Cardiac Catheterization *and* Angiography

EDITED BY

William Grossman, M.D.

SECOND EDITION

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William Grossman, M.D.

Associate Professor of Medicine, Harvard Medical School;
Director, Cardiac Catheterization Laboratory,
Peter Bent Brigham Hospital, Boston, Massachusetts

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Preface

THIS textbook in both its conception and design is aimed at the instruction of physicians training to become cardiologists. The intent was to compile a book that would be practical, and that would bring together clear and concise descriptions of the major techniques currently employed in cardiac catheterization and angiography. No effort was made to be exhaustive or to construct a compendium of every technique that has been reported; instead, we have concentrated on the detailed description of a few methods that are moderately successful, that are practical, and whose strengths and weaknesses are well known.

The book begins with a section on general principles of cardiac catheterization and angiography. This has been substantially expanded from the first edition, and contains new chapters on proper utilization of radiologic and cineangiographic equipment, and the incidence, causes, and prevention of complications of cardiac catheterization. The second section deals with techniques of catheter placement, including discussions of arteriotomy, percutaneous technique, transseptal catheterization, balloon-tipped flow-directed catheters, and special considerations in the catheterization of infants and children. Subsequent sections on hemodynamic principles and angiographic techniques attempt to cover basic knowledge in these areas, with an emphasis on practical application and on how to avoid commonly encountered mistakes and pitfalls. Discussion of the interpretation of hemodynamic and angiographic findings has been largely separated from the description of techniques. Interpretation is discussed and illustrated at the end of the book in the chapters on profiles of characteristic hemodynamic and angiographic abnormalities in specific disorders (Part VI). This separation is purposeful, and serves to emphasize the importance of considering hemodynamic and angiographic data together when analyzing the physiologic and anatomic abnormalities presented by a given disorder.

A unique section on "Evaluation of Cardiac Function" offers pragmatic discussions of recent advances and the current state of the art in left ventricular mechanics, atrial pacing, ventricular volume analysis, myocardial blood flow, and dynamic and isometric exercise.

This book could not have been written without the help of many individuals whose names do not appear on the list of contributors. In particular, I am grateful to Dr. Eugene Braunwald; my many colleagues in the Departments of Medicine at Harvard Medical School and the Peter Bent Brigham Hospital who gave me encouragement and advice; to our Cardiology Fellows whose thoughtful questions and comments stimulated me to undertake this task in the first instance; and to the technicians and staff of our laboratory whose hard work and dedication allow the precepts of this book to be transformed into action each day.

I hope that this book will be of value not only to those involved in the daily practice of cardiac catheterization and angiography, but to all who are involved in the care of patients with serious heart disease. Most of all, I sincerely hope that the lessons of this book will benefit the patients themselves; without this final result, it will have been a sterile venture.

WILLIAM GROSSMAN, M.D.

Boston, Massachusetts

Contributors

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PETER F. COHN, M.D.
Associate Professor of Medicine, Harvard Medical School; Director, Clinical Cardiology Service, Peter Bent Brigham Hospital, Boston

C. RICHARD CONTI, M.D.
Professor of Medicine and Chief, Division of Cardiology, University of Florida College of Medicine, Gainesville, Florida

JAMES E. DALEN, M.D.
Professor and Chairman, Department of Medicine, University of Massachusetts Medical School; Physician-in-Chief, University of Massachusetts Medical Center, Worcester

ANTHONY N. DAMATO, M.D.
Director, Cardiopulmonary Laboratory, and Chief, Cardiovascular Program, U.S. Public Health Service Hospital, Staten Island

DAVID DELANY, M.B., B.CHIR., F.F.R.
Associate Professor of Radiology, University of North Carolina School of Medicine; Director of Special Procedures, Department of Radiology, and Radiological Director of Cardiac Catheterization Laboratory, North Carolina Memorial Hospital, Chapel Hill

LEWIS DEXTER, M.D.
Professor of Medicine, Emeritus, Harvard Medical School; Physician, Peter Bent Brigham Hospital, Boston

LANCE DUNHAM, R. T.
Chief Technologist, Cardiovascular Radiology, Peter Bent Brigham Hospital, Boston

MICHAEL D. FREED, M.D.
Associate Professor of Pediatrics, Harvard Medical School; Senior Associate in Cardiology, The Children's Hospital Medical Center, Boston

JOHN J. GALLAGHER, M.D.
Associate Professor of Medicine, Duke University Medical School, Durham, North Carolina

WILLIAM GANZ, M.D., C.SC.
Professor of Medicine, University of California at Los Angeles School of Medicine; Senior Research Scientist, Department of Cardiology, Cedars-Sinai Medical Center, Los Angeles

WILLIAM GROSSMAN, M.D.
Associate Professor of Medicine, Harvard Medical School; Director, Cardiac Catheterization Laboratory, Peter Bent Brigham Hospital, Boston

RICHARD GORLIN, M.D.
Professor and Chairman, Department of Medicine, Mount Sinai School of Medicine, New York

MICHAEL V. HERMAN, M.D.
Professor of Medicine and Chief, Division of Cardiology, New York

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Medical College; Chief of Cardiology, Westchester County Medical Center, Valhalla, N.Y.

WILLIAM P. HOOD, JR., M.D.

Professor of Medicine and Director, Adult Cardiac Catheterization Laboratories, University of Alabama School of Medicine, Birmingham

JOEL S. KARLINER, M.D.

Associate Professor of Medicine and Director, Clinical Cardiology, University Hospital, University of California School of Medicine, San Diego

JOHN F. KEANE, M.D.

Assistant Professor of Pediatrics, Harvard Medical School; Senior Associate in Cardiology, and Associate Director, Cardiac Catheterization Laboratory, The Children's Hospital Medical Center, Boston

DAVID C. LEVIN, M.D.

Associate Professor of Radiology, Harvard Medical School, and Director, Cardiovascular Radiology, Peter Bent Brigham Hospital, Boston

LAMBERT P. MCLAURIN, M.D.

Department of Medicine, University of North Carolina School of Medicine, Chapel Hill

JOHN O. PARKER, M.D.

Professor and Chairman, Division of Cardiology, Department of Medicine, Queen's University, Kingston, Ontario

KIRK L. PETERSON, M.D.

Associate Professor of Medicine and Director, Cardiac Catheterization Laboratory, University of California School of Medicine, San Diego

CHARLES E. RACKLEY, M.D.

Professor of Medicine and Director, Specialized Center of Research on Ischemic Heart Disease, University of Alabama School of Medicine, Birmingham

JOHN ROSS, JR., M.D.

Professor of Medicine and Director, Cardiovascular Division, University of California School of Medicine, San Diego

RALPH SHABETAI, M.D.

Professor of Medicine, University of California School of Medicine, San Diego, and Chief, Cardiology Service, Veterans Administration Hospital, San Diego

H.J.C. SWAN, M.D., PH.D., F.R.C.P.

Professor of Medicine, University of California at Los Angeles School of Medicine; Director, Department of Cardiology, Cedars-Sinai Medical Center, Los Angeles

Contents

PART I
General Principles of Cardiac Catheterization and Angiography

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1. Cardiac Catheterization: Historical Perspective and Present Practice

WILLIAM GROSSMAN, M.D.

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 during the past 30 years 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 man.

HISTORICAL REVIEW

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. An era of investigation of cardiovascular physiology in animals then followed, resulting in the development of many important techniques and principles (pressure manometry, the Fick cardiac output method) which awaited direct application to the patient with heart disease.

Although others had previously passed catheters into the great veins, Werner Forssmann is generally credited with being the first person to pass a catheter into the heart of a living person—himself.[3] 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 (he looked through a mirror held by his nurse in front of the fluoroscope screen) 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 two 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.

The potentials of Forssmann's technique were appreciated by others. In 1930, Klein reported 11 right heart catheterizations, including passage to the right ventricle and measurement of cardiac output using Fick's principle.[4] The cardiac outputs were 4.5 and 5.6 L/min in two patients without heart disease. In 1932 Padillo and co-workers reported right heart catheterization and measurement of cardiac output in two subjects.[2] Except for these few studies, application of cardiac catheterization to study of the circulation in normal and disease states was fragmentary until the work of Andre Cournand and Dickinson Richards, who separately and in collaboration produced a remarkable series of investigations of right heart physiology in man.[5-7] In 1947 Dexter reported his studies on congenital heart disease.[8] He went further than his predecessors by passing the catheter to the pulmonary artery, and in addition he mentioned some observations on "the oxygen saturation and source of pulmonary capillary blood" obtained from the pulmonary artery "wedge" position. Subsequent

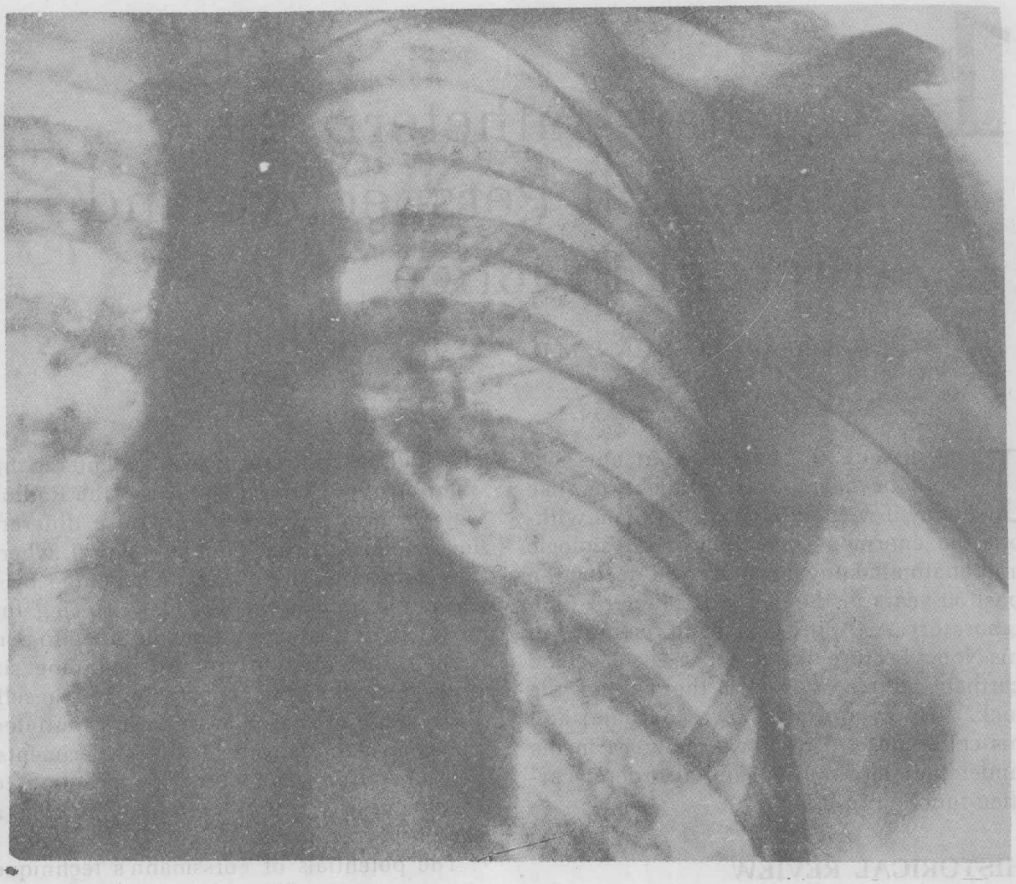

Fig. 1-1. The first documented cardiac catheterization. At age 25, while receiving clinical instruction in surgery at Eberswalde, Werner Forssmann passed a catheter 65 mm through one of his left antecubital veins until its tip entered the right atrium. He then walked to the Radiology Department, where this x-ray was taken.[2] (Klin Wschr 8:2085, 1929. © Springer-Verlag Berlin, Heidelberg, New York)

studies from Dexter's laboratory[9] and by Werko[10] elaborated on this pulmonary artery "wedge" position, and pressure measured at this position was reported to be a good estimate of pulmonary venous and left atrial pressure. During this exciting early period, catheterization was used to investigate problems in cardiovascular physiology by McMichael in England,[11] Lènegre in Paris,[12,13] and Warren, Stead, Bing, Dexter, Cournand, and others in this country.[14-23]

Further developments came rapidly. To touch briefly on some of the highlights: Retrograde left heart catheterization was first introduced by Zimmerman[24] and Limon Lason[25] in 1950. The percutaneous technique developed by Seldinger in 1953[26] 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 developed by Sones in 1959 and 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 a practical balloon-tipped flow-guided catheter technique was introduced by Swan and Ganz, making possible the applicability of catheterization outside the catheterization laboratory.[33] There are many other landmarks that could be mentioned, and many individuals whose

contributions should be recognized; the interested reader is referred elsewhere[34] for details.

INDICATIONS FOR CARDIAC CATHETERIZATION

As performed today, cardiac catheterization may be defined as a combined hemodynamic and angiographic procedure undertaken for diagnostic purposes.

As with any diagnostic procedure, the decision to perform cardiac catheterization must be based upon a careful balance of the risk of the procedure against the anticipated value of the information. Cardiac catheterization is generally recommended when there is a need to confirm the presence of a clinically suspected condition, define its anatomic and physiologic severity, and determine the presence or absence of associated conditions. This need most commonly arises when the clinical assessment suggests that the patient is approaching the stage of rapid deterioration, incapacitation, and death when viewed in the context of the natural history of his or her specific disorder. Cardiac catheterization may yield information that will be crucial in defining the need for cardiac surgery as well as its timing, risks, and anticipated benefit in a given patient.

Although few would disagree that consideration of heart surgery is an adequate reason for the performance of catheterization, there are differences of opinion about whether *all* patients being considered for heart surgery should undergo preoperative cardiac catheterization. In this regard I would emphasize that the risks of catheterization are small compared to those of cardiac surgery in a patient with an incorrect clinical diagnosis, or in a patient in whom 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: cardiac catheterization can provide the surgical team with a precise and complete roadmap of the course ahead, and thereby 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 and the patency of the coronary arteries. For these reasons, I recommend cardiac catheterization in virtually all patients in whom heart surgery is contemplated.

There are other major therapeutic considerations besides heart surgery that may depend upon the type of information afforded by cardiac catheterization. For example, pharmacologic intervention with heparin in suspected acute pulmonary embolism, or with high doses of propranolol in suspected hypertrophic subaortic stenosis, might well be considered decisions of sufficient magnitude to warrant confirmation of the diagnoses by angiographic and hemodynamic investigation.

A second broad indication for performing cardiac catheterization is to diagnose obscure or confusing problems in heart disease, even when a major therapeutic decision is not imminent. Currently, the most common instance of this indication in our laboratory is presented by the patient with chest pain of uncertain etiology, 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 (such as long-term bed rest or chronic anticoagulant therapy) are so important that I feel it worthwhile to be aggressive in ruling out potentially correctable conditions with certainty (e.g., pericardial effusive-constrictive disease), even though the likelihood of their presence may appear remote on clinical grounds.

On occasion, cardiac catheterization is performed primarily as a research procedure. Although research is conducted to some degree in nearly all routine diagnostic studies performed in our laboratory, this is quite different from the performance of catheterization for the sole purpose of a research

investigation. Such studies should only be carried out under the direct supervision of an experienced investigator who is expert in cardiac catheterization, using a protocol that has been carefully scrutinized and approved by the Human Studies Committee 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 determine whether there are any contraindications. Over the past several years, our concepts of contraindications have been modified because patients with acute myocardial infarction, cardiogenic shock, intractable ventricular tachycardia and other extreme conditions have tolerated catheterization and coronary arteriography surprisingly well.[35-38] At present the only absolute contraindication to cardiac catheterization in our laboratory 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. For example, ventricular irritability can increase the risk and difficulty of left heart catheterization and can greatly interfere with interpretation of ventriculography (see Chapter 14); it should be suppressed medically prior to catheterization. Hypertension increases predisposition to ischemia, and should be controlled prior to and during catheterization. Other conditions that should be controlled prior to elective catheterization include intercurrent febrile illness, decompensated left heart failure, correctable anemia, digitalis toxicity, and hypokalemia. Acute myocardial infarction is clearly a contraindication unless emergency surgery is contemplated, such as mitral valve replacement for papillary muscle rupture, repair of acute ventricular septal defect, or coronary artery by-pass because of continued pain.

Anticoagulant therapy is more controversial as a contraindication. Some authors have cautioned against the use of anticoagulants, particularly when percutaneous techniques are utilized,[39-42] while others suggest that their use may be safe or even desirable.[43-44] As pointed out in Chapters 5 and 13, heparin may lower the incidence of thromboembolic complications during percutaneous coronary angiography by the Judkins technique. It is important to distinguish anticoagulation with oral anticoagulants (e.g., coumadin) from that with heparin. Heparin anticoagulation can be reversed easily and safely during catheterization if necessary (e.g., perforation of the heart or great vessels, uncontrolled bleeding from femoral or brachial sites). Reversal of the prolonged prothrombin time of oral anticoagulation represents a more complex problem. I strongly oppose acute reversal of oral anticoagulation with vitamin K because of the occasional induction of a hypercoagulable state. This in turn may result in thrombosis of prosthetic valves, or thrombus formation within cardiac chambers, arteries, or veins. If reversal of oral anticoagulation is required, I recommend administration of fresh frozen plasma. For patients chronically anticoagulated with an oral agent, I routinely recommend discontinuation of the oral anticoagulant the day prior to hospital admission and anticoagulation with heparin (full dose) on admission; heparin is not given prior to the catheterization procedure. I prefer to have the prothrombin time less than 18 seconds, and no heparin administration for six hours. If anticoagulant therapy cannot be interrupted at all, I 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, suprasternal puncture of the left atrium), and the reader is referred elsewhere for details.[34] In this book we will discuss in detail only

(a) catheterization by direct exposure of artery and vein, and (b) catheterization by percutaneous approach (including transseptal catheterization). Left ventricular puncture will be mentioned briefly, although this has not been required in our laboratory in several years.

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

The direct approach usually utilizes cutdown on the brachial artery and basilic vein at the elbow, while the percutaneous approach of Seldinger traditionally involves entry of the femoral artery and vein at the groin.[26] Thus the direct brachial approach may have advantages in a patient with 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 direct brachial approach may also have advantages in the very obese patient, in whom the percutaneous femoral technique may be technically difficult and bleeding hard to control after catheter removal. Some prefer the brachial approach in patients who have significant hypertension, aortic regurgitation, or wide pulse pressure from other causes, or who are receiving anticoagulants. In these three circumstances, an increased hazard of bleeding has been reported with the percutaneous femoral technique.[42] Other advantages frequently cited for the direct brachial approach include greater catheter control, greater potential selection of catheters (end-hole, side-hole, micromanometer-tipped catheters), greater ease of catheter exchange in case of a clotted catheter, and so on.

In contrast, the percutaneous femoral approach has its own broad set of advantages and indications. Arteriotomy and arterial repair are not required; it can be performed repeatedly in the same patient at intervals, whereas the brachial approach can rarely be repeated more than once or twice with safety; infection and thrombophlebitis at the catheterization site are rare; and there is no need for surgical (suture) closure of the skin. It is clearly the method of choice in a patient with absent or diminished radial and brachial pulsations, or when direct brachial approach has been unsuccessful. This last indication is important, for example, in the patient with tight aortic stenosis in whom retrograde catheterization may prove impossible; in this circumstance, percutaneous transseptal catheterization of the left atrium and ventricle is helpful (see Chapter 5). In the rare instance when retrograde arterial and transseptal catheterization have not been successful in gaining entry into the left ventricle, direct transthoracic puncture of the left ventricle may be considered.

DESIGN OF THE CATHETERIZATION PROTOCOL

Every cardiac catheterization should have a protocol; that is, a carefully reasoned sequential plan designed specifically for the individual patient being studied. Although this protocol may exist only in the mind of the operator, it is our practice to prepare a written protocol and post it on the hemodynamic recorder so that all personnel in the laboratory may be aware of exactly what is planned, and thus may be reasonably expected to anticipate the needs of the operator.

Certain general principles should be considered in the design of a protocol. First, we prefer to have an arterial monitor line present in virtually all cases; when complications develop (and they do, no matter how skilled the operator), it is helpful to be able to monitor arterial pressure continuously. In our laboratory, an arterial monitor line (usually a percutaneously introduced short length of polyethylene tubing in the left brachial or femoral artery) is placed at the start of each cardiac catheterization. Second, hemodynamic measurements should precede angiographic studies, so that the physiologic values may be as basal as possible at the time of crucial pressure and flow measurements.

Third, pressures and oxygen saturations should be measured and recorded in each chamber immediately after entry and before passing on to 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 wish that he had measured pressures and saturations "on the way in," rather than waiting until the time of catheter pullback. A fourth principle is that pressure and cardiac output measurements 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 will reflect individual differences from patient to patient. With regard to angiography, it is important to keep Sutton's Law* in mind, and order the contrast injections in relation to what are 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. In contrast to the approach of others,[45] we believe it is our firm obligation to fully explain the proposed procedure in such terms that the patient will be in a position to give truly informed consent. We *always* tell the patient and his family that there is some risk involved, although we generally reassure them we do not anticipate any special problems in their case. Our consent form lists these 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 his family want to know more about these risks, they will ask for details. We do not understate the discomfort or duration of the procedure, and believe that to do so runs the risk of losing one's credibility. We have been quite satisfied with this overall approach, and can heartily recommend it.

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 prothrombin time less than 18 sec and no heparin administered for six hours. For patients on chronic anticoagulation, we discontinue oral anticoagulants the day prior to hospitalization, and on admission we begin intravenous heparin, which is stopped after midnight on the night preceding the catheterization. Heparin and oral anticoagulants are reinstituted following the catheterization, and heparin is stopped once adequate prothrombin time prolongation has been achieved. This may be unnecessary, since reports previously mentioned have suggested that it is safe to perform cardiac catheterization on a patient receiving anticoagulants.[43,44] Further studies are needed to clarify this issue.

The question of administering antibiotics prophylactically is frequently raised, and some laboratories routinely administer them prior to catheterization.[30] We do not administer antibiotics prophylactically before cardiac catheterization, and we know of no controlled studies to support their use.[46]

A wide variety of sedatives has been employed for premedication. We routinely use diazepam (Valium), 5 to 10 mg p.o., and diphenhydramine (Benadryl), 25 to 50 mg p.o., one-half hour prior to starting the procedure. For coronary angiography, atropine, 0.4 mg subcutaneously, is recommended by some.[47] In a patient in whom unusual anxiety or discomfort is anticipated, meperidine (Demerol) may be added in doses from 25 to 100 mg IM, depending on body size.

It is probably worthwhile to have both antecubital fossae scrubbed with pHisoHex the night prior to catheterization if the brachial approach is to be used, and to have one or both groins shaved if a femoral approach is planned. It is our practice to have the patient fasting (except for his oral medications) after midnight, but many laborato-

*When once asked why he robbed banks, Willie Sutton is reported to have replied: "because that's where the money is."

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