may be lacking. Additionally, opportunities for self-referral may be fostered and the perception of commercialism and entrepreneurial excess in practice created” (48). The report concluded that “in view of the lack of appropriately controlled safety and need data for hospital-based, mobile or freestanding laboratories operating without on-site (accessible by gurney) cardiac surgical facilities, the Task Force reaffirms the position that further development of these facilities cannot be endorsed at this time” (48).

**Outpatient Cardiac Catheterization**

Outpatient cardiac catheterization has been demonstrated by a variety of groups to be safe, practical, and highly cost-efficient, and it is widely practiced throughout the world. Outpatient catheterization can be accomplished by the radial or brachial approach, which allows the patient to be ambulatory within minutes after completion of the catheterization study(42,44-46,51). However, outpatient catheterization also can be accomplished safely by the percutaneous femoral technique(52-54). In one study (52), 2,207 patients underwent elective outpatient cardiac catheterization at the Kaiser Permanente Regional Cardiac Catheterization Laboratory in Los Angeles, California. Ninety-seven percent of the procedures were done by the percutaneous femoral approach, using 7F catheters without sheaths. Heparin was given intraarterially in a relatively low dose (2,000 to 3,000 units) and was not reversed with protamine at the end of the procedure. Hemostasis was obtained by manual compression for 10 minutes over the femoral artery, followed by placement of a pressure dressing and sandbag for 4 hours. Patients were checked at 15-minute intervals during the 4-hour surveillance period and discharged after they had become ambulatory. Each patient was contacted at home by telephone on the following day by a nurse from the outpatient observation area, and patients were seen after 1 to 2 weeks by their referring cardiologist for follow-up consultation and discussion of results. Complication rates were extremely low, lower than rates generally reported for inpatient diagnostic catheterization (see Chapter 3). More recently, 5F catheters (55),(56) and radial artery catheterization techniques(42,44-46) have been used for outpatient cardiac catheterization, substantially reducing the potential risks.

**On-site Cardiac Surgery**

Another issue addressed in the ACC/AHA Guidelines is the question of proximity and availability of cardiac surgical facilities. The report emphasized that laboratories without in-house cardiovascular surgery must have formal arrangements with a hospital that has on-site cardiovascular surgery facilities and that regulatory and third-party reimbursement agencies should review these arrangements on a regular basis (48). Immediately available cardiac surgical backup is particularly critical for laboratories performing diagnostic catheterization on unstable, acutely ill, or high-risk patients and for those performing coronary angioplasty, endomyocardial biopsy, or transseptal catheterization.

**Physician and Laboratory Caseload**

Utilization levels and optimal physician caseload represent a third issue of general interest addressed in the ACC/AHA Guidelines (48). The report recommended certain levels of utilization for cost-effectiveness and maintenance of skills (Table 1.3). Note that the optimal caseload has an upper limit as well as a lower limit. A cardiologist should not have such an excessive caseload that it interferes with proper precatheterization evaluation of the patient or with adequate postcatheterization interpretation of the data, report preparation, patient follow-up, and continuing medical education.

**Performing the Procedure**
Having carefully considered indications and contraindications, chosen a method of approach, designed the catheterization protocol, and prepared the patient, the physician's next step is to perform the cardiac catheterization itself and thereby gain the anatomic and physiologic information needed in the individual case. The individual cardiac catheterization selectively draws on the procedures that are described throughout this text. Detailed descriptions of catheter insertion and hemodynamic measurements are contained in Section II (Chapters 4–6) and Section III (Chapters 7–10), respectively. Descriptions of angiographic and interventional techniques are given in Section IV (Chapters 11–14) and Section VII (Chapters 23–28). Methods for evaluation of cardiac function and special techniques used only in selected situations are described in Section V (Chapters 15–17) and Section VI (Chapters 18–22).

These descriptions are not proposed as the only correct approaches to cardiac catheterization (many laboratories and operators take different approaches, and yet obtain excellent results). Rather, they are the methods that we have consistently found to be safe, successful, and practical. Their strengths and weaknesses are well characterized, and I believe that they constitute an excellent point of reference as one's practice continues to evolve based on new data and personal preference.