Endovascular Skills




Guidewire and Catheter Skills for Endovascular Surgery

Second Edition
Revised and Expanded

Peter A. Schneider

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To
Victoria

Foreword

This book does an excellent job of meeting the goals as expressed in its title, *Endovascular Skills: Guidewire and Catheter Skills for Endovascular Surgery*. It is straightforward and easy to read and takes a step-by-step approach. The first edition, published in 1998, recognized the need for a comprehensive review of basic catheter and guidewire skills for those entering the endovascular arena. The importance of this type of work continues to grow. As a single-author text written by a vascular surgeon experienced in endovascular methods, there is a continuity of thought and conceptual approach to patients with vascular disease that emphasizes the selection of the best method of treatment for an individual patient.

In this second edition, Dr. Schneider captures the progress that has been made in recent years and incorporates the expanding knowledge base in a detailed discussion of instruments, technical capabilities, and a developing range of therapeutic applications. In the chapters relating to stent applications to branch vessels, where individual stents are not yet FDA approved, he appropriately comments on the current status of techniques while recognizing that these remain "off-label" applications for individual use in patients for whom no alternative treatment is available. As is needed in discussing an evolving technology, there is a careful balance between describing the state of the art and evolution while providing disclaimers regarding currently approved utilization of the technologies. Throughout the text, Dr. Schneider does an excellent job of addressing these issues while describing the fundamental knowledge required to adopt the methods.

An important aspect of the book is that the author is a fully accomplished vascular and endovascular surgeon. This enables him to provide a perspective on the approach to individual lesions, with the option for treatment ultimately being determined by the potential success of the endovascular procedure contrasted with that of a conventional open repair. The text is well illustrated. It addresses issues regarding the performance of endovascular procedures in an operating room versus an interventional suite, a topic of particular interest to physicians and centers initiating endovascular programs. It also contains a section that provides additional information regarding manufacturers of instrumentation and imaging modalities.

The book focuses on techniques, basic instrumentation, balloons, and stents rather than on the use and indications for endovascular prostheses or similar endovascular technologies. From this perspective, it is a valuable source of information for any interventionalist or vascular specialist who is training in endovascular technologies.

I strongly recommend this book for individuals and institutions adopting endovascular methods and congratulate Dr. Schneider for producing a high-quality text that addresses the fundamental issues important to training and continued evolution in endovascular therapy.

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Preface to the Second Edition

A lot has happened since the mid-1990s when work began on the first edition of this book. Endovascular skills have become essential for the vascular clinician: these skills are required for the majority of revascularization procedures that are currently being performed. Devices and the technology that drives them have continued to evolve, mostly to the benefit of patients. In its infancy, endovascular therapy was best saved for patients with severe medical comorbidities who could not have the more durable open surgical option or for patients with less severe forms of vascular disease, such as focal iliac artery stenosis. The field has matured and endovascular techniques are competitive with, and for many patients better than, traditional open vascular surgical approaches. Miniaturization of the tools, new techniques, better durability, and new ideas for endovascular therapy will continue to be developed beyond the careers of anyone practicing today. The severity of arterial and venous disease that can be treated using endovascular skills will continue to increase. The last major vascular bed to experience the effects of the endovascular revolution, the cerebrovasculature, may be the most important one, since carotid endarterectomy is the most common vascular index procedure performed and the one for which the best level 1 evidence exists. Open vascular surgery is not obsolete. However, it is required as the first-line treatment in only a minority of patients and will continue to diminish in importance as an option.

Endovascular therapy is the most exciting development in the treatment of vascular disease in a generation. When vascular doctors embrace endovascular concepts, it liberates the way we think. Within this book are described the skills that assist the clinician in that process.

ACKNOWLEDGMENTS

I would like to express great and humble thanks to the following individuals who contributed in different ways to help make the second edition of *Endovascular Skills* possible. Lila Harris, my editor at Marcel Dekker, Inc., did a wonderful job of putting this book together. My partners, Drs. Michael Caps and Nicolas Nelken, put up with me most days and offer feedback on a myriad of otherwise crazy ideas. Nancy Quernel, MA, assists me in a way that makes me look better than I am. Dr. Al Mariani, Chief of Surgery, has been forward thinking and rock solid in his support of our vascular program. Vivia Carter, RN, runs the most efficient Vascular OR in the business, without which any further discussion would be meaningless.

Peter A. Schneider

Preface to the First Edition

Endovascular Skills has two purposes. This is a book that I wish had been available 10 years ago when I became interested in performing endovascular procedures. There is currently a significant gap in patient care between the clinical knowledge of and technical expertise in endovascular procedures. This book attempts to fill that gap.

Consideration of several factors will enhance the use of this book. First, this book was assembled on a "need-to-know" basis in an effort to answer the question "What do you need to know to acquire basic endovascular skills?" Second, there is almost always more than one way to achieve clinical success. Endovascular intervention is a young field and precious little of its technique is incontrovertible. Third, patient care will be improved with a greater understanding of endovascular techniques, regardless of whether readers of this book perform these procedures. Fourth, my experience with endovascular techniques has been accumulated, analyzed, and presented from a surgical point of view. However, its use is meant to be nondenominational. Finally, guidewires and catheters are destined to play a major role in vascular therapy of the twenty-first century and the devices attached to them and their applications will continue to evolve.

Peter A. Schneider

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1

Endovascular Concepts

Endovascular Skills in Practice
Reinvention of Vascular Care
Arteriographic Schism
Working Environment
Qualifications
Selected Readings

Endovascular Skills in Practice

Endovascular skills are an integral part of vascular patient care. As the scope of catheter-based treatment broadens, the ability to manage more complex lesions with these techniques will increase. The development of guidewire–catheter skills is not an easily definable goal, but is a dynamic process. Knowledge and facility must be achieved in several nonintuitive areas, including coordinating *fluoroscopic–eye–hand movements*, predicting guidewire–lesion interactions, understanding the behavior of various guidewire and catheter combinations, learning the limits of each technique (knowing when to quit), and becoming familiar with the available, and rapidly evolving, technology. These are the basic *endovascular skills*. Part I of this book provides an overview of basic endovascular skills. Part II presents techniques in endovascular therapy that build upon the basic skills.

Reinvention of Vascular Care

Endovascular concepts are reshaping treatment. The potential for simple, low-morbidity solutions to complex clinical problems is a common goal among vascular specialists. Near-term progress in reconstructive capability is likely to result from advances in endoluminal technique. Guidewires and catheters form the technical and conceptual basis of endovascular intervention. Endovascular procedures have dramatically changed the spectrum of vascular practice (e.g., iliac angioplasty, renal stents, stent–graft AAA, etc.). Although some endovascular procedures are not currently durable enough to offer long-term solutions, they may still be adequate for patients with multiple comorbidities or limited life expectancy. These techniques may also become more clinically useful as they are refined. Endovascular techniques were initially complementary to open vascular surgical techniques in terms of the spectrum of disease that could be treated. Now endovascular intervention appears to be a reasonable alternative to open surgery in many patients with open operations reserved for endovascular failures and complications. The natural history of all surgical fields suggests that the days of long incisions represent the end of an era.

Arteriographic Schism

The currently existing arteriographic schism represents an arbitrary division of labor and knowledge between technicians and clinicians, which is the basis for discontinuity in vascular patient care. The idea that one set of physicians understands the patients and their problems and an entirely different set performs the procedure is a failed paradigm. It never worked well. No one would design a system from scratch that looked like that. This schism creates a huge *black box* in vascular patient care pathways. For nonclinician interventionists, the patient is a black box available for the insertion of guidewires. For many vascular physicians over the years, the special procedures suite, and what went on there, has been a black box. To carry these arbitrary boundaries into the future would be a major setback for the patient and the development of treatment for vascular disease. The past preoccupation with categorizing procedures on the basis of percutaneous versus open access is counterproductive. Anyone with the skills to make a 6-in.-long incision should be able to learn the intricacies of making 6 Fr incisions. The focus should be on making incisions smaller and intervention safer, not forcing a procedure into one category or another. Lack of familiarity with a variety of approaches encourages advocates of a specific technique to crusade for the exclusive application of that technique, regardless of whether it is an open or endoluminal operation. Some of the gaps in endovascular therapy would be narrowed significantly with better technical orientation for clinicians.

Working Environment

Surgeons understand that top performance is something that does not just happen. It develops only with preparation. Judgment and technical skills take time, effort, and enthusiasm to develop. The staff that assists you, the equipment available, and the facility where you use those skills can either promote or detract from your ability to get sick patients through difficult situations. These preparations help to limit the variables and facilitate excellent results. Endovascular work is no different. There is a substantial learning curve associated with each procedure. Creating that working environment where high quality endovascular practice can be carried out is essential.

Qualifications

How many times do you need to do a procedure before you know how to do it? Should that number differ for someone who already spent years learning every other aspect of a disease process and its management? How many Whipple procedures or esophagectomies or pelvic exenterations does the average surgeon perform prior to performing the first one in practice? How about something really complicated and challenging like open suprarenal aneurysms? Clearly, the more the better. However, the actual number of cases is not as important as the technical and clinical foundation upon which the performance of those cases is based. Each society has its own recommendations for how many endovascular cases it takes to become qualified (Table 1). These numbers differ from each other because they are arbitrary. Most vascular specialists do not enter practice already having performed 50

Table 1 Case Requirements to Perform Endovascular Interventions

	SCVIR	SCAI	ACC	AHA	SVS/AAVS
Angiograms	200	100/50[a]	100	100	100/50[a]
Interventions	25	50/25[a]	50/25[a]	50/25[a]	50/25[a]

SCVIR, Society of Cardiovascular and Interventional Radiology; SCAI, Society for Cardiac Angiography and Interventions; ACC, American College of Cardiology; AHA, American Heart Association; SVS/AAVS, Society for Vascular Surgery/American Association of Vascular Surgery.
[a] As primary interventionist.

suprarenal aneurysms. Nevertheless, it would be wise to have at least 50 endovascular interventions under the belt. And the more the better.

When a new technique or treatment modality becomes available, the specialists in that field make arrangements for incorporating the new technique into practice. When coronary stents initially became available, the cardiologists who placed them and trained others in how they should be placed had no residency training in these areas. They learned through courses and on-the-job training. The key is that most of these physicians had a foundation in endovascular skills to build upon.

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2

How to Get In

Percutaneous Vascular Access

Percutaneous Access Is the Future

Angio Consult: What Are the Principles of Percutaneous Access?

Prior to the Puncture

Percutaneous or Open?

Choosing Your Approach

Anatomy for Arterial Access

Percutaneous Retrograde Puncture of Femoral Artery

Plan of Attack: Guidewire Won't Pass Through the Needle

Percutaneous Antegrade Puncture of Femoral Artery

Percutaneous Puncture of Pulseless Femoral Artery

Micropuncture Technique

Proximal Access

Percutaneous Puncture of Brachial Artery

Percutaneous Puncture of Prosthetic Grafts

Puncture with Ultrasound

Puncture Site Complications

Summary of Puncture Site Options

Selected Readings

Percutaneous Access Is the Future

Surgical heritage has prompted surgeons to be comfortable with huge incisions but not tiny ones. The development of endovascular and videoscopic techniques is changing that. A brief retrospective evaluation of the history of these fields suggests that the thousands of physicians, engineers, and entrepreneurs and the millions of dollars dedicated to making standard open surgery a thing of the past will eventually be successful, at least to a degree that will continue to significantly affect the treatment of vascular disease. Miniaturization, if safe and efficacious, will be a great benefit to patients. Vascular specialists must be ready and able to provide percutaneous services.

ANGIO CONSULT: What Are the Principles of Percutaneous Access?

1. It's not that complicated!
2. Choose the puncture site with the individual patient's needs in mind.
3. Determine the likelihood of endovascular intervention prior to the puncture and take that into account when choosing a puncture site.
4. Feel the artery intended for puncture so you know what to expect. Is it soft or hard and what is the quality of the pulse?
5. Palpate the anatomic landmarks.
6. Visualize the artery and its relationship to anatomic landmarks before skin puncture.
7. Standardize your technique.
8. Use fluoroscopy for guidance.
9. Don't be afraid to abandon the access and puncture elsewhere if the risk is too high.
10. No one gets in every single time.
11. If there is a problem, hold pressure for a few minutes.

Prior to the Puncture

Informed consent is best obtained in the office, when the patient is afforded time to consider issues and to consult with family. The current method of practice in many special procedures suites involves a patient, deprived of coffee, food, and sleep, sitting in front of millions of dollars worth of complicated equipment in a cold room with a physician that patient has not previously met.

Patients on coumadin or antiplatelet agents should be considered on a case-by-case basis. It is usually safe to perform either arteriography or endovascular intervention in patients on antiplatelet therapy, as long as there are no other factors that are likely to promote hemorrhage, such as dialysis dependency. If the antiplatelet agent must be stopped, it should be 10 days or more prior to the procedure. Arteriography is usually safe in patients on Coumadin, especially if 4 Fr catheters are used (see Chapter 8 for more detail). If endovascular intervention is required, Coumadin should be stopped approximately five days prior to the procedure. At the operator's discretion is whether a protime should be obtained on the day of the procedure. Patients with renal insufficiency are managed with preoperative hydration with normal saline and mucormyst. Methods of preprocedural evaluation are available that help to limit the contrast required for the study. These are discussed in Chapter 8. Contrast agents that are less toxic to the kidneys, such as gadolinium or CO_2, should also be considered (Chapter 5). Patients with a history of contrast allergy should be treated before the procedure with prednisone and Benadryl. This protocol is detailed in Chapter 13.

Percutaneous or Open?

Whether access should be gained through percutaneous needle puncture or open exposure was an unrewarding preoccupation that was based upon an arbitrary division of labor. This dilemma was prompted by the fact that most vascular workshops were prepared to carry out percutaneous exposure or open exposure, but not both. A true vascular specialist should be facile with either method of access, and the vascular workshop should be set up to handle the full range of approaches. More about the vascular workshop is presented in Chapter 11.

The goal of arterial access is the smallest incision that provides safe and effective entry. Access site complications occur when the operator is committed to one approach, and the intended procedure is forced to conform. There is some increase in the risk of puncture site complications with progressively larger arteriotomies. Arterial access sheaths up to 10 Fr can usually be placed safely using a percutaneous approach. For access devices larger than 10 Fr (greater than 3.3 mm), open access is advisable Recently developed arterial closure devices may permit safe percutaneous access for larger devices.

Choosing Your Approach

The most important maneuver for successful vascular access occurs prior to the procedure: that is, choosing the puncture site. The optimal puncture site choice should provide a low risk of complications, easy conversion to an endovascular intervention, and reasonable proximity to the site of intended intervention. Table 1 provides a list of puncture site choices. The retrograde femoral puncture is the most commonly used since it is safest and offers the highest degree of versatility. Left brachial or axillary artery punctures are usually the second choice. Some operators routinely perform open exposure when brachial artery access is required. Other puncture sites that have been used less commonly include the left subclavian artery, the retrogeniculate popliteal artery, and the common carotid artery. Chapter 8 includes a detailed discussion of puncture site evaluation prior to arteriography. Once the puncture site has been chosen, the operator should set up the case so that the work may be performed forehand if at all possible. This usually helps to avoid needless struggle. Fig. 1 demonstrates options for a forehand approach.

Anatomy for Arterial Access

The most common complications following arteriography or endovascular intervention occur at the puncture site. An understanding of anatomy helps avoid complications. The goal is a single perfect pass of the entry needle on every case. The operator should visualize the femoral artery passing from beneath the inguinal ligament. The inguinal ligament extends from the anterior superior iliac spine to the public tubercle. This landmark is usually possible to define and is essential in helping to determine how far superior or inferior the puncture should be. The fossa ovalis may also be palpated as a discontinuity in the fascia of the leg. Since this is directly over the lower aspect of the common femoral vein, it may also be used as an anatomic marker. Occasionally, it is helpful to use a skin marker to define the inguinal ligament and location of the common femoral artery. The quality of the artery may be understood prior to the procedure by palpating it. Fluoroscopy may also be used prior to puncture to locate the head of the femur. Puncture of the artery proximal to the femoral head is likely to be too high. The artery usually passes over the medial side of the femoral head. The temptation is to use the groin crease to determine the location of the puncture. Obese patients often have a groin crease that is significantly below the location of the inguinal ligament, and this may lead to a puncture that is too far distal (Fig. 2).

Percutaneous Retrograde Puncture of Femoral Artery

Both groins are prepared and draped. A towel holding each of the items immediately required for puncture and guidewire placement (a syringe for local anesthetic, a scalpel, a mosquito clamp, a puncture needle, and a

Table 1 Percutaneous Puncture Site Choices

Puncture site	Approach	Provides access to…	Comments
Femoral	Retrograde	Aorta and its branches	When either femoral artery can be used, most right-handed operators will stand on the patient's right side and puncture the right common femoral artery.
Femoral	Antegrade	Ipsilateral infrainguinal	Contraindicated when there is inflow disease or a high profunda origin or when the patient is obese.
Brachial or axillary	Retrograde	Aorta and its branches	Prefer the left side. Sheath larger than 6 or 7 Fr should be done through open exposure. Risk higher than with femoral puncture.
Alternative sites			
Left subclavian	Retrograde	Aorta and its branches	Risk higher than with femoral puncture. Alternative to brachial or axillary artery puncture.
Retrogeniculate popliteal	Retrograde	Ipsilateral SFA	Patient in prone position.
Common carotid	Retrograde	Aorta and its branches	Increased risk of stroke and bleeding.
	Antegrade	Carotid bifurcation	Minimal working room to bifurcation.
Translumbar		Aorta and its branches	Prone position, limited to arteriography, increased risk of bleeding.

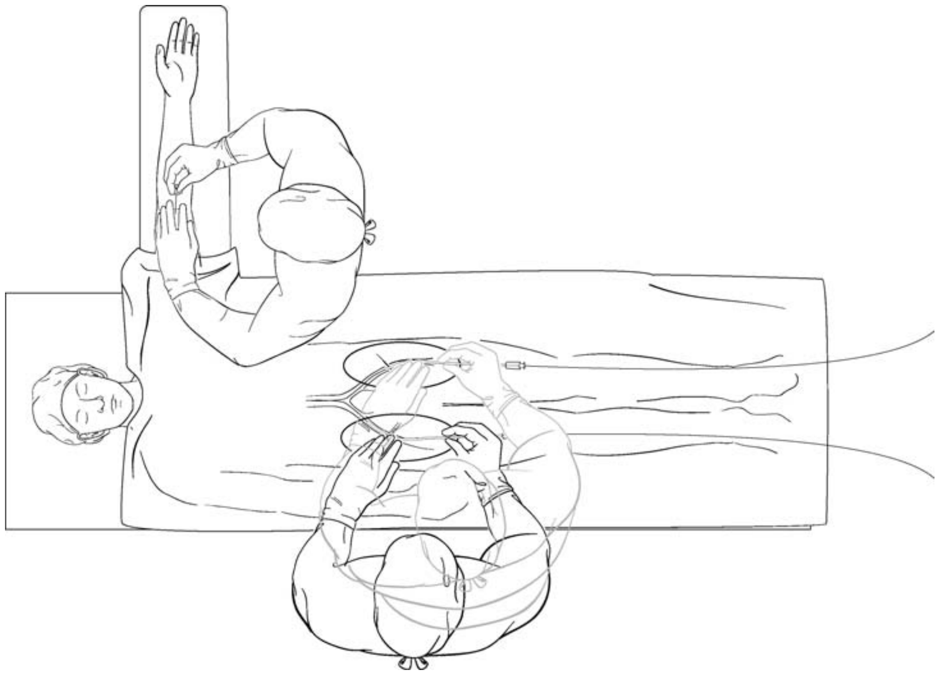


Fig. 1 Working forehand. The operator works forehand whenever possible. In this example, the right-handed surgeon stands on the patient's right side to puncture either femoral artery. Brachial puncture is also performed forehand.

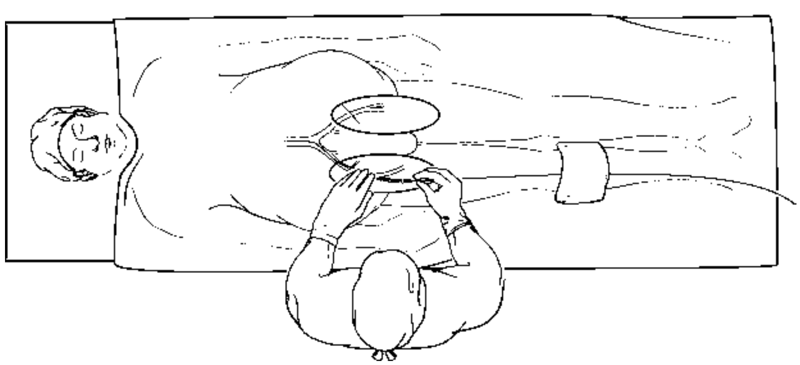


Fig. 2 Identify the anatomic landmarks before arterial puncture. Identification of landmarks for arterial puncture may be challenging in the obese patient. The groin crease is usually substantially distal to the actual inguinal ligament and this must be taken into account when planning femoral access.

guidewire) is placed on the patient's lap. Intravenous antibiotics are administered if the patient has a prosthetic graft or heart valve in place or if an endovascular device implantation is anticipated. The right-handed operator stands on the patient's right side for the puncture of either groin so that the forehand approach can be used (Fig. 3). The femoral artery of choice is palpated and the inguinal ligament is traced from the anterior superior iliac spine to the pubic tubercle. The goal is to puncture the proximal to middle common femoral artery. In most patients this represents a segment 4 to 8 cm in length. The operator must anticipate the trajectory of the needle with an angle of approach of 45 degrees.

The operator uses the nondominant hand to trap the common femoral artery. The right-handed surgeon uses the left hand to trap the common femoral artery between the forefinger and third finger. The third, fourth, and fifth fingers fan out on one side of the artery and the thumb and forefinger on the other side of the artery to hold back the surrounding tissue. Plain lidocaine (1%) is injected into the skin and subcutaneous tissues in the area for the prospective puncture between the forefinger and third finger of the operator's left hand. Infiltration with local anesthetic causes increased transmission of femoral artery pulsation to the surrounding soft tissue, which can be appreciated if the fingers are in the correct location. A 1 to 2 mm stab wound incision is created with a No. 11 blade in the area of the lidocaine injection. A mosquito clamp is used to dilate the puncture site. A No. 18 straight angiographic entry needle is then used to approach the artery at a 45-degree angle. Either a single wall or a double wall puncture needle may be used (Fig. 4). The vessel is usually 2 to 5 cm beneath the skin entry site. The anterior wall of the common femoral artery can usually be palpated with the tip of the needle and identified by the pulsation of the artery against the needle. The needle tip is advanced through the anterior wall of the artery.

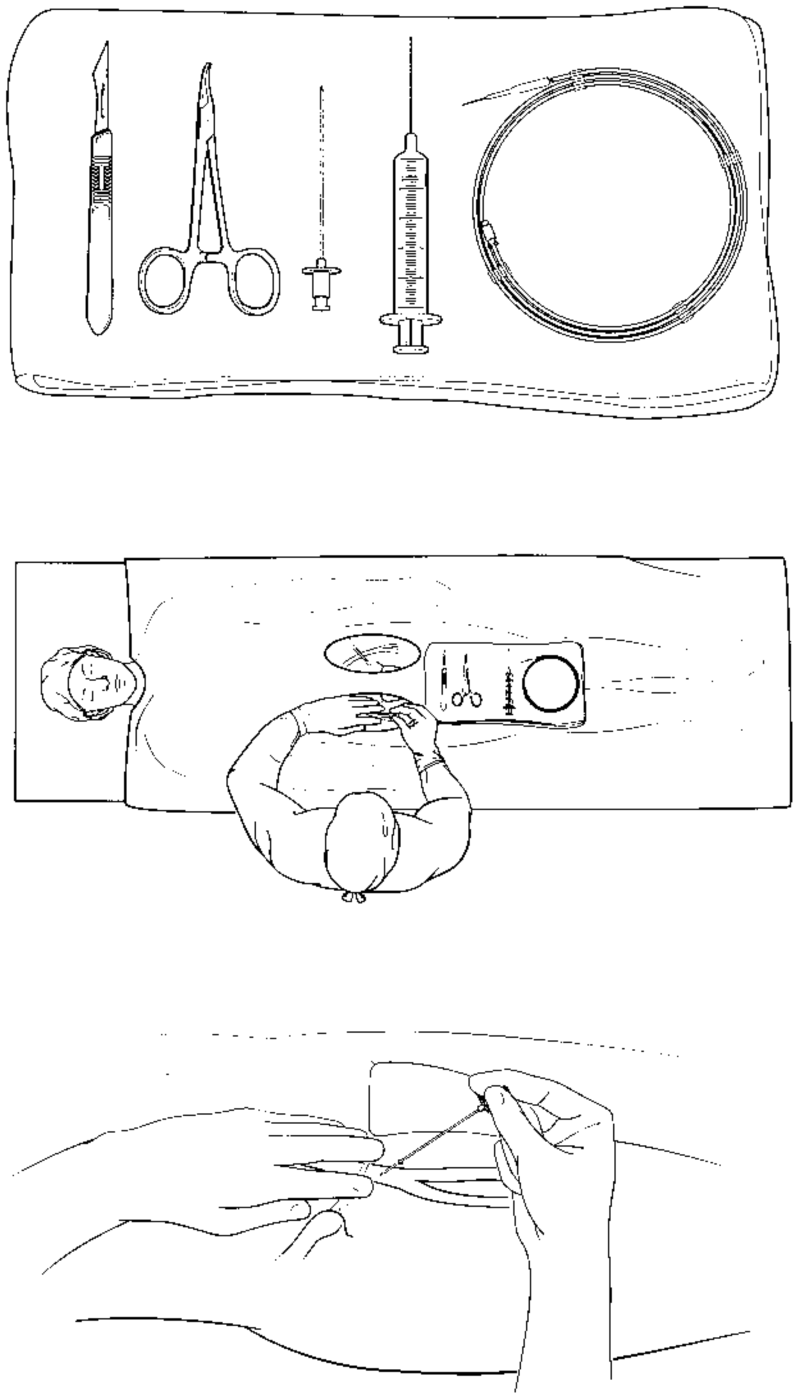
Because the anterior wall is usually softer and the posterior wall more firm, the needle may immediately abut the posterior wall of the common femoral artery. Occasionally the needle must be withdrawn just slightly to allow guidewire passage (Fig. 5).

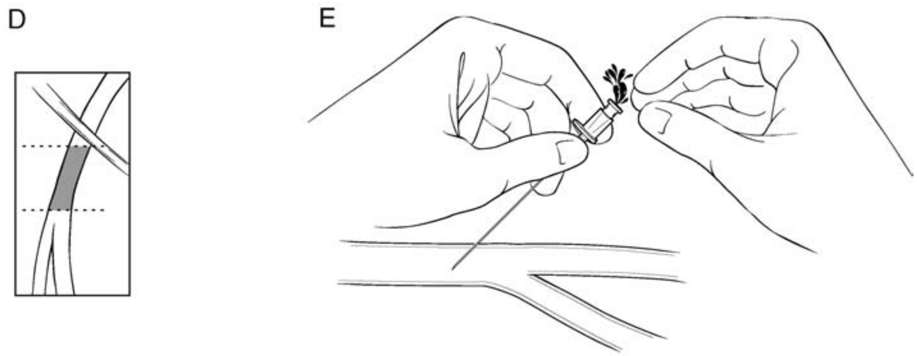
When pulsatile back bleeding is achieved, the operator's nondominant hand is released from its location over the common femoral artery. The nondominant hand is then used to hold the needle and secure back bleeding from the hub until the guidewire can be passed through the needle. The needle is held between the thumb and third finger, and the pad of the forefinger is placed over the hub to prevent back bleeding while the guidewire approaches. The several-centimeter floppy-tip portion of the guidewire is advanced through the needle until the stiffer portion of the guidewire is traversing the arterial entry site. If the lesion is near the puncture site (e.g., distal external iliac artery lesion), fluoroscopy is initiated immediately. The next

A

B

C





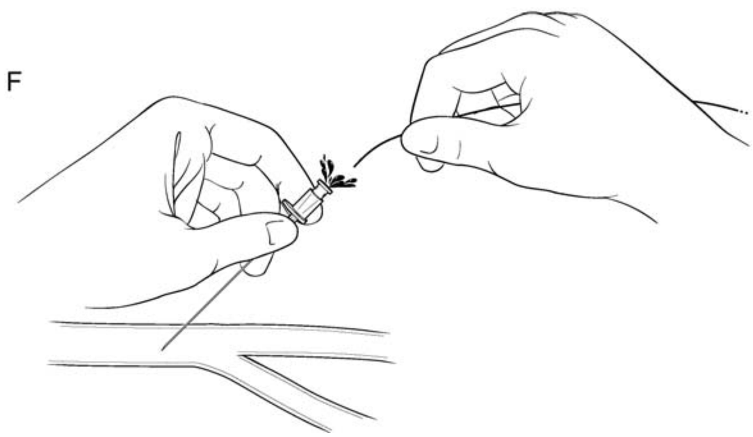


Fig. 3 Percutaneous retrograde puncture of femoral artery. A, A sterile towel is placed on the patient's lap with the tools immediately required for percutaneous arterial entry *(from left to right):* a scalpel, a hemostat, a percutaneous entry needle, a syringe with local anesthetic, and a guidewire. **B,** The right-handed operator stands on the patient's right side for puncture of either femoral artery to permit a forehand approach. If the left femoral artery requires puncture, the operator leans over the patient. **C,** The prospective location of the middle to proximal common femoral artery puncture is evaluated by tracing the inguinal ligament from the anterior superior iliac spine to the pubic tubercle. The artery is trapped between the forefinger and third finger of the operator's nondominant hand. The thumb and forefinger hold back the surrounding soft tissue, as do the third, fourth, and fifth fingers. When local anesthetic is administered into the subcutaneous tissue, the femoral pulse usually becomes more pronounced. The entry needle approaches the artery at a 45-degree angle. **D,** The femoral arteriotomy is safest in the proximal to middle common femoral artery. **E,** When pulsatile backbleeding indicates that the needle tip is in the artery, The nondominant hand is released from its position trapping the artery. The nondominant hand accepts the needle and steadies it. **F,** The dominant hand retrieves the guidewire, straightens the guidewire tip, and inserts it into the needle hub. The guidewire tip may be straightened using the maneuver shown in Fig. 4 of Chapter 3.

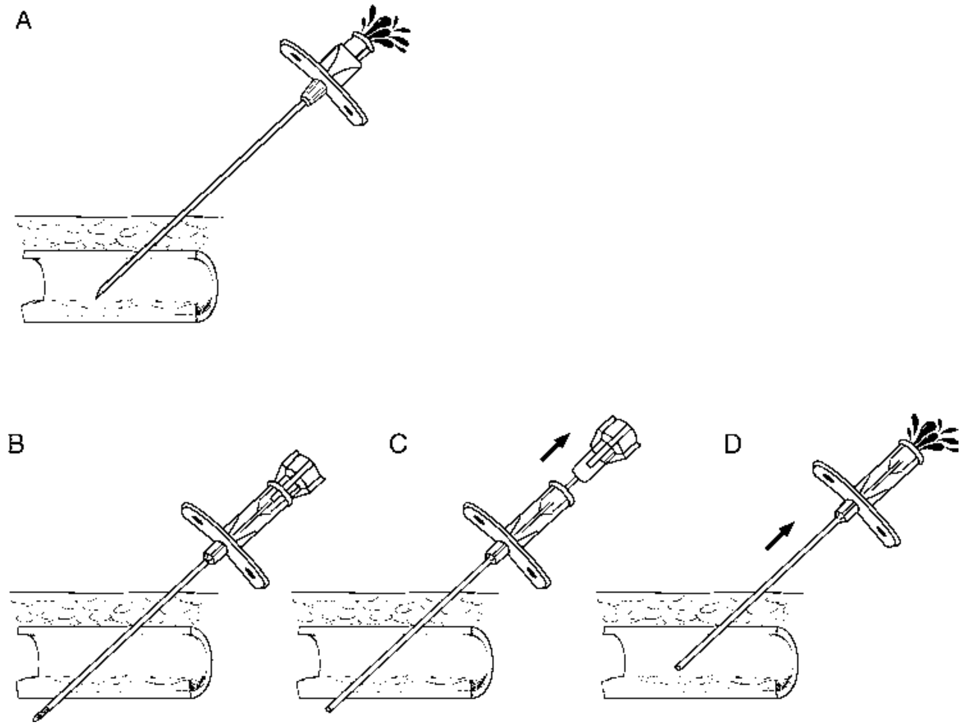


Fig. 4 Single-wall or double-wall puncture technique. A, The single-wall puncture needle has a beveled tip that is placed into the anterior wall of the artery. **B,** The double-wall puncture needle has a trochar with a sharp beveled tip that is inserted through the artery. **C,** The needle is removed. **D,** The blunt tip outer casing is then gradually withdrawn until its tip is in the arterial lumen and pulsatile backbleeding is evident.

steps in guidewire and catheter passage after obtaining percutaneous access are detailed in Chapter 4.

Most puncture site complications are related to arteriotomies that are too high, too low, or forced into an area too hostile for simple puncture (Fig. 6). The anterior wall of the common femoral artery often has a soft spot, even when the femoral artery and its bifurcation are heavily diseased. Puncture of the external iliac artery is difficult to compress and it is surrounded by the potential space of the retroperitoneum (Fig. 7). Hemorrhage from a high puncture of this type often requires surgical control. A covered stent placed at the site of extravasation could also be considered. Unfortunately, a dangerously proximal puncture is often not recognized until after the access is removed and the patient develops pain or vital sign instability. The proximal deep femoral artery is also difficult to compress because of its deep course. The proximal superficial femoral artery is usually calcified and often a site of substantial plaque formation. Puncture site compression at

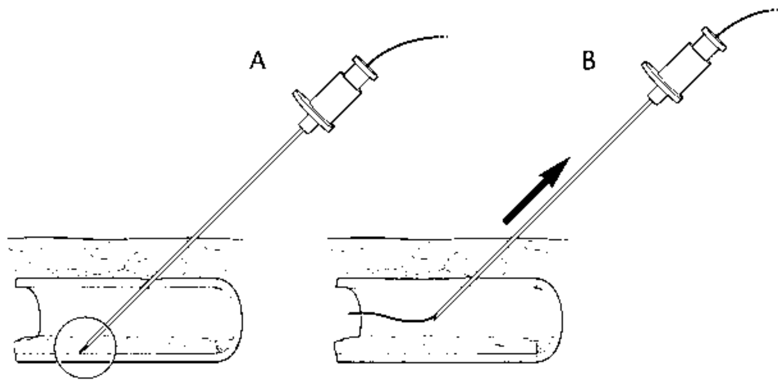


Fig. 5 Guidewire hits posterior wall. The tip of the needle often pushes the softer anterior wall of the common femoral artery against the thicker posterior wall before it enters the lumen. **A,** When the guidewire is advanced through the needle, it hits the posterior wall of the artery and is unable to pass. **B,** The needle is withdrawn 1 to 2 mm and the guidewire is passed again.

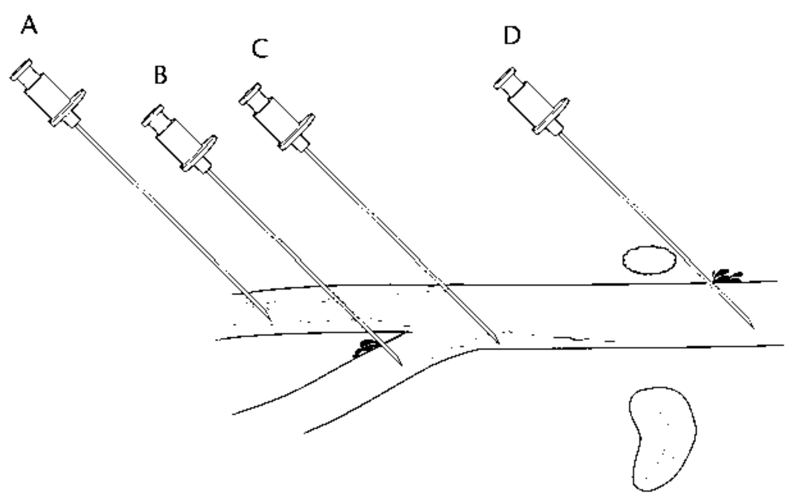


Fig. 6 Incorrect femoral artery punctures. Entry site complications result from poorly placed femoral artery punctures. **A,** Proximal superficial femoral artery puncture is too low and may cause puncture site thrombosis. The proximal superficial femoral artery is frequently the site of significant plaque formation. **B,** A proximal deep femoral artery entry is difficult to compress and may result in hemorrhage. **C,** The needle tip may disrupt posterior wall common femoral artery plaque. This is more likely in proximity to the bifurcation. **D,** Puncture of the distal external iliac artery is contiguous with the retroperitoneal space and is prone to hemorrhage.

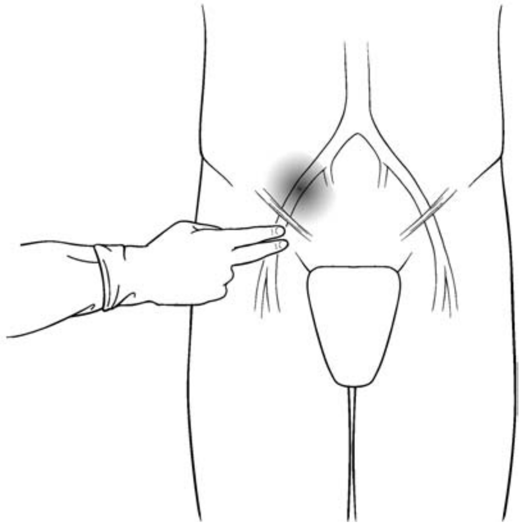


Fig. 7 Retroperitoneal hemorrhage from a proximal groin puncture. A groin puncture that is too far proximal may enter the external iliac artery and cause hemorrhage into the retroperitoneal space. If it is unrecognized, pressure at the skin puncture site, which is somewhat distal to the arterial puncture site, may exacerbate hemorrhage by creating additional outflow resistance downstream from the bleeding arteriotomy, as in the example shown. If the abdominal wall is relaxed, manual pressure can often be held satisfactorily over a distal external iliac artery puncture site with a little extra effort.

the superficial femoral artery origin may cause thrombosis. Since common femoral artery plaque forms preferentially along the posterior wall, double wall puncture confers no advantages and may add some risk. Double wall puncture should always be avoided if thrombolytic therapy is a possibility.

PLAN OF ATTACK: Guidewire Won't Pass Through the Needle

1. If the tip of the entry needle is against the posterior wall of the artery, withdraw the needle 1 to 2 mm very slowly while gently attempting to pass the guidewire (Fig. 5).
2. If the guidewire encounters a common femoral artery lesion, irregular posterior wall plaque may be disrupted, form a dissection plane, or embolize. Don't force the guidewire.
3. Withdraw the guidewire to ensure that the needle tip is still intra-arterial and that backbleeding is pulsatile.
4. Establish that arterial return is consistent with the clinical impression of inflow to that level (e.g., dampened arterial inflow should be expected if the patient has aortoiliac disease on physical examination).

5. Reinsert the guidewire and use fluoroscopy to see where the guidewire hangs up. Sometimes it goes just beyond the needle tip and into a medial or lateral collateral.
6. Try a smaller-diameter guidewire (e.g., 0.025 in. rather than the standard 0.035 in.).
7. If there is appropriate blood return from the needle, puff contrast while under fluoroscopy or use road mapping. Visualize the puncture site and the cause of the obstruction.
8. Consider a new puncture at the same location or a different approach altogether.
9. The needle may be too low and hitting femoral bifurcation plaque. Pull the needle, and hold pressure at the arterial puncture site. Repeat the puncture 1 to 2 cm more proximally along the common femoral artery.

Percutaneous Antegrade Puncture of Femoral Artery

Antegrade femoral access permits optimal control of guidewires and catheters for infrainguinal endovascular intervention. The puncture in the skin must be proximal to the inguinal ligament to allow entry of the needle into the proximal to middle common femoral artery, taking into account a 45-degree angle of approach (Fig. 8). A high puncture in the distal external iliac artery may result in hemorrhage. A distal puncture, which is too near the femoral bifurcation, results in inadequate working room to selectively catheterize the origin of the superficial femoral artery.

In patients with a large abdominal pannus, wide silk adhesive tape is used as a truss to hold the pannus back or an assistant provides pannus control. A huge pannus is a relative contraindication to the antegrade approach. Once the guidewire is in place, the assistant may be excused if the pannus has been at least partially taped away from the operative field.

The right-handed operator stands on the patient's left side for forehand delivery of the needle and guidewire. The image intensifier should hover over the patient from the side opposite the operator. This arrangement may be a problem in an angiographic suite where the C-arm unit is mounted on ceiling rails or on the floor. The left or nondominant hand is used to trap the common femoral artery between the forefinger and the third finger in the same way as for a retrograde femoral artery puncture. The proposed arterial puncture site is visualized in juxtaposition to the location of the inguinal ligament. The skin puncture site is then chosen and infiltrated with 1% plain lidocaine. A 1 to 2 mm skin incision is created with a No. 11 blade and dilated with a mosquito clamp. The angiographic entry needle is advanced at an angle of 45 degrees toward the pulse, which

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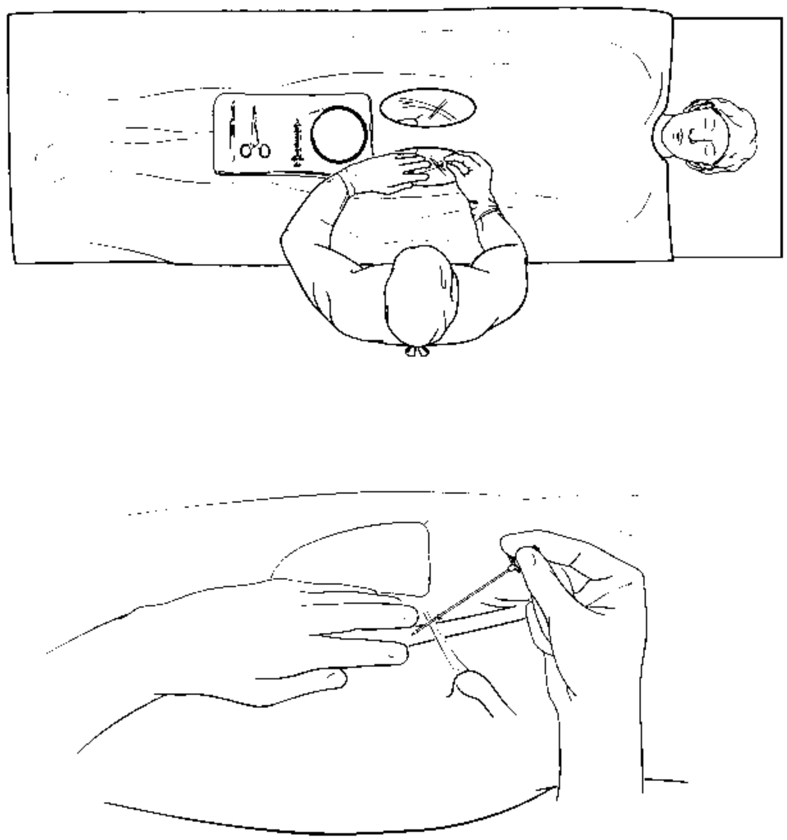
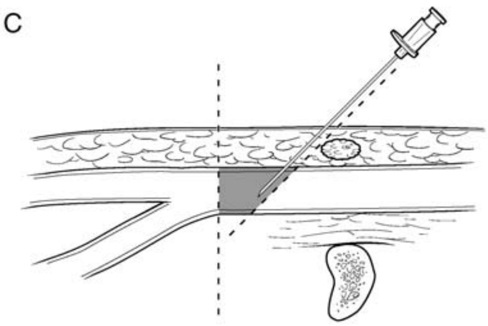


Fig. 8 Percutaneous antegrade puncture of femoral artery. A, The right-handed operator stands on the patient's left side to permit a forehand approach, and a towel is placed on the patient's lap with the tools needed for arterial puncture. **B,** The common femoral artery is trapped between the forefinger and third finger of the nondominant hand. The intended arterial puncture site is at the proximal to middle common femoral artery with the needle approach at 45 degrees. The skin puncture site is proximal to the inguinal ligament. **C,** The common femoral artery available for antegrade puncture is limited. Puncture above the inguinal ligament must be avoided because of the risk of hemorrhage. Puncture near the common femoral artery bifurcation leaves inadequate working room for cannulation of the superficial femoral artery. **D,** After the needle tip enters the artery, the position of the nondominant hand is modified to hold the needle rather than trap the artery. The forefinger is placed over the hub to stop backbleeding, and the guidewire is advanced with the dominant hand.



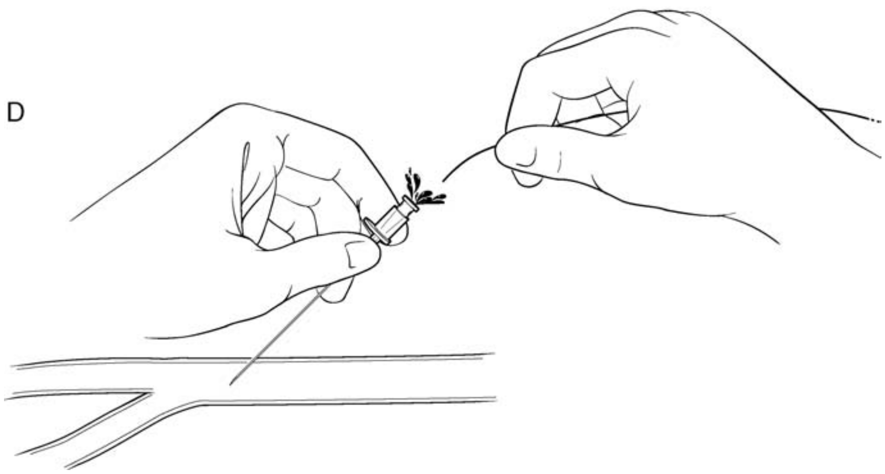


Fig. 8 (Continued)

is trapped between the forefinger and third finger. When pulsatile back bleeding is achieved, the needle is held steady by the dominant hand momentarily. The nondominant hand position over the artery is relinquished. The nondominant hand rests on the patient on its ulnar side and takes over the needle in its intra-arterial position. The dominant hand reaches for the guidewire and inserts the guidewire into the needle hub. The guidewire is advanced with the dominant hand.

Since the superficial femoral artery is on the level plane and the deep femoral artery proceeds posteriorly from the bifurcation, the guidewire usually enters the deep artery preferentially following antegrade puncture. The guidewire must be redirected into the origin of the superficial femoral artery (see Chapter 6 for a detailed discussion of selective catheterization). Working distance between the antegrade puncture site in the common femoral artery and the femoral artery bifurcation is limited. Any previously performed arteriography should be assessed to determine the level of the femoral bifurcation. Even if only contralateral lower extremity films are available, evidence of an unusually high femoral bifurcation may alter puncture site choice. Prior to performing antegrade femoral artery puncture, any previous arteriograms should be checked for the location of the deep femoral artery origin and the length of the common femoral artery. Duplex evaluation and marking of the common femoral artery bifurcation may also be performed before proceeding with antegrade puncture.

Percutaneous Puncture of Pulseless Femoral Artery

The clinical situation that requires puncture of a pulseless femoral artery usually includes plans for iliac artery reconstruction or recanalization, rather than simple arteriography. Aortoiliac duplex scanning is valuable in this setting to assess the severity, location, and length of the lesion. The location of the femoral artery is marked after duplex evaluation. The patent but pulseless femoral artery is cannulated using a combination of several techniques (Fig. 9). The artery itself is often palpable, even when there is no

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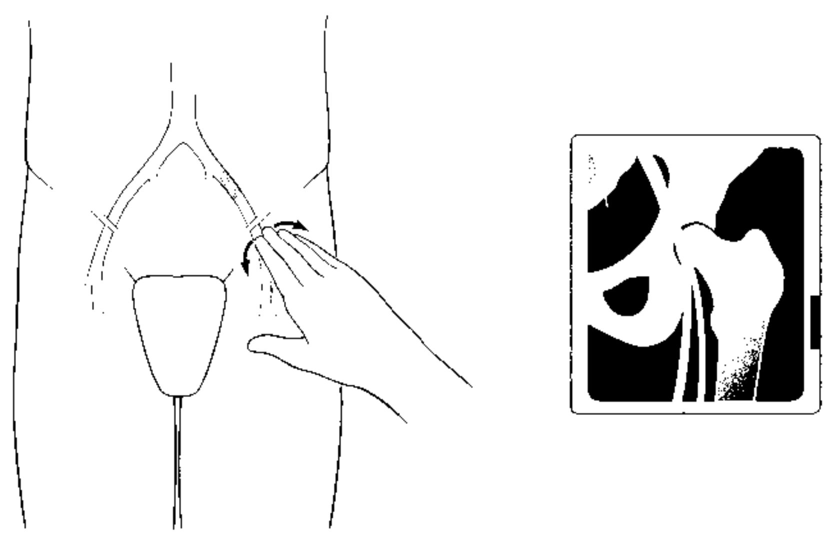

B

Fig. 9 Percutaneous puncture of pulseless femoral artery. A, The patent but pulseless femoral artery can often be palpated. **B,** A review of previous arteriograms shows the location of the artery relative to the femoral head. It usually passes over the medial half of the femoral head. **C,** Fluoroscopy may reveal vascular calcification and help guide puncture. **D,** An arteriographic catheter placed through another entry site (either contralateral femoral or proximal approach) can be used to administer contrast and road map the location of the artery. Puncture of the pulseless artery is performed using the road map as the guide.

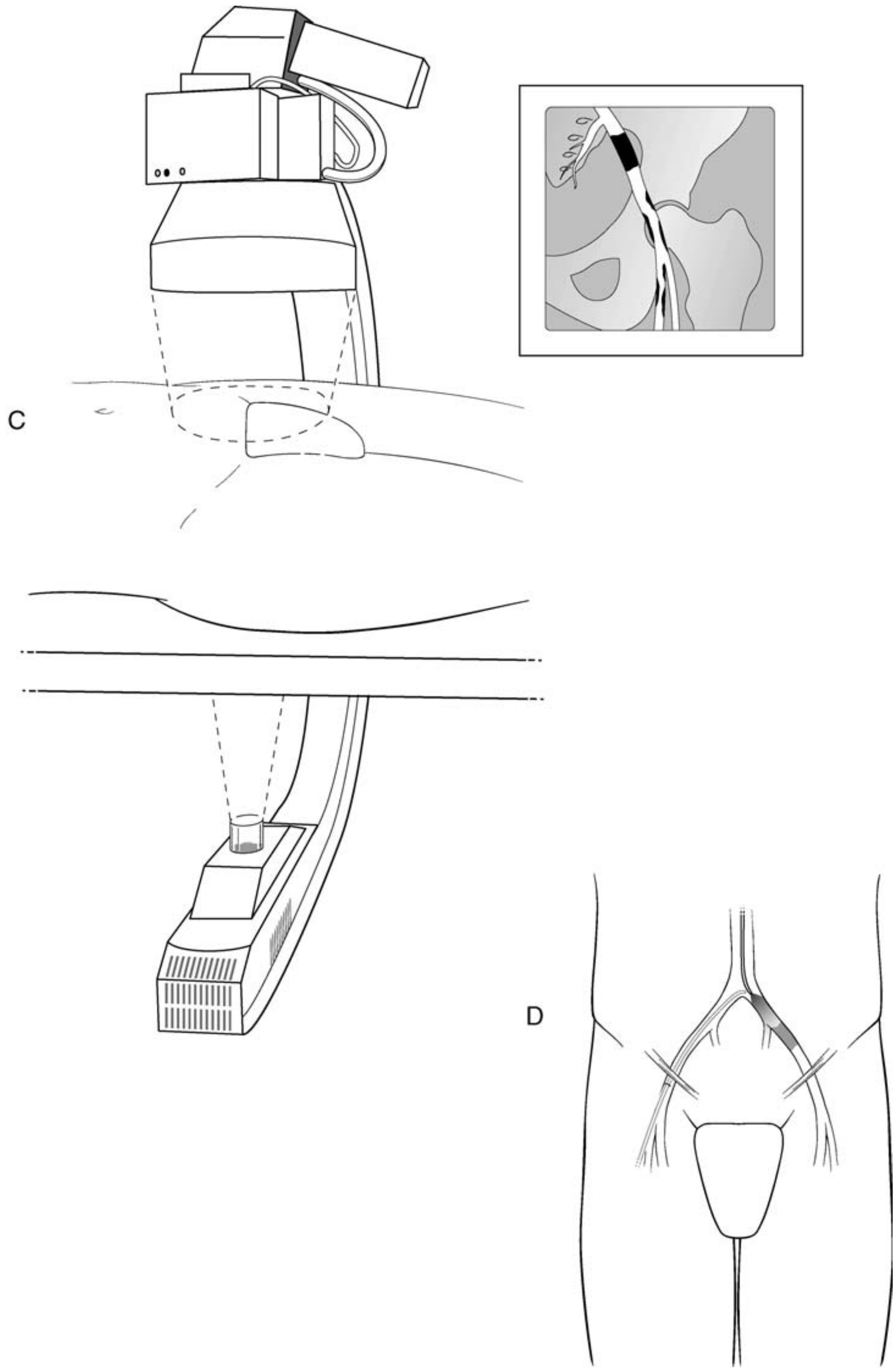

Fig. 9 (Continued)

pulse. The common femoral artery almost always passes over the medial half of the femoral head. Its location may be revealed by a previous arteriogram or is identifiable by vascular calcification using fluoroscopy. A blood pressure cuff placed on the ipsilateral thigh can increase peripheral resistance and enhance a diminished pulse. A catheter can be placed through another access site, either on the contralateral side or proximal, and contrast can be injected to road map the femoral artery. Delayed filming is required.

Micropuncture Technique

A coaxial micropuncture set (Cook, Inc., Bloomington, Ind.) includes a 21-gauge needle to enter the artery, a 0.018-in. guidewire with a floppy tip, a 4 Fr short catheter with an inner smaller diameter dilator that passes over the 0.018-in. guidewire (Fig. 10).

The 21-gauge needle is placed in the artery. When backbleeding occurs, the floppy tipped 0.018 in guidewire is advanced through the needle under fluoroscopic guidance. Arterial backbleeding through a 21-gauge needle is usually much less pulsatile than through the usual, larger 18-gauge needle. The needle is removed and the 4 Fr short catheter with the 3 Fr inner dilator is passed over the guidewire. After the catheter is in place, the dilator and guidewire may be removed. The 4 Fr catheter is flushed with heparinized saline and a longer, appropriately sized guidewire (usually 0.035-in. diameter) is passed. The short 4 Fr catheter is removed and the desired 4 or 5 Fr catheter is passed. A well-performed direct puncture of the axillary or brachial artery decreases the likelihood of subfascial hematoma or neuropathy.

Proximal Access

Most arteriography and endovascular procedures are performed through the femoral arteries. When this is not possible, proximal access is the next best option. Proximal access may be secured through percutaneous or open approaches to the brachial or axillary arteries (Fig. 11). There are several disadvantages to a proximal approach. Although percutaneous puncture can be safely performed, the complication rate is higher and the complications are generally worse when they occur. The arteries of the upper extremity are smaller, less forgiving, and more prone to spasm than arteries of the lower extremity. A constrictive fascial sheath encircles the artery and nerves in the upper arm, and a small hematoma may be enough to cause a brachial plexopathy. Passage of larger endovascular devices for performance of procedures any more complex than arteriography is accompanied by a proportionately greater risk of puncture site complications. The extra distance from the proximal access site to the infrarenal vasculature requires

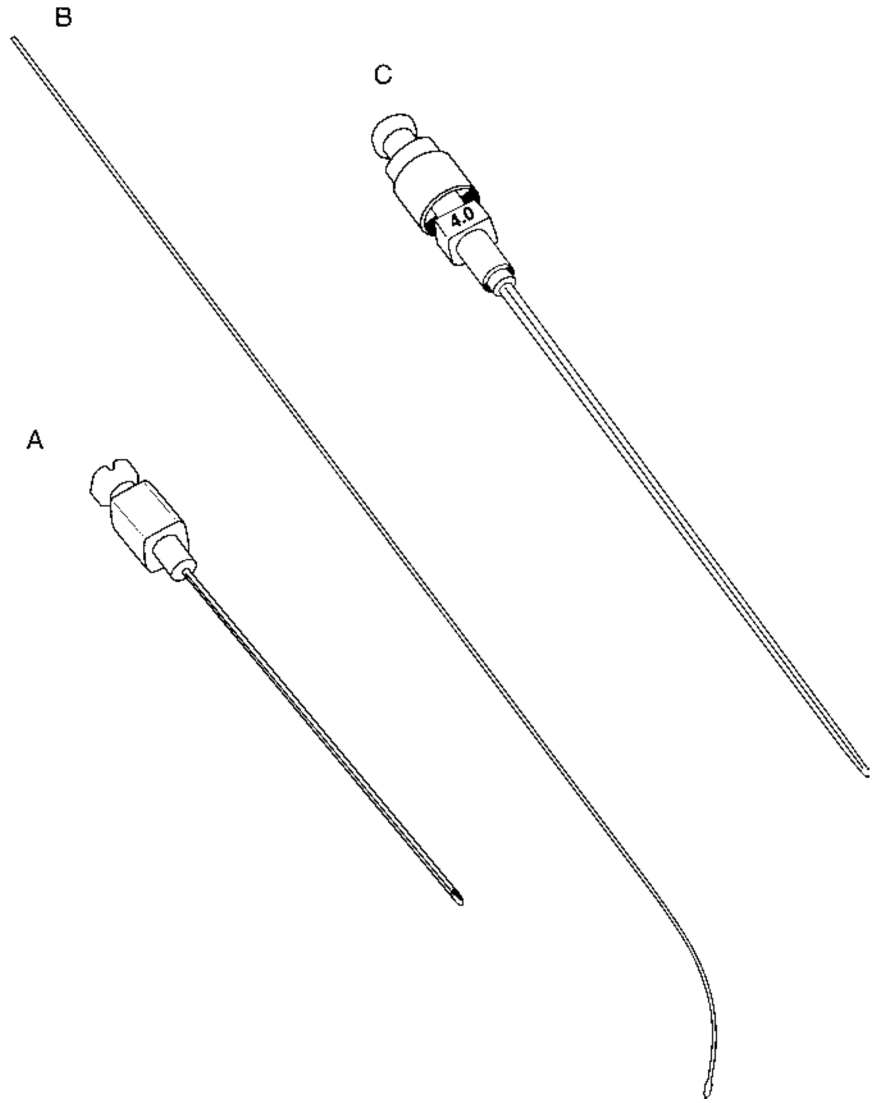

Fig. 10 The micropuncture set (Cook, Inc. Bloomington, Ind.) includes **A,** a 21-gauge needle, **B,** a 0.018-in. floppy tip guidewire, and **C,** a 4 Fr short catheter with an inner 3 Fr trochar to slide over the low profile guidewire.

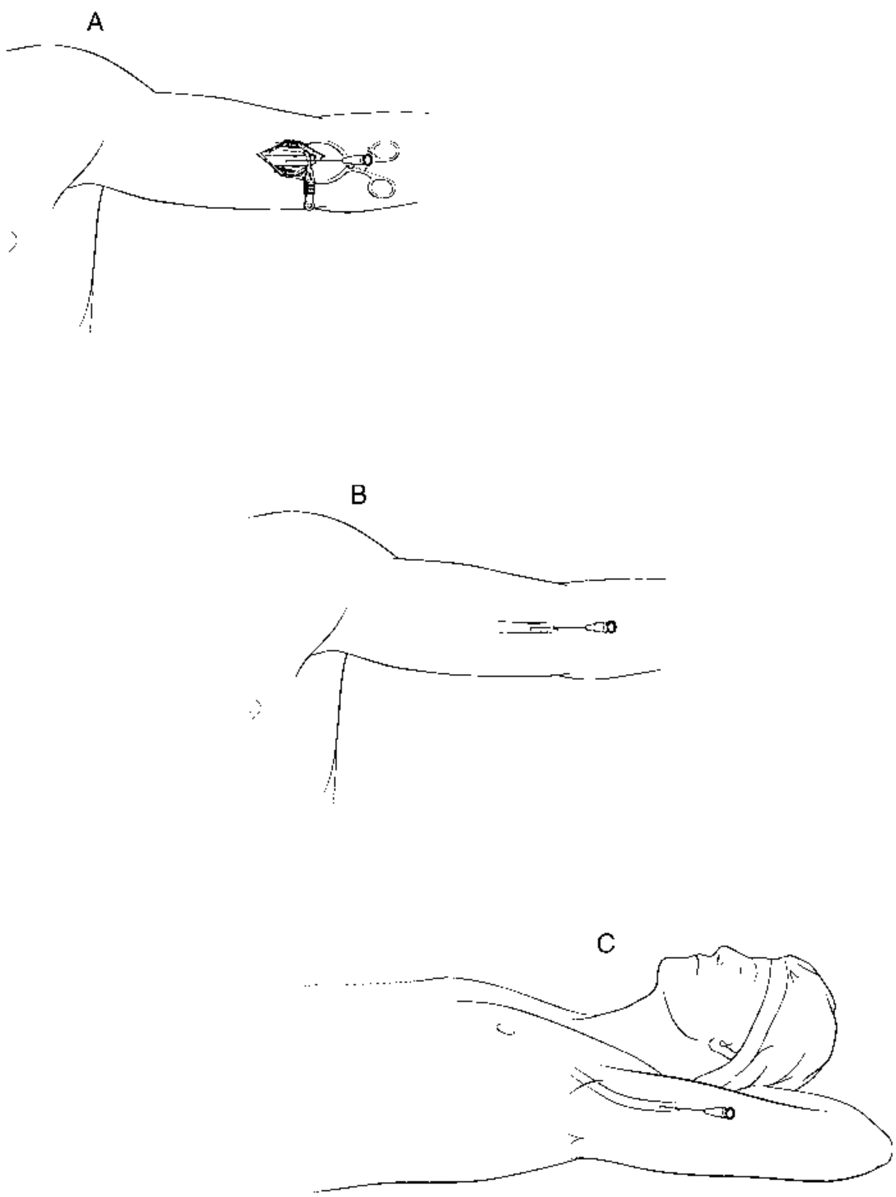

Fig. 11 Proximal access. Brachial or axillary artery entry is usually performed on the left side. **A,** Brachial artery cutdown is performed just proximal to the antecubital crease. **B,** Brachial artery puncture may be performed at the same location (see Fig. 2–12). **C,** Axillary artery puncture (as it is commonly labeled) is performed just lateral to the axilla and is actually a high brachial artery puncture.

longer guidewires and catheters that are more cumbersome and less responsive to manipulation.

Percutaneous Puncture of Brachial Artery

The most common location for brachial artery puncture is just proximal to the antecubital crease. The left side is the first choice since the carotid artery origin may be avoided. In average-sized patients, sheaths up to 6 Fr may be placed without major risk of puncture site hemorrhage or thrombosis. Open access should be considered for larger devices or in smaller individuals.

The patient's arm is abducted and placed on an armboard (Fig. 12). A circumferential preparation of the arm is performed. The brachial artery pulse is palpated just proximal to the antecubital crease where the bicep has generally thinned to its tendinous portion. The artery is trapped between the forefinger and third finger of the nondominant hand. The tips of the two fingers are held at enough distance to allow the artery to pass underneath without compressing it significantly. The 21-gauge micropuncture needle is advanced at a 45-degree angle by the dominant hand. The goal is for the needle tip to enter the anterior wall of the artery in the space between the two fingers. When backbleeding occurs, the short 0.018-in.-diameter guidewire is passed. Backbleeding through the micropuncture needle is usually not pulsatile because of its small caliber. The needle must be moved and manipulated slowly and any backbleeding carefully assessed. Heparin is administered to prevent thrombosis. Intra-arterial nitroglycerine or papaverine may be required if spasm of the upper extremity arteries occurs.

Percutaneous Puncture of Prosthetic Grafts

Substantial scar tissue may surround a prosthetic graft, especially in an area where an extensive open arterial exposure was performed. This is most common in the femoral area. Antibiotics are administered prior to puncture. Positioning of the patient is the same as for standard, retrograde femoral artery puncture. The position of needle entry should be proximal to the anastomosis with the native artery so that anastomotic sutures and/or thrombi are not disrupted. Dacron grafts have a tightly knitted fabric matrix that may be challenging to puncture. Considerable force may be required to push the needle through the anterior wall of the prosthetic graft. Care should be taken to avoid pushing the needle through the back wall of the graft, especially if the graft is not yet well incorporated. Once the needle is in place, a steel starter guidewire should be used to enter the artery. Slight enlargement of the tract with a 4 or 5 Fr dilator is usually advisable before attempting to pass the catheter. If the scar tissue prevents advance of the dilator, place the guidewire well inside the vasculature and have the

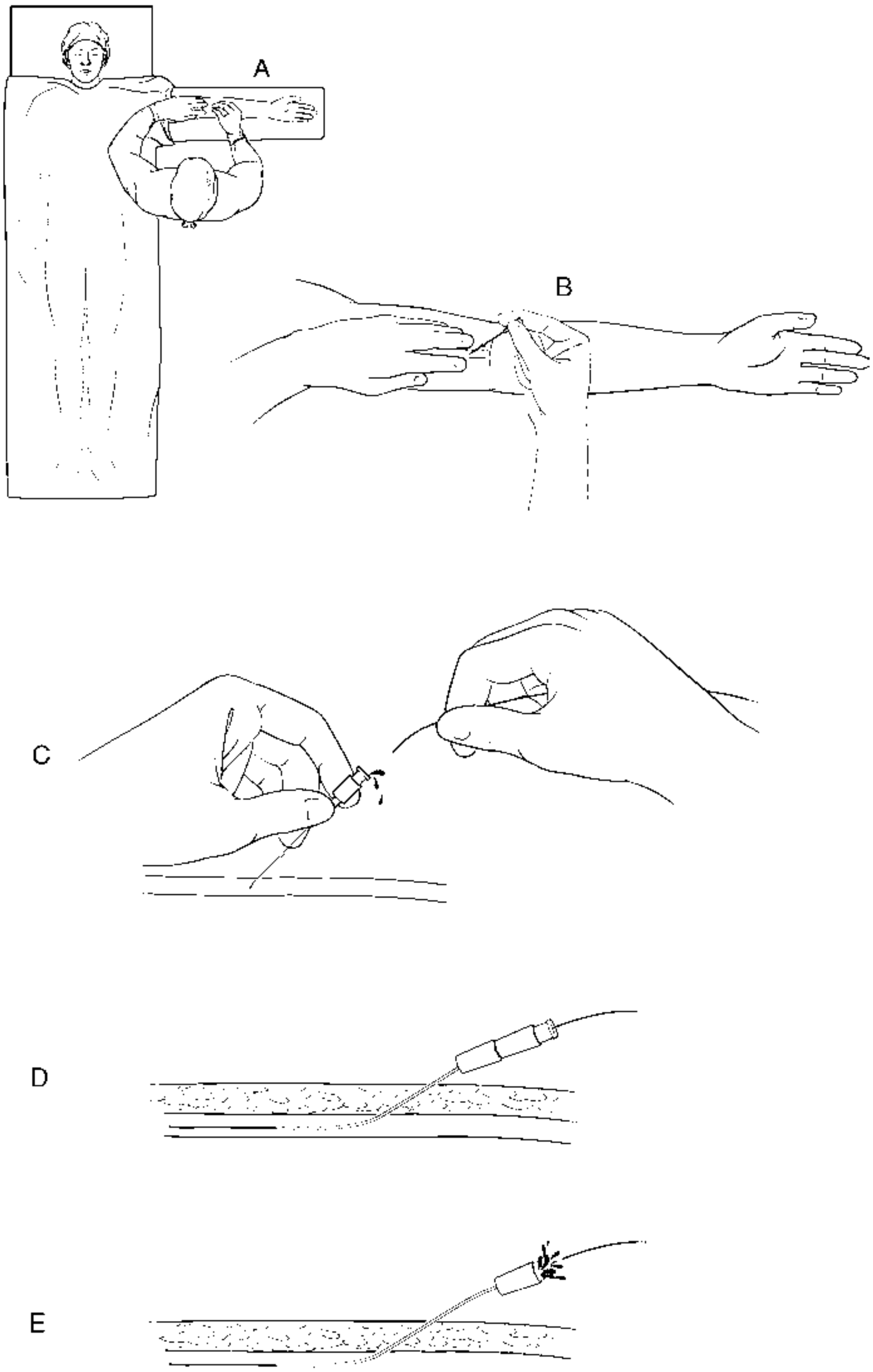
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Table 2 Complications of Femoral Artery Puncture and Catheterization

Complication	Frequency (%)[a]	SCVIR complication threshold (%)[b]
Minor bleeding or hematoma	6.0–10.0	
Major bleeding or hematoma (requiring transfusion, surgery, or delayed discharge)	1.0–2.4	3.0
Pseudoaneurysm	0.5–5.0	0.5
Arteriovenous fistula	0.01–0.1	0.1
Occlusion (thrombosis or dissection)	0.3–1.0	0.5
Perforation	<0.5	
Distal embolization	<0.5	
Infection	<0.1	

[a] From Valji, 1999, and Brown et al., 1997.
[b] From Spies et al., 1993.

assistant gently and gradually withdraw the guidewire as the operator advances the catheter. Occasionally, a larger-diameter (6 Fr), but stiffer, dilator will be required to follow the guidewire.

Percutaneous puncture may also be performed on a prosthetic graft that is immediately subcutaneous. The most common situation that calls for this is evaluation of a dialysis access graft. Occasionally, an axillofemoral, femoral–femoral or infrainguinal bypass graft requires direct puncture. Local anesthetic is injected into the skin and subcutaneous tissue over the graft. No skin incision is made. The needle tip is used to puncture the skin and to travel several millimeters in the subcutaneous tissue parallel to the graft. The needle hub is then tipped away from the skin so that the needle is at a 45-degree angle to the graft. The tip of the needle is then inserted into the graft. This maneuver creates a short subcutaneous tract that will help protect the graft from infection. The needle should be introduced at 45 degrees or more to avoid a larger, oval-shaped, or skiving type of puncture site hole in the graft, which may be more difficult to control. After the guidewire is placed, introduce the smallest-caliber catheter that is adequate for the

Fig. 12 Percutaneous puncture of brachial artery. Percutaneous puncture of the brachial artery should be considered for interventions requiring a sheath of 6 Fr or less. **A,** The left arm is fully abducted. **B,** The brachial artery is trapped between the forefinger and third finger just proximal to the antecubital crease. A 21-gauge micropuncture needle is advanced into the artery. **C,** A 0.018-in. guidewire is advanced through the needle. **D,** A coaxial dilator system is advanced over the guidewire. The inner dilator and the guidewire are removed and exchanged for a 0.035-in. guidewire that passes through the remaining (5 Fr) outer dilator. **E,** After the 0.018-in. guidewire and the inner 3 Fr trochar are removed, the 4 Fr catheter may be used to introduce the desired guidewire for the case.

Table 3 Comparison of Puncture Site Options

Puncture	Usefulness	Technical difficulty	Overall risk of significant complication[a]	Comments
Retrograde femoral	Most useful	Simplest	1.7%	More than 90% of cases may be performed transfemorally. It is the simplest and has the lowest complication rate.
Antegrade femoral	Useful for ipsilateral infrainguinal arteriogram or intervention	Entering the origin of the SFA can be challenging		A relatively safe but challenging approach. Especially useful for infrainguinal catheterization in patients who have a contraindication to crossing the aortic bifurcation.
Axillary	When femoral access not possible, provides alternative access for arteriography but not intervention	Challenging, blind stick	3.3%	Larger than brachial artery but also deeper. Less useful for intervention since it is difficult for patient to keep arm fully abducted with hand behind head for extended period of time.
Brachial	Useful for arteriography and/or intervention when femoral access not possible	More challenging than femoral puncture but simpler than axillary	7.0%	Smaller artery with tighter neurovascular sheath. Higher risk of of neurologic complications or distal/hand ischemia. Consider open exposure for sheath $\geq$ 6 Fr.
Previously placed graft	Useful in patients whose anatomy is altered by previous surgical reconstruction	Perigraft scar tissue can make catheter passage difficult		Administer prophylactic antibiotics if graft is prosthetic.

[a] From La Berge et al., 2000.

intended purpose. Since these puncture sites are usually away from anastomoses, they are less subject to extensive scarring around the graft.

Puncture with Ultrasound

Assistance with a difficult access can usually be obtained using ultrasound. Evaluating the vascular sheath in cross section (transverse), the vein is larger, thin-walled, and compressible while the artery is smaller in caliber, thick-walled, and pulsatile.

Puncture Site Complications

Complications of arterial puncture are listed in Table 2. The rates presented were accumulated using various techniques but do not include those who have undergone closure procedures at the puncture sites.

Summary of Puncture Site Options

Puncture site options and their relative rates of risk are summarized in Table 3. The retrograde femoral puncture is by far the most common and the most useful approach. Antegrade femoral puncture is limited in its use to the ipsilateral infrainguinal arteries. Proximal puncture sites in the brachial or axillary arteries are used when there is no adequate femoral puncture site.

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3

Guidewire–Catheter Skills

Guidewire–Catheter Skills Are the Basis of Endovascular Surgery
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Guidewire–Cathether Skills Are the Basis of Endovascular Surgery

Guidewires and catheters comprise the foundation of endovascular intervention, both technically and conceptually. Guidewire–catheter skills are not necessarily intuitive but must be developed. Once acquired, these skills permit a different way of considering and treating vascular problems. Guidewires and catheters are useless without each other. However, the guidewire–catheter apparatus plays a role similar to that of the arterial clamp. It provides control and permits access to the vasculature. Although understanding the various types of guidewires and catheters is important, the specific function of each does not ring true until the clinician handles the apparatus and puts it to use. Although there are many correct choices, the wrong choice of a guidewire–catheter apparatus may become painfully obvious, often at the worst time, and may threaten the success of the procedure.

Mastering Guidewires

Guidewires are the simplest tool available in the vascular specialist's workshop. Yet, nothing can happen without them. Mastering guidewires involves developing facility and understanding in guidewire choices, guidewire-handling techniques, and guidewire–lesion interactions.

Guidewire choices. Successful guidewire deployment requires a knowledge of choices. The goal is to choose the most appropriate guidewire first as often as possible and to know what to do next if the first choice turns out to be a bust. There are a full range of guidewires available. Rather than use them all, most vascular specialists develop a quiver of guidewires, that works for them in most situations.

Guidewire-handling techniques. Mastering the use of guidewires requires learning specific maneuvers. The facility and speed with which the specialist manipulates guidewires often determines the pace and success of the case.

Guidewire–lesion interactions. An essential step in the process of mastering guidewires is to understand the interaction between the guidewire's leading edge and the lesion with fluoroscopic imaging as the intermediary (Fig. 1). Observation of guidewire behavior in vivo requires patience. As the operator gains experience, the guidewire–lesion interaction becomes more predictable. A large proportion of guidewire–lesion interactions are predictable. The interactions that are not

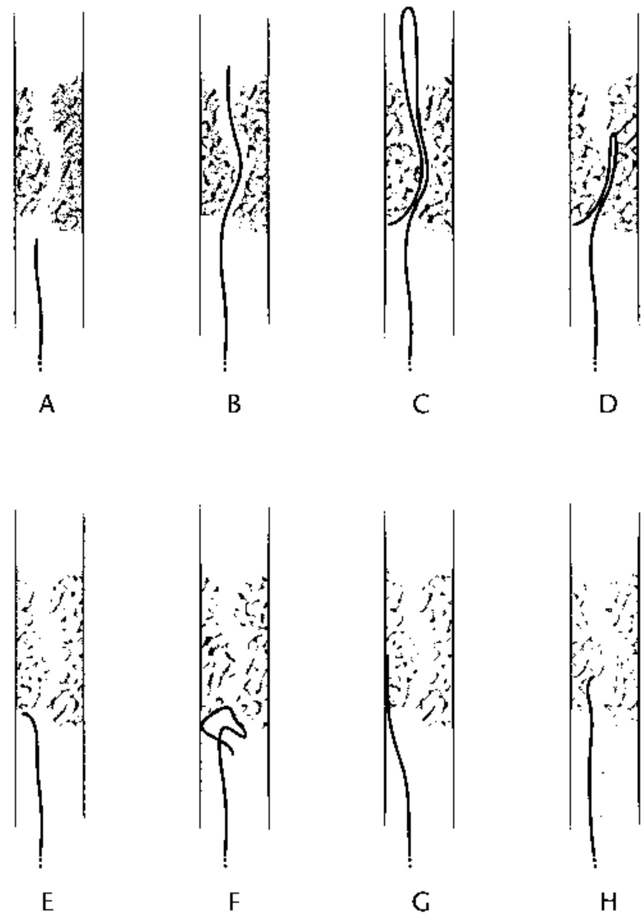

Fig. 1 Guidewire–lesion interactions. Several possible outcomes may result from interaction between the tip of the guidewire and an occlusive lesion. **A,** A guidewire tip approaches a lesion. **B,** The guidewire traverses the lesion on its first pass. **C,** The guidewire's leading edge catches on the proximal end of the stenosis. The floppy tip buckles allowing an elbow of guidewire to traverse the lesion. **D,** The floppy tip begins to buckle but catches on a ledge of plaque and is unable to cross the lesion. **E,** The guidewire tip hits plaque and is unable to find the eccentric lumen. **F,** The guidewire piles up proximal to the lesion. **G,** The guidewire finds a subintimal plane. **H,** The guidewire disrupts plaque, which results in embolization of atherosclerotic material.

predictable usually occur because the fluoroscopic image provides a two-dimensional image of a three-dimensional process. These situations occasionally require a second or third choice of guidewire and use of selective catheters.

What Makes Guidewires Different from Each Other?

Basic construction affects handling characteristics and makes each guidewire unique. Guidewires differ with respect to length, diameter, stiffness, coating, tip shape, and special features.

LENGTH

The operator must be certain that guidewire length is adequate to cover the cumulative distance required, both inside and outside the patient. The length inside the patient includes the distance from the access site to well beyond the lesion, so that access across the lesion will not be lost during the procedure. The length outside the patient includes the distance required to support the longest catheter intended for usage (most are between 65 and 130 cm in length) and permit the guidewire to extend beyond the catheter so that hand control of the guidewire is always maintained (Fig. 2). Guidewire lengths vary from 145 to 300 cm.

DIAMETER

Vascular catheters are designed with a guidewire port of a specific diameter, and the diameter of the chosen guidewire must reflect this specification. Most procedures can be performed with guidewires that are 0.035 in. in diameter, referred to as O35 guidewires. Large devices, such as aortic stent-graft carriers, may require 0.038-in. guidewires. Small-caliber angioplasty may be performed with 0.018- or 0.014-in. guidewires.

STIFFNESS

Most guidewires have a tightly wound inner steel core that confers differing magnitudes of stiffness on the body of the guidewire. A surrounding wrap of lighter, more flexible wire helps prevent fracture and fragmentation while the guidewire is in use.

COATING

The coefficient of friction is reduced by coating the guidewire with a layer of Teflon or silicone.

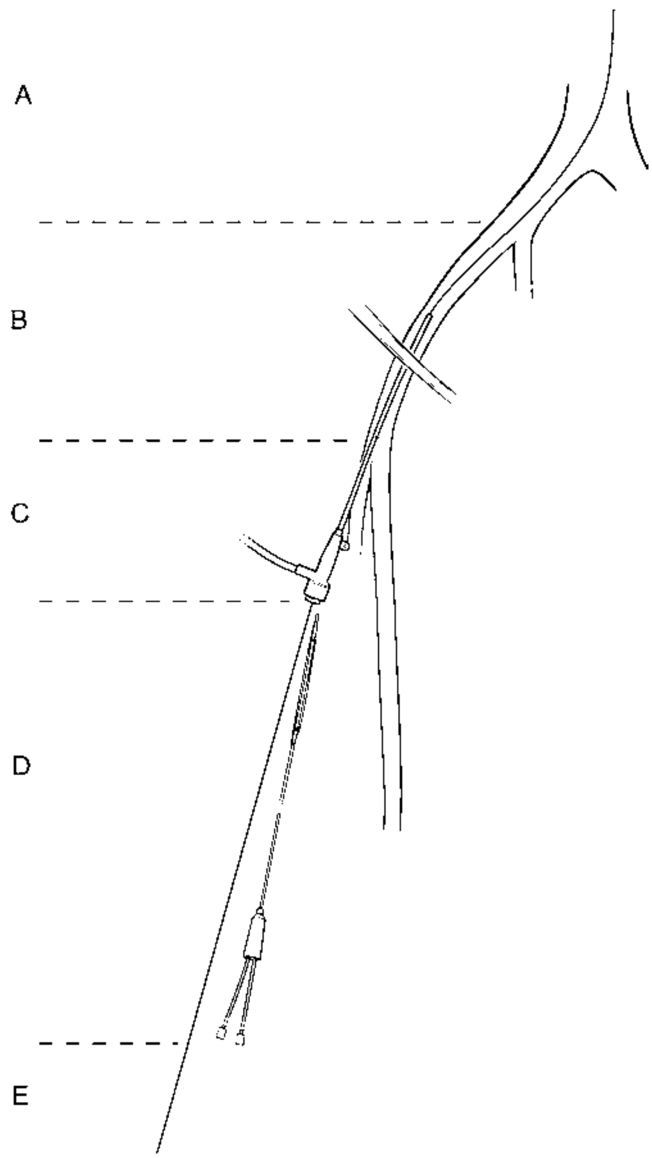

Fig. 2 Guidewire length requirements. Guidewire length requirements are represented in diagrammatic form. The length of guidewire required includes **A,** the distance beyond the lesion to secure access across the intended site of intervention, **B,** the distance from the arterial access site to the lesion, **C,** the distance from the hub of the sheath to the puncture site, **D,** the length of the catheter intended for use, and **E,** the length of guidewire beyond the end of the catheter so that hand control may be maintained.

Table 1 Guidewires for General Endovascular Practice

Guidewire type	Guidewire	Function	Features	Length (cm)	Diameter (in.)	Comments
Starting	Bentson[a]	General use, start the case.	20-cm flexible tip, 6-cm distal floppy segment, straight, standard steel, TFE-coated.	145, 180	0.035	Inexpensive, widely useful, good way to start the case.
	Newton[a]	General use, start the case.	10–15 cm flexible tip, 0–15 mm J-curved tip, standard steel, TFE coated.	145, 180	0.035	
Selective	Wholey[b]	Selective catheterization.	Floppy tip, shapeable curve, standard steel, steerable.	150	0.035	Useful for catheterizing the superficial femoral artery after antegrade femoral approach.
	Glidewire[c]	Crossing critical lesions, selective catheterization.	Angled-tip, hydrophilic coating, steerable, regular or stiff shaft.	150, 180, 260	0.018, 0.025, 0.035	Best choice for most selective catheterizations and crossing critical lesions. Once across a lesion or a branch it does not provide much support.

Exchange	Rosen	Exchange around major turns (e.g., aortic bifurcation)	J tip, not as stiff as Amplatz.	180, 260	0.035	Useful for passing up and over sheath.
	Amplatz SuperStiff[a,c]	Standard exchange, passing devices, support for endovascular interventions.	1-cm flexible tip, straight.	180, 260	0.035, 0.038	Best general exchange guidewire.
	Lunderquist[a] Exchange	Stiffest exchange.	Straight, stainless steel shaft, resembles coat hanger.	260	0.035, 0.038	Used for stent–grafts in tortuous arteries.
Specialty	J-guidewire[a,d]	Cross stents.	Fixed-core, 5–10 cm flexible tip.	145	0.025, 0.035	
	TAD[b]	Renal.	36-cm tapered-tip extension available.	145, 200	0.035→tapers to 0.018	
	Magic Torque[c]	Renal.	Flexible tip, cm markers.	180	0.035	
	Roadrunner[a]	Crossing critical lesions, cerebral.	Angled-tip, platinum spring coil tip, steerable TFE coating, 5-cm flexible tip.	180, 300	0.018	

[a] Cook, Inc., Bloomington, Ind.
[b] Mallinckrodt, Inc. St. Louis, Mo.
[c] Boston Scientific, Natick, Mass.
[d] Cordis, Miami, Fla.

TIP SHAPE

The shape of the guidewire tip reveals a lot about what a guidewire is best used for. A starting guidewire (used to start the case) has a floppy tip. A floppy-tip guidewire, which has no inner core in its tip and is therefore flexible, reduces the potential for endoluminal injury by buckling when it encounters resistance. A guidewire used for selective cannulation is curved or angled and may be steered into a desired location.

SPECIAL FEATURES

Some special features of guidewire construction include varying lengths of the floppy tip, antithrombotic surfacing, steerability with a high torque 1:1 ratio between the shaft and the tip, and varying degrees of stiffness of the shaft.

Guidewire Types in Practice

Although many features differentiate guidewires, most endovascular procedures may be accomplished using only a few types (Table 1). Starting guidewires, selective guidewires, and exchange guidewires are the three general types of guidewires that are employed in endovascular intervention. There are also a few specialty guidewires designed for specific tasks.

There are numerous starting guidewires on the market. These are floppy-tipped, general usage guidewires that are useful for catheter introduction and some interventional procedures. The Bentson guidewire (Cook, Inc., Bloomington, Ind.) is a reasonable choice. It has a floppy tip, steel construction, and a 0.035-in. diameter and it is relatively inexpensive. Most routine arteriography and angioplasty can be performed with this guidewire. The length is 145 cm. There are other guidewires that accomplish the same purpose such as the Starterwire (Meditech) and the Newton guidewire (Cook).

Selective guidewires are employed in cannulating side branches for selective catheterization or crossing critical lesions. These guidewires are steerable and some have hydrophilic coating. This class of guidewire includes, but is not limited to, the Glidewire and the Wholey wire. For crossing tight stenoses or highly irregular arterial segments, a hydrophilic-coated guidewire (i.e., Glidewire; Boston Scientific Corp., Medi-Tech Division, Natick, Mass.) is best, but it is more expensive and more difficult to handle. These guidewires can be obtained with a straight, firm tip, or a steerable, angled tip. The straight tip is best as a backup for crossing occluded arteries. The steerable tip is useful for selective cannulation of side branches or critical stenoses. The steerable or angled-tip hydrophilic guidewire is the most widely used and for many specialists is the first- or second-choice guidewire for a critically stenotic lesion. However, the hydrophilic-coated guidewire is so slick when it is wet that the operator often has the impression that the guidewire is being advanced when, in fact, it is stationary. Occasionally, the guidewire may be withdrawn from the lesion without the operator realizing that this movement has taken place. If multiple catheter exchanges are required for treatment of a lesion that has been crossed with a hydrophilic-coated guidewire, it is often best to exchange this guidewire for a stiffer, less mobile one. In addition, because of the hydrophilic coating, the guidewire can slide easily along a dissection plane, which can be a problem if undetected, especially if a larger endovascular device is passed over it.

Another selective, steerable guidewire useful for negotiating turns and for selective catheterization is the steerable tip, steel wire (i.e., Wholey; Mallinckrodt, Inc., St. Louis, Mo.). Simple manipulation of the end of the

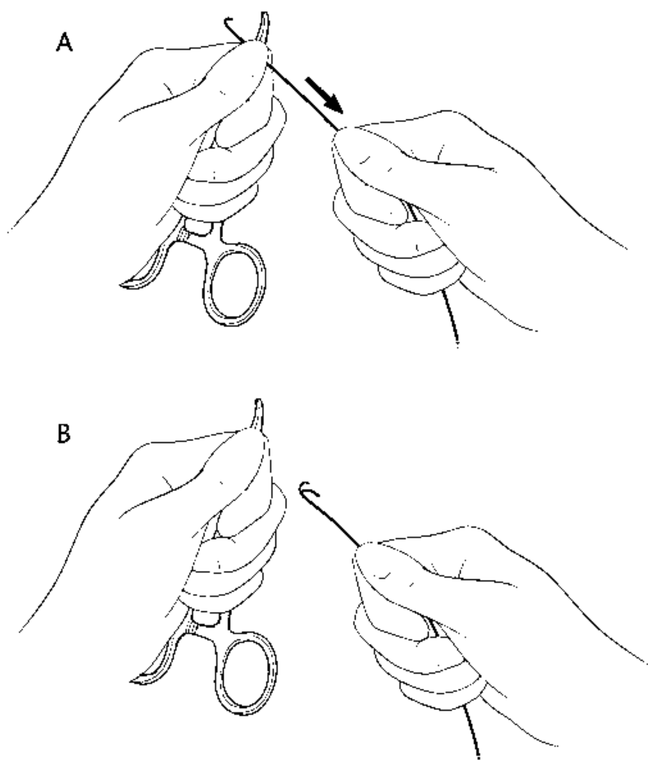

Fig. 3 Tighten the curve on a guidewire tip. The steerable Wholey guidewire is useful for selective catheterization and crossing irregular stenoses and occlusions. The amount of curvature at the tip of the guidewire can be adjusted using a simple maneuver. **A,** The tip of the Wholey guidewire is trapped between the thumb and the edge of a hemostat. **B,** The guidewire is pulled so that the metal edge of the clamp runs along the guidewire, which results in a tighter curvature at the tip.

guidewire with a clamp adjusts the degree of curvature on the steerable tip (Fig. 3). Steerable guidewires come with a torque device that is locked onto the shaft of the catheter to provide a 1:1 turning ratio. This wire is useful for superficial femoral artery cannulation after antegrade puncture and for crossing occlusions. The Wholey guidewire is also useful for cannulating aortic side branches with severe orificial stenoses. The extra body of the guidewire shaft permits better purchase upon the artery once the lesion has been crossed.

Exchange guidewires are stiffer than other guidewires and have a firm inner core. Once a guidewire has been appropriately placed (into a side branch, across a lesion, etc.), the security of that control may be enhanced by exchanging the initial guidewire for an exchange guidewire. The increased strength of the body of the guidewire makes it easier to pass devices over it and to maintain control across tortuous or distant passages. Some of the available exchange guidewires are the Amplatz (Cook or Boston Scientific Corp., Medi-Tech Division, Natick, Mass.), the Rosen (Medi-Tech), and the Lunderquist (Cook). The stiff guidewire should not be used as the lead passage device or for initial entry through a lesion because it can cause damage. During complicated endovascular procedures, such as a complex, multistent reconstruction or stent-graft placement, a stiff guidewire is very useful.

J-tip guidewires are useful for passage through an occlusion or a previously stented arterial segment. The curved J tip is less likely to pass through the struts of a stent or create a false passage.

Most clinical practice requires guidewires that are 0.035 in. in diameter. Smaller-diameter guidewires (0.025, 0.018, and 0.014 in.) are sometimes useful for passage through preocclusive lesions that cannot be traversed with standard-diameter wires. Low-profile balloon angioplasty systems for the carotid, renal, and tibial and pedal arteries (1 to 4 mm diameter) pass over only smaller-diameter guidewires.

Table 2 Guidewire Length Requirements

Length (cm)	Purpose
50–80	Catheterization of dialysis access.
	Retrograde femoral catheterization for ipsilateral femoral arteriogram.
145–150	General arteriography and catheterization of the abdominal aorta and its branches, aortoiliac interventions, antegrade approach to infrainguinal arteries
180–210	Arch and carotid arteriography, renal and visceral interventions, contralateral infrainguinal interventions, subclavian interventions
200–300	Carotid intervention, exchange guidewire for aortic stent–graft placement

Standard guidewire lengths are 145 to 300 cm. A guidewire length of 145 cm is adequate for catheter passage when performing general arteriography (Table 2). A 180-cm-length guidewire may be required for passage over the aortic bifurcation if the catheter is advanced into the contralateral SFA. A 260-cm guidewire may be required for arch aortography or carotid arteriography, especially in a tall individual. A 260-cm guidewire is required for long distances within the vasculature (e.g., brachial artery access to the lower extremity) or if the device intended for passage is particularly long (e.g., aortic stent-graft; Fig. 2).

TECHNIQUE: Guidewire Handling

Although choosing the appropriate initial guidewire is the most important decision to ensure success, facility with specific maneuvers makes the guidewire knowledge clinically applicable.

1. Wet the guidewire with heparin–saline solution. All guidewires function better when wet, and hydrophilic-coated guidewires must be wet to function at all.
2. Stiffen the floppy tip of the starting guidewire (Fig. 4) so that it will pass through the entry needle hub and into the arterial access site.
3. Seek alternatives if the guidewire won't pass through the needle (see Chapter 2 for plan of attack if the guidewire won't pass through the needle).

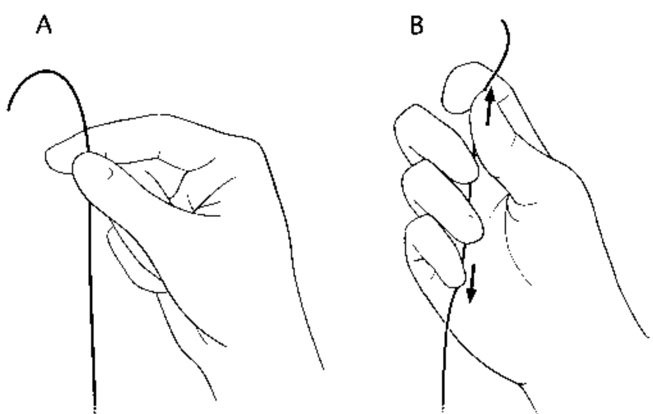

Fig. 4 Stiffen the floppy tip of the guidewire. A, Floppy-tip guidewires (i.e., the Bentson) are relatively atraumatic to the endoluminal surface, but the tip is very flexible and sometimes difficult to handle. **B,** The floppy tip of the guidewire can be stiffened by applying one-handed traction to pass it more easily through the hub of the needle or catheter. The guidewire is grasped with the thumb and forefinger near its leading edge and the third, fourth, and fifth fingers pin the guidewire against the palm. Applying traction causes the tip to stiffen and straighten.

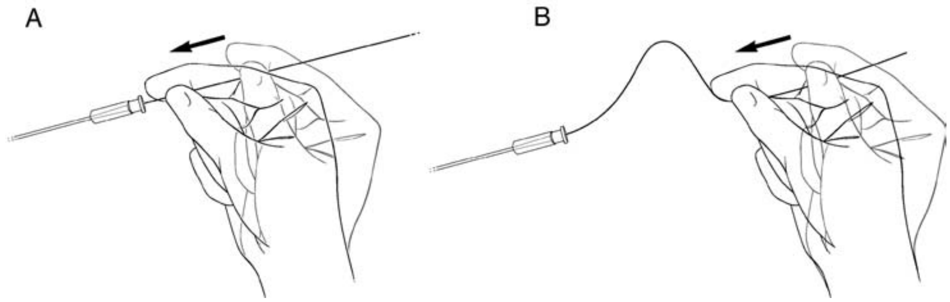

Fig. 5 Advance the guidewire incrementally. A, The guidewire must be advanced a few centimeters at a time. **B,** If there is too much length between the catheter hub and the location where the guidewire is grasped, the guidewire kinks.

4. Always use fluoroscopic guidance, especially when encountering a lesion. Blind passage is random and may cause harm. Start fluoroscopic guidance soon after the tip of the guidewire passes the end of the needle.
5. Never give up hand control of the guidewire outside the patient.
6. Don't force the guidewire.
7. Advance the guidewire in increments of a few centimeters (Fig. 5). Many small pushes are required. If there is too much length between the operator's hand position and the guidewire entry site, the guidewire

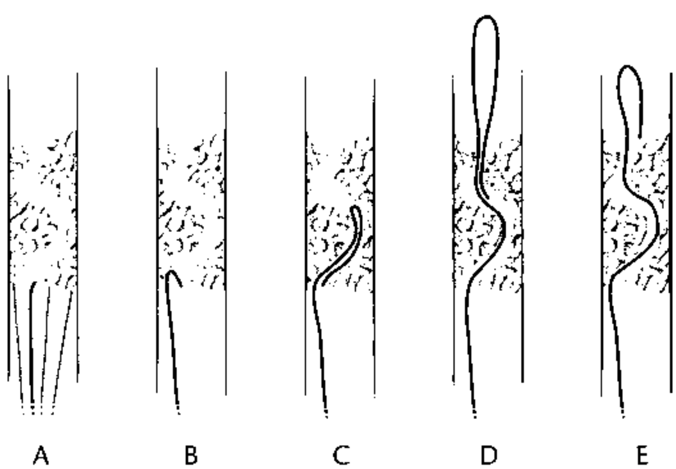

Fig. 6 Buckle the guidewire to cross a lesion. The leading edge of the guidewire may not be able to traverse an eccentric stenosis. If the guidewire begins to buckle, follow it and allow the elbow of buckled guidewire to become the leading edge. **A,** The tip of the guidewire probes an eccentric lesion. **B,** The leading edge of the guidewire does not enter the lumen of the lesion but the floppy tip begins to buckle. **C,** The floppy tip forms an atraumatic elbow of guidewire. The guidewire is pushed as long as the elbow advances easily. **D,** The elbow of the floppy tip emerges from the other end of the lesion. **E,** After the end of the guidewire comes through the lesion, the buckle can be removed.

kinks. Once a guidewire has a kink in it, it may be difficult to pass anything over it.

8. Allow the guidewire to buckle to cross a lesion (Fig. 6) (see Chapter 7 for a detailed discussion of crossing lesions).
9. Shape the guidewire tip. The curved tip of a Wholey steerable guidewire can be made more curved by running a metal clamp over the guidewire tip while holding the guidewire between the clamp and the thumb (Fig. 3). This is the same maneuver used to curl ribbon.
10. Have a torque device available whenever a steerable guidewire is used (Fig. 7). The torque device permits the operator to take advantage of the 1:1 turning ratio of the steerable guidewire.
11. Pin the guidewire during exchanges (Fig. 8). If the tip of the guidewire is near a lesion that should not yet be crossed, use intermittent fluoroscopy to ensure that the guidewire tip is not migrating.
12. Wipe the guidewire with heparin-saline solution–soaked gauze or Telfa after each exchange.

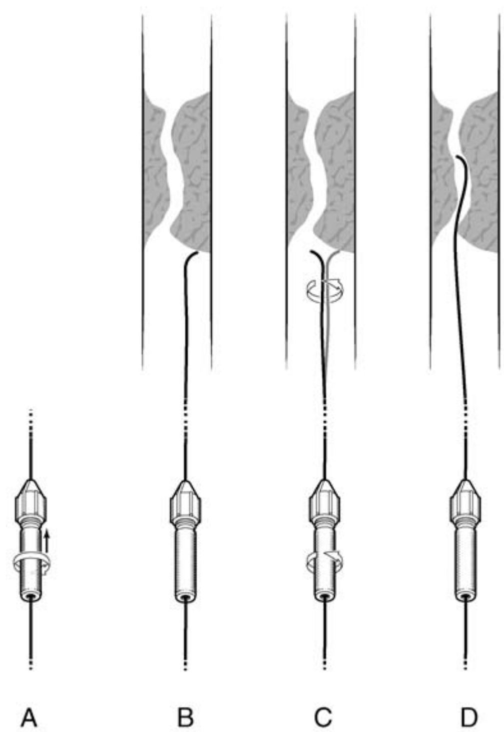

Fig. 7 Use a torque device with a steerable guidewire. A, A torque device is placed on a steerable guidewire by holding the head of the torque device steady and turning its handle. **B,** The steerable guidewire has a 1:1 turning ratio between the shaft and the tip. The guidewire tip approaches an eccentric stenosis. **C,** The torque device turns the guidewire tip toward the lumen. **D,** The steerable tip crosses the lesion.

Fig. 8 Pin the guidewire. As the catheter is advanced, the guidewire is pinned so that it cannot advance simultaneously with the catheter. During catheter exchanges, the location of the tip is confirmed intermittently with fluoroscopy (inset).

13. Confirm the intraluminal position of the guidewire before passing any large endovascular devices over it.
14. Handle a hydrophilic-coated wire with the pincer grasp (between the thumb and the forefinger). Otherwise it will slide either too far in or out.
15. Rewind or put back in its case any guidewire that has been removed so that your backtable work area does not degenerate into a confusing tangle.
16. Place a towel over the end of the guidewire outside the patient so it cannot flop around (Fig. 9). Some operators use a shodded clamp to secure the guidewire. If a guidewire is contaminated, the procedure must begin again with a new guidewire.
17. Alter the qualities of a guidewire by placing a catheter or sheath over it. This may confer additional stiffness or body to the guidewire, which increases pushability.
18. Exchange a kinked or bent guidewire.
19. Always leave the guidewire in place until the procedure is completely finished, especially if endovascular therapy has been performed. Do not give up guidewire position!
20. Handle the guidewires. Important factors for successful guidewire placement are the way the guidewire feels as it advances and the appearance using fluoroscopy. These can only be learned by handling guidewires.

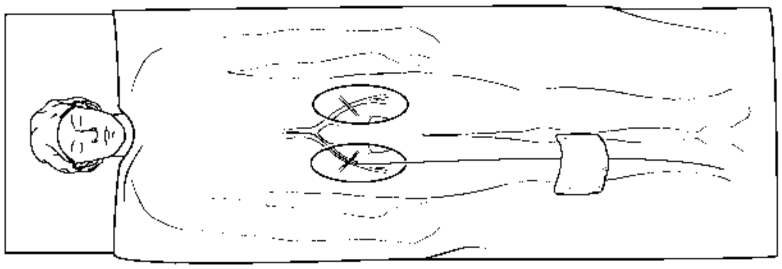

Fig. 9 Secure the guidewire. The segment of guidewire outside the patient is often quite lengthy and must be secured. A folded towel can be placed over the guidewire to prevent it from falling off the table. A contaminated guidewire must be cut off and exchanged.

Introduction to Catheters: Dilators and Exchange, Flush, and Selective Catheters

The simplest catheter is a vascular dilator. This is a short (12 to 15 cm), slightly firm catheter with a single hole in the end. A dilator is most often used to secure vascular access or to enlarge a percutaneous arteriotomy. Occasionally it is appropriate to perform arteriography through a dilator (e.g., femoral arteriography). An exchange catheter is straight and long (at least 65 cm) and is used to exchange one type of guidewire for another. An exchange catheter may also be used for interval arteriography to assess the results of an endovascular procedure. A flush catheter is used for general arteriography. It has an end hole and multiple side holes for administration of contrast. Flush catheter lengths vary from 65 to 100 cm. The shape of the catheter head is usually rounded and promotes contrast administration in multiple directions to create a blush. Selective catheters have a multitude of head shapes since they are used to direct a guidewire into a specific location. Some selective catheters were designed with specific arteries in mind (e.g., carotid, visceral, etc.).

When Is a Dilator Needed?

After a guidewire has been placed through an entry needle, a catheter is placed. Catheters are usually soft and flexible and occasionally cannot be advanced over the guidewire through the entry site. This may occur if there is scar tissue, arterial calcification, or a deep entry site. Make sure the guidewire is still straight using fluoroscopy and not twisted in the subcutaneous tissue. A dilator may then be advanced to secure the entry site and slightly dilate the tract. When the operator is concerned about these factors, it is appropriate to initiate catheter passage with a dilator. If a sheath is being placed, it is often useful to dilate the arteriotomy first. Most arteriography is performed with 4 or 5 Fr catheters. A dilator of the same size as the proposed catheter should be used if the tract needs to be dilated before catheter placement. When endovascular therapy is planned, the arterial access site may require substantial enlargement, from 4 or 5 Fr to 10 Fr or larger. This is done by passing progressively larger dilators over the guidewire (e.g., 6, 8, 10 Fr dilators) until the site is adequately sized to accept the intended therapeutic device. Since dilators are sized by outside diameter and sheaths are sized by inside diameter, a 7 Fr dilator is used to prepare the tract for a 6 Fr sheath.

Which Angiographic Catheter Should I Use?

Working with angiographic catheters is marked by the pleasant dilemma of too many choices, rather than too few. Catheters differ with respect to construction material, diameter, length, head shape, and special features.

Construction. Angiographic catheters are constructed of polyethylene, polyurethane, nylon, Teflon, or a combination of these materials. Catheters made of polyethylene have a low coefficient of friction and they are pliable, have good shape memory, can be torqued, and are useful for selective catheterization. Polyurethane catheters are softer and more pliable and follow guidewires more easily, but they have a higher coefficient of friction. Nylon catheters, which are stiffer and tolerate higher flow rates, are useful for aortography and general arteriography. Teflon is the stiffest material and is used mainly for dilators and sheaths.

Diameter. The diameter of the catheter should be as small as possible to accomplish the task at hand. Most angiography is performed with 4 or 5 Fr catheters over 0.035-in. guidewires.

Length. The catheter must be long enough to reach the target site and still have enough length outside the patient for appropriate manipulations. Most catheters range from 65 to 100 cm in length. In general, use the shortest catheter that will perform the task (Table 3).

Head shape. Catheter head shape determines function.

Special features. Some special features of catheters include various coatings, radiopaque tips, and graduated measurement markers.

Table 3 Catheter Length Requirements

Length (cm)	Purpose
15–20	Dilator
65	Abdominal aortography with lower-extremity runoff
65–80	Selective renal and visceral catheterization
90	Arch aortography
	Thoracic aortography
100	Selective cerebral catheters

Catheter Head Shape Determines Function

The potential for constructing different catheter head shapes is unlimited. Although hundreds are currently being marketed, most endovascular practice is based on the consistent and well-developed use of just a few types. Each specialist has functional favorites. Flush and selective catheters have divergent purposes and substantially different appearances. General catheter types are shown in Fig. 10. These include flush, exchange, and selective catheters. The selective catheters may have either a simple curve or a complex curve. Some catheters commonly used in endovascular practice are listed in Table 4.

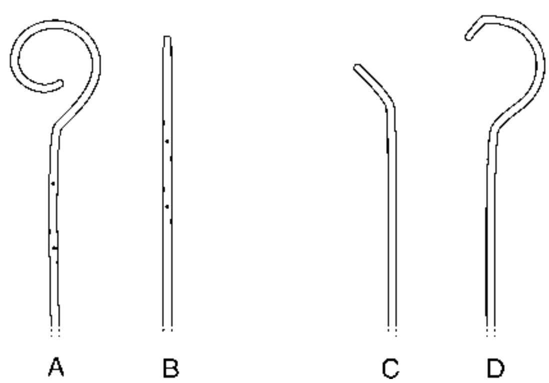

Fig. 10 Catheter head shape determines function: flush, exchange, simple-curve selective, and complex-curve selective catheters. Representative examples of the major categories of catheters as detailed in Table 4. **A,** Flush catheters are used for aortography. They have an end hole and multiple side holes for high-pressure, high-volume contrast administration. This flush catheter example is a tennis racket catheter. **B,** The straight catheter is used as an exchange catheter, to place a different guidewire into the artery. **C,** Selective catheters have an end hole and a specially shaped tip. Selective catheters may have a simple curve, for directing a guidewire, as this Teg-T catheter. **D,** Selective catheters may also have a complex curve, as this C2 Cobra. These catheters have a larger head which must be reformed in the aorta before using it to cannulate an artery. These catheters have specifically designed shapes and are used to enter aortic side branches such as carotid or renal arteries.

Table 4 Catheters for General Endovascular Practice

Catheter type	Catheter	Function	Length (cm)	Caliber (Fr)	Comments
Flush	Pigtail	Aortography	65, 90, 100	4, 5	
	Tennis Racket	Aortography		5	
	Omni-Flush	Aortography: select aortic bifurcation, select renal artery	65	4,5	
Exchange	Straight	Exchange guidewires, general arteriography	70, 90, 100	4, 5	
Selective: simple curve					
Short bent tip	TegT	Direct guidewire through lesion or into branch (30°)	70, 100	5	
	Kumpe	More angled than Teg-T (45°)	40, 65	5	Other examples: Berenstein, vert, DAV
Long bent tip	Multipurpose A	Direct guidewire, longer tip (45°)	65, 100	5	
	Multipurpose B	More angled than MPA (70°)	100	5	
Hook shape	RIM	Tight curve	65	5	Other examples: Hook, celiac/8MA, Chuang A,B,D,E, Shepherd Hook
Selective: complex curve					
Cerebral	Simmons	Reshape to enter difficult arch branches, direct guide	100	5	Other examples: see Table 2 in Chapter 6
	Vitek	Reshape to enter difficult arch branches	100, 125	5	
Renal	C2 Cobra	Directs guidewire into side branch at 90° angle	65, 80	4, 5	Other examples: Sos-Omni 2, C_3 Cobra
	Renal double curve	Directs guidewire laterally and inferiorly acute angle	80	5	Other examples: Renal curve, and Renal Curve 2

Flush arteriographic catheters such as the pigtail are useful for high-pressure injection (up to 1200 psi) performed while minimizing a jet effect that might destabilize arterial plaque or thrombus. Most aortography and some peripheral arteriography can be performed with these catheters. The rounded catheter head can be converted to a hook shape by positioning a guidewire partially into the head. Most aortography begins with one of these

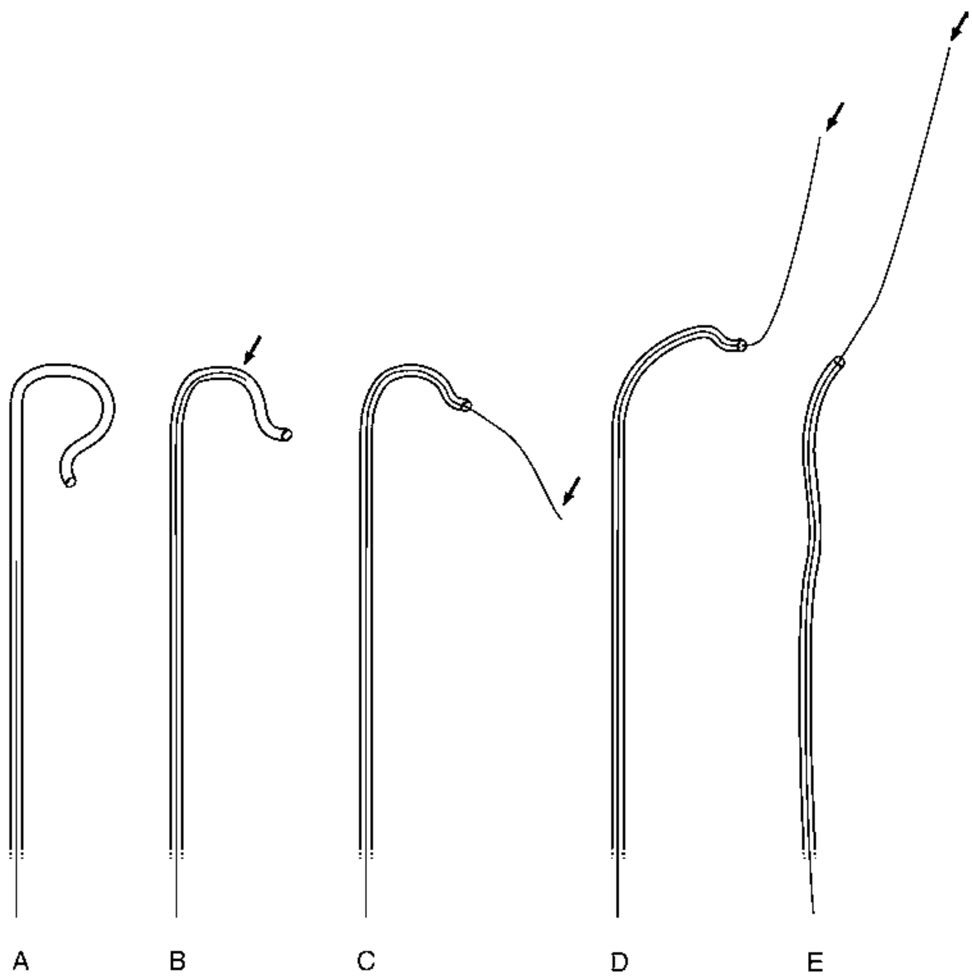

Fig. 11 Catheter head shape depends on guidewire position. The shape of the catheter head can be significantly modified by the position of the guidewire. This is especially true for flush catheters and complex-curve selective catheters. **A,** A guidewire is present within the shaft of a hook-shaped visceral catheter. **B,** The hook of the catheters head splays out as the guidewire enters the curve. **C,** As the floppy part of the guidewire tip exits the catheter, the head of the catheter splays further. **D,** The catheter straightens as the firm portion of the guidewire shaft occupies the curved portion of the catheter head. **E,** As the firm portion of the guidewire exits the catheter head, the catheter straightens out completely.

catheters. The shape of the catheter head may be altered dramatically, depending upon the location of a guidewire placed within it. Although this is true for all catheters that are not straight, catheters with a complex curve may assume the widest variety of configurations depending upon the location of the guidewire (Fig. 11).

The straight catheter is useful as a general exchange tool, for interval arteriography, and to measure pressure proximal and distal to a lesion. It can add stiffness to a guidewire to allow it to pass or probe a lesion more easily or uncoil a guidewire that has piled up proximal to an unpassable lesion.

Selective catheters have either a simple or complex curved head shape (Fig. 12). A simple way to distinguish between the two is that a complex curve needs to be reshaped in the aorta before it can be used to selectively cannulate a side branch. The bent-tip Berenstein catheter (Boston Scientific Corp., Medi-Tech Division, Natick, Mass.) is a simple-curve selective catheter, but it can be used simultaneously for general applications. This catheter is useful for directing a guidewire through a critical lesion or into a branch vessel. The bend at the tip of the catheter confers directionality to the guidewire tip. Hook-shaped catheter heads are useful for turning an acute angle at a tight corner. Complex-curve catheter heads have a curve in one direction, then back in the other direction. These are used primarily to select out aortic side branches for cannulation. Examples include the Simmons and the H3 Headhunter cerebral catheters. Many head shape configurations have been designed for selective catheterization, each with a different purpose (see Chapter 6 for a detailed discussion of selective catheterization). The rate at which contrast may be administered through a catheter varies with the catheter caliber, its length, and the number of sideholes (Table 5).

LINGO: Catheter Talk

Trackability. The ability of the catheter to follow the guidewire through tortuous vessels and around corners without pulling the wire out of its intended location.

Pushability. The description of how a force applied by the operator at the hub of the catheter relates to the forward movement of the tip (the leading edge) of the catheter.

Crossability. The facility with which a catheter follows the guidewire across a lesion or through a diseased arterial segment.

Steerability. The steering responsiveness of the catheter tip to handling maneuvers performed at the hub.

French. The scale used to size catheters (1 Fr=0.33 mm).

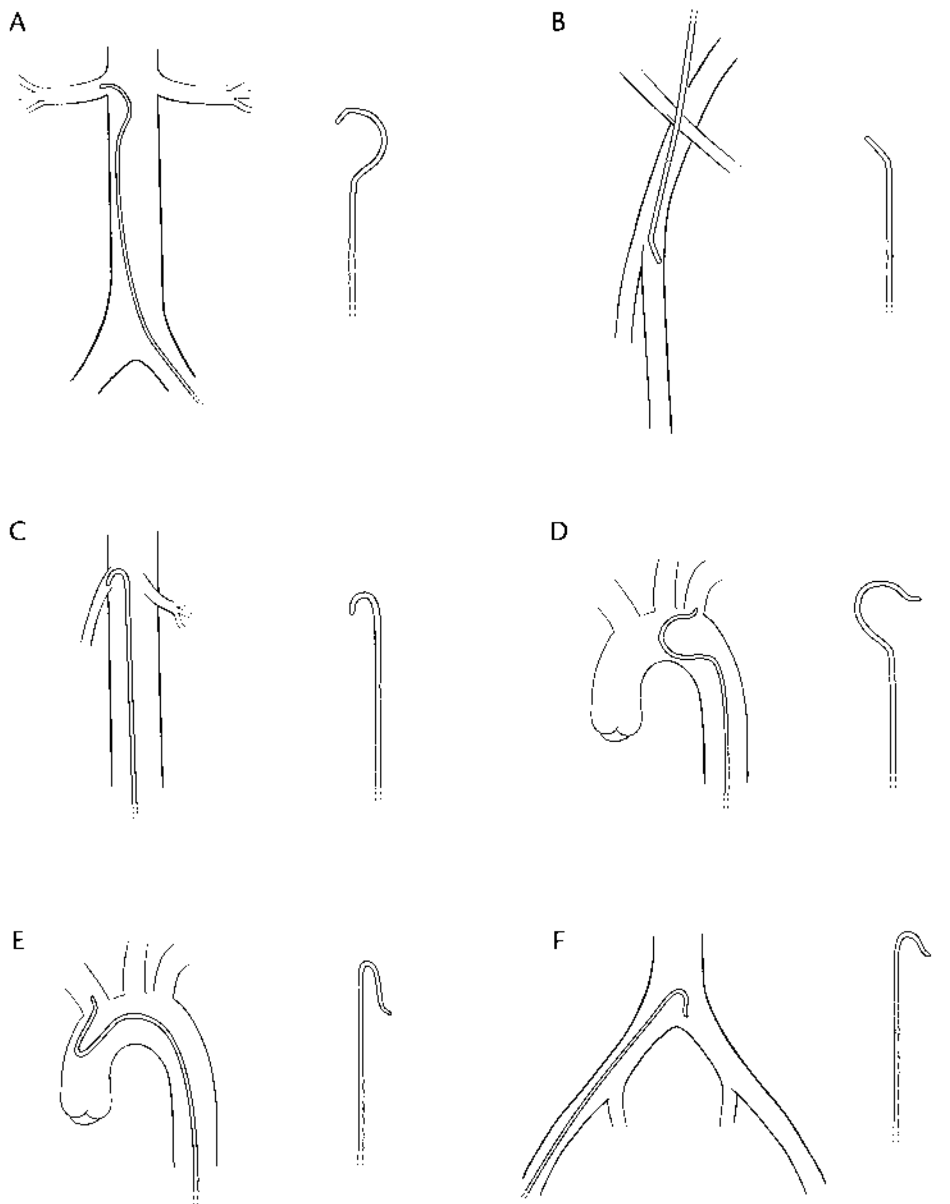

Fig. 12 Selective catheters in action. A, A cobra catheter is used for renal artery catheterization. **B,** A Berenstein catheter is used for cannulation of the superficial femoral artery. **C,** A tightly curved hook-shaped catheter is used for catheterization of the visceral arteries. **D,** A headhunter catheter can be used to enter the branches of the aortic arch. **E,** A Simmons catheter is used to cannulate the carotid and innominate arteries. **F,** A shepherd's hook catheter is used to cross the aortic bifurcation.

Table 5 Contrast Media Flow Through Catheters[a]

Type	Caliber (Fr)	Length (cm)	Maximum flow route (ml/sec)[b]
Flush (multiple side holes)	4	65	19
	4	100	15
	5	65	32
	5	100	27
Selective (end hole)	5	65	15
	5	100	11

[a] Data from Cook, Inc. (Bloomington, Ind.) using 100% Oxilan 350 at 25°C.
[b] Maximum pressure=1200 psi.

Handling Catheters

After the guidewire has been placed into the major flow stream of the arterial segment of interest, the next challenge is to pass the catheter into the correct location. The catheter must be suitable for the diameter sizing of the guidewire. In general, the catheter will follow the guidewire when it is advanced incrementally and the guidewire is pinned to ensure that it does not also advance.

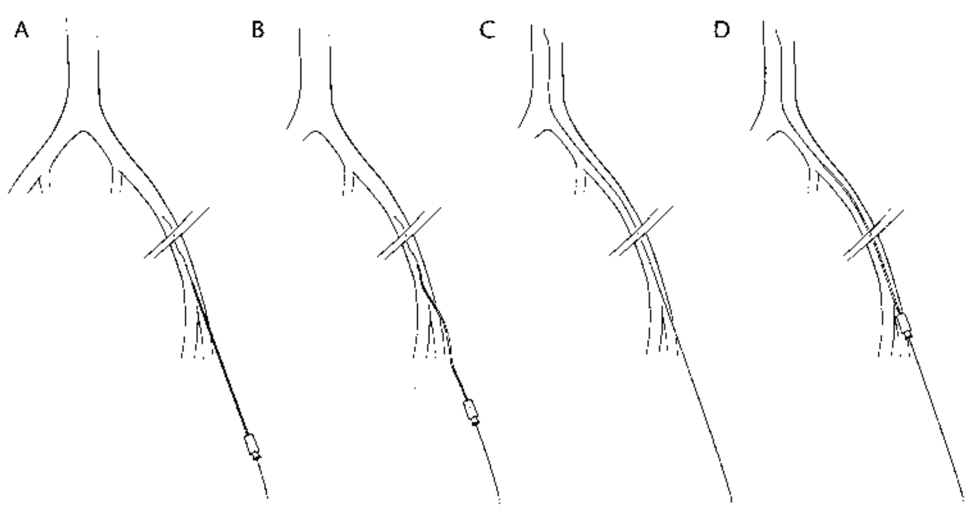

Fig. 13 Advance the catheter over the stiff portion of the guidewire. A, The catheter is advanced into the arterial entry site over the floppy portion of the guidewire, which lacks the shaft strength to support guidewire advancement. **B,** The catheter buckles and advancement stalls. **C,** The guidewire is advanced so that the floppy portion is well inside the vasculature. **D,** The catheter is advanced over the stiffer portion of the guidewire.

The puncture wound in the skin must be of adequate size to permit the catheter to cross it. If the catheter buckles at the arterial entry site, the operator must determine whether the degree of guidewire stiffness at that location is adequate. The catheter won't advance over the floppy portion of the guidewire (Fig. 13). The guidewire may be advanced to ensure that a firm segment of the guidewire is located at the arterial entry site. If the catheter cannot be advanced through the arterial entry site over the firm portion of the guidewire, an arterial dilator should be passed to predilate the entry site or a stiffer guidewire should be used to give additional support to the catheter (Fig. 14).

If pushability is lost after the vasculature has been entered, a stiffer guidewire should be considered. If the catheter cannot be advanced over the guidewire through a lesion, the lesion itself may be providing the resistance; either the stenosis is so severe that the guidewire itself occludes the residual lumen or the guidewire is subintimal. A preocclusive lesion may require a slight amount of predilatation, which can be performed with a tapered van Andel catheter (Cook, Inc., Bloomington, Ind.). If the guidewire is subintimal, the operator has a choice of proceeding with subintimal angioplasty or replacing the guidewire into the true lumen.

When the catheter cannot be advanced into position because of significant vessel tortuosity or because of the long distance between the catheter head and the entry site, a steady and gentle withdrawal of the guidewire while the catheter is advanced decreases friction at the level of the catheter head and usually accomplishes the requisite advancement, if it is not too far. Do not advance the catheter beyond the end of the guidewire or

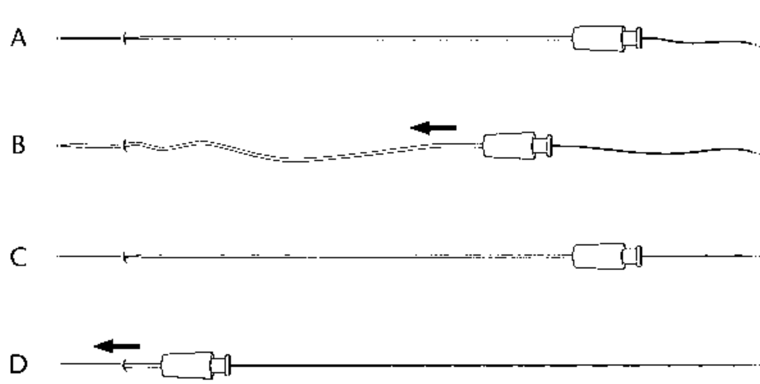

Fig. 14 Use stiffer guidewire if catheter buckles at entry site. If the catheter will not advance through the entry site over the firm portion of the guidewire, exchange for a stiffer guidewire. **A,** Catheter tip attempts advance over standard guidewire. **B,** The catheter tip advances a short distance beyond the entry site, but then begins to buckle. **C,** A 4 or 5 Fr arterial dilator is passed to dilate the entry site and exchanged for a stiffer guidewire, such an an Amplatz Super-stiff guidewire. **D,** The catheter is passed over the stiffer guidewire.

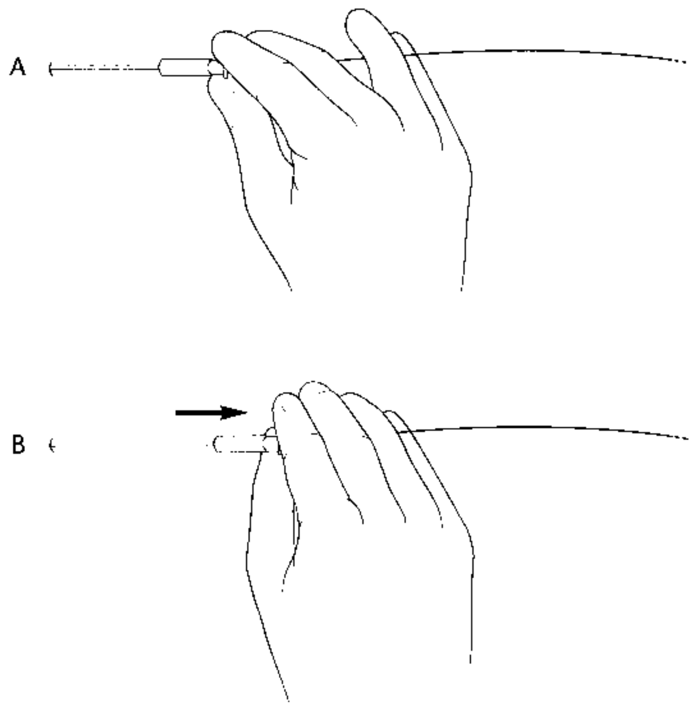

Fig. 15 "Walk along" the guidewire to remove catheter. When a catheter is exchanged, the guidewire position is maintained while the catheter is removed. **A,** The catheter hub is grasped between the thumb and forefinger and the guidewire is grasped between the fourth and fifth fingers of the same hand. **B,** The catheter hub is withdrawn while the guidewire position is held constant. The fourth and fifth fingers then grasp the guidewire again at the further distance along its length and the maneuver is repeated. This creates the appearance of the hand "walking along" the guidewire.

allow the catheter head to reform during advancement. If the catheter and guidewire combination tends to buckle freely, the operator can choose to either insert a stiffer guidewire or attempt to advance both the catheter and guidewire simultaneously. Another option is to leave the guidewire in place, remove the catheter, insert a long sheath to decrease friction, and reinsert the catheter through the sheath.

TECHNIQUE: Catheter Handling

1. Prepare the catheter by flushing and wiping with heparin–saline solution.
2. Choose catheter size, length, and head shape that will most easily accomplish the proposed task. The catheter may usually be selected prior to puncture for routine cases.

3. Place the guidewire in the correct location. This is probably the most important factor in successful catheter placement.
4. Whenever the guidewire is in place across the access site without a catheter, hold pressure at the arterial entry site until the appropriate catheter is passed to tamponade bleeding from the arteriotomy and into the subcutaneous tissue. This helps to minimize the likelihood of hematoma formation.
5. Use mosquito clamp to dilate skin entry site to the appropriate size for the intended catheter.
6. Pass the catheter through the skin and soft tissue over the stiff portion of the guidewire, not on the floppy segment (Fig. 13).
7. Consider using sequential arterial dilators, a stiffer guidewire, or a hemostatic access sheath if the catheter cannot be advanced across the entry site.
8. Advance the catheter incrementally, a few centimeters at a time.
9. Handle the catheter near its skin entry site when advancing and at its hub when steering.
10. Maintain hand control of the guidewire. An assistant should pin the guidewire so that it does not simultaneously advance (Fig. 8).
11. If the catheter won't cross a lesion, and arteriography is the goal, use a different approach and don't force it. If therapy is the goal (e.g., balloon angioplasty), make sure the guidewire is in the correct location across the lesion. Then predilate the lesion with a van Andel catheter or a small-diameter angioplasty balloon.
12. If the catheter won't advance because of long distance and/or multiple turns from the leading edge to the operator's hand, and there is plenty of guidewire in place ahead of the catheter tip, gently and steadily withdraw the guidewire while advancing the catheter to reduce friction. Continuous fluoroscopy is required during this maneuver to ensure that the guidewire is not withdrawn too far.
13. If the catheter has a longer distance to travel and cannot be advanced, it is usually due to accumulated friction. Place a long sheath to decrease friction, use a stiffer guidewire, or choose an alternative entry site.
14. After the catheter is in place, aspirate and flush with heparin–saline solution. Do not inject contrast unless there is appropriate blood return.
15. Puff contrast to verify placement and ensure that the catheter tip is in a safe position before high-pressure injection is performed.
16. When removing or exchanging the catheter, maintain guidewire placement, either by advancing the guidewire intermittently while the catheter is being withdrawn or by "walking along" the guidewire while the catheter is being pulled (Fig. 15). Intermittent fluoroscopy checks should be performed to ensure that guidewire position is maintained.
17. If the end of the catheter becomes knotted, pass a stiff guidewire into the catheter to untangle it.
18. If there is any doubt about the location of the catheter, make sure it is intraluminal. Check for blood return. Twirl the catheter and visualize the catheter head moving using fluoroscopy to be certain that it moves freely. Puff contrast to see that it rapidly enters the flow stream rather than staining the wall of the artery or remaining stagnant.

19. It is common to have difficulty identifying the catheter as it is being placed. Consider using a catheter with a radiopaque tip. When advancing any catheter over a guidewire, there is a slight bend of the guidewire at the location of the catheter head and this imprint can be monitored fluoroscopically as it is advanced.
20. Remove the catheter over a guidewire to straighten the catheter head. This prevents injury to the endoluminal surface and the arterial entry site.
21. After the guidewire has been removed, if there is uncertainty about the location of the catheter head, add a milliliter of contrast to fill the catheter and it may be better visualized.

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4

How to Get Where You Are Going

Guidewire and Catheter Passage

The Goal of the Procedure Determines the Course of the Guidewire–Catheter
Into the Flow Stream
When to Use Fluoroscopy
Guidewire and Catheter Combinations
Passing Through Diseased Arteries
  Plan of Attack: Catheter Won't Follow Guidewire
Negotiating Tortuous Arteries
Going the Distance: The Very Remote Puncture Site
  Plan of Attack: Guidewire–Catheter Buckling
Passing Through Aneurysms
Selected Readings

The Goal of the Procedure Determines the Course of the Guidewire–Catheter

After percutaneous access has been achieved (Chapter 2) and guidewires and catheters have become familiar tools (Chapter 3), the next step is guidewire and catheter passage to the desired location. The goal of the intended procedure should be well proscribed prior to the puncture. Whether an arteriogram or a therapeutic intervention is planned will influence the puncture site choice and the approach. Options should be considered for converting the procedure from a strategic one to a therapeutic one if the need should arise. Access for endovascular therapy is discussed in Chapter 12.

When arteriography is the goal, it usually first requires catheter head placement at specific locations for visualization of the desired anatomic area. Selective catheterization for arteriography or therapy requires specific steps, which are discussed in Chapter 6. Crossing lesions with guidewires and catheters prior to endovascular therapy is presented in Chapter 7. Other details of catheter head placement for arteriography are discussed in Chapter 8. These maneuvers have been separated into a stepwise approach for illustrative purposes. As the operator gains facility, one step leads to the next in an often seamless flow of events toward the goal of the procedure.

Into the Flow Stream

After the guidewire is in the artery, it is advanced away from the entry site. The guidewire must be advanced through the entry needle and into the artery at least far enough so that the floppy tip portion of the guidewire has cleared the entry site. Fluoroscopy is initiated and the guidewire is advanced into the desired location. Pressure at the puncture site is held as the needle is removed. The guidewire is wiped with heparin-saline–soaked gauze or Telfa. The assistant places the chosen catheter onto the guidewire and advances it to within a few centimeters of the access site. The assistant pins the guidewire. The operator maintains gentle manual pressure with one hand at the access site and with the other hand advances the catheter over the guidewire, through the skin, and into the artery. Pressure is maintained at the puncture site until the tip of the catheter is inside the artery to tamponade the arteriotomy. If the operator is anticipating difficulty with catheter insertion, an arterial dilator may be used initially to prepare the tract (see Chapter 3). Fluoroscopy is initiated and the catheter is advanced over the guidewire. When lesions are encountered on the initial guidewire pass, it is usually best to stop the guidewire advance and secure the access site before crossing. If the guidewire is not far enough inside the artery to secure the access, a careful attempt should be made to cross the lesion. Guidewire and catheter exchanges are difficult or impossible in this position, with the guidewire barely inside the artery.

After the initial catheter placement, the guidewire may be replaced if a different one is required for negotiation of lesions. A catheter with a radiopaque tip is easy to see as it is advanced over the guidewire. The slight curve of the guidewire at the location of the passing catheter head may also be visible.

Bony landmarks are usually adequate to establish the correct location for catheter head placement (Fig. 1). The catheter head may be advanced or withdrawn slightly without reintroducing the guidewire. Hand-powered injection of contrast to establish the position is usually worthless through a 5 Fr catheter into the aorta. Hand-powered contrast injection may be used to

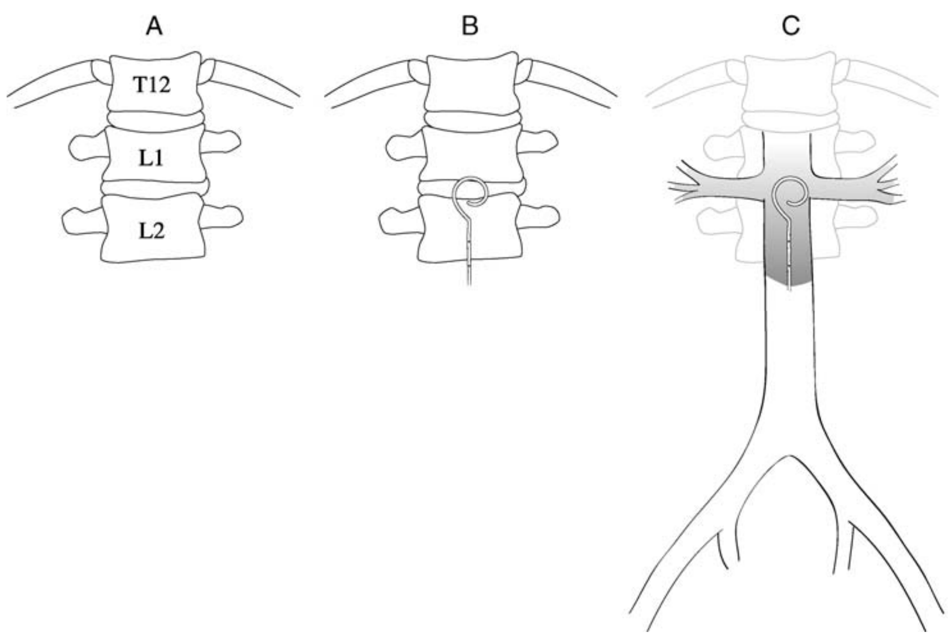

Fig. 1 Use landmarks to assist with catheter positioning. Bony landmarks are used to help place the arteriographic catheter. **A,** The renal arteries are usually located near the junction of the first and second lumbar vertebral bodies. The twelfth thoracic vertebral body is identified by its attached ribs and the operator counts down. **B,** The catheter head is placed near the L1–L2 junction so that a high-pressure injection of contrast will reflux a few centimeters above that level. **C,** The aortogram demonstrates the origins of the renal arteries.

visualize smaller, lower-flow arteries (see Chapter 5). After the catheter is in place, aspirate, remove bubbles, flush with heparin–saline and connect to the injector, meniscus to meniscus. Then have the technician aspirate through the injector and inspect the line for air bubbles.

When to Use Fluoroscopy

Fluoroscopy-eye-hand coordination is a developmental skill that must be gained by endovascular specialists (Chapter 1). Surgeons learned a long time ago that surgical electrocautery is most efficient when the foot is not required as an intermediary in the process. Nevertheless, virtually all modern fluoroscopic equipment uses foot pedal controls. This introduces the potential for overuse and inefficiency since plantarflexion and dorsiflexion are required intermittently throughout the case.

Fluoroscopy is occasionally useful in planning the puncture (see Chapter 2). This is especially true for the pulseless femoral artery or for antegrade femoral puncture (Table 1). Fluoroscopy is almost never required during the actual puncture. Occasionally, when there is blood return from the puncture needle but the guidewire cannot be advanced, a fluoroscopy spot check of the guidewire position is warranted. Soon after the guidewire has been placed into the artery after a routine puncture, fluoroscopy should be initiated. Fluoroscopy may be continuous or may be intermittent but frequent. If there is any resistance to guidewire advancement on the first pass, the operator should stop and check the guidewire's progress with fluoroscopy. The guidewire may have turned into the iliac circumflex vessel or another collateral route. Any encounters with lesions must be observed using fluoroscopy. The guidewire should be advanced so that its floppy portion extends beyond the location desired for catheter head placement. After the guidewire is appropriately placed, fluoroscopy stops while the catheter is prepared. Fluoroscopy is initiated again when the catheter is in the artery. The progress of the catheter is monitored using fluoroscopy until it is in the desired location. Fluoroscopy is used as the guidewire is withdrawn to ensure that the head of the flush catheter assumes its proper shape (Fig. 2). Occasionally, it is useful to twirl the catheter to ensure its tip is free within the flow stream.

Guidewire and Catheter Combinations

There are many correct guidewire and catheter choices. But if the one you have chosen is not working, move on. The goal of the procedure, whether strategic or therapeutic, determines the order and range of choices of guidewires and catheters. The guidewire is chosen first for routine arteriography and for crossing lesions to set up a therapeutic procedure. If the initial

Table 1 When to Use Fluoroscopy During Guidewire and Catheter Passage

Task	When?	Purpose	How Often Is It Necessary?
Planning puncture	Prior to arterial puncture	Identify anatomy when there is no pulse or poor pulse; locate proximal femoral artery for antegrade puncture	Occasional Usually
Guidewire passage through entry site	Guidewire won't pass	Guidewire passes through needle but won't advance into artery; check guidewire position/direction with fluoroscopy	Occasional
Advancing guidewire into position	Soon after guidewire enters the artery	Observe guidewire progress, avoid endoluminal injury, avoid passing the guidewire into the wrong place	Always
Advancing catheter through entry site	Catheter won't advance through entry site	Check to see if catheter is coiling in the subcutaneous tissue; check to see if guidewire is bent	Rare
Advancing catheter into position	Soon after catheter enters the artery	Observe catheter progress; monitor position	Always
Removing guidewire	As guidewire is withdrawn from catheter head	Observe appropriate formation and final position of catheter head	Always

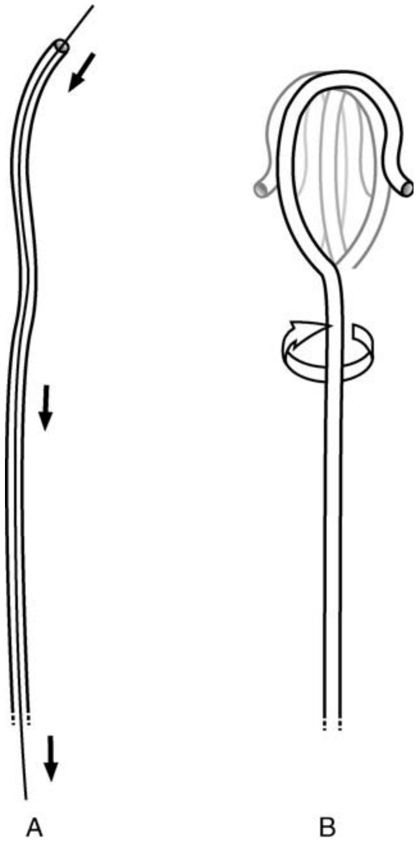

Fig. 2 Evaluate the catheter head to ensure that it has reached its appropriate shape and location. A, As the guidewire is removed, the catheter head can be observed to take its preformed shape. **B,** The catheter may be twirled to make certain that the catheter head is not stuck against the wall of the artery.

guidewire choice is not successful, a catheter may be placed over it to alter the handling characteristics of the guidewire. A catheter may add stiffness, steering, and pushing strength to a guidewire. When the goal is selective catheterization of a branch artery before the lesion is encountered, the catheter is selected first. When a selective catheter is required, the usual guidewire choice is hydrophilic (low friction) and steerable (directionality).

Passing Through Diseased Arteries

As a general rule, lesions are crossed when therapy is planned (Chapter 7). Occasionally, arteries may be so diffusely diseased that there is no approach through relatively healthy segments for arteriographic catheter placement. In addition, a puncture may be placed in an artery with a relatively normal pulse,

Fig. 3 Passing through severely diseased arterial segments can be challenging. A steerable guidewire may be used to make multiple turns in attempting to cross a lengthy critical lesion. The guidewire tip may be used to probe the lesion.

and there may be a severe but unsuspected stenosis just upstream from the puncture site. These factors indicate that fluoroscopy should be initiated early after guidewire insertion. The guidewire should be advanced steadily but carefully through diseased segments. If the guidewire forms a leading elbow, continue to advance the guidewire but do not force it. You don't want the guidewire to become a loop stripper. When the guidewire does not cross the desired arterial segment, place a dilator over the guidewire to secure the access site and remove the initial choice guidewire. Puff contrast to ensure intraluminal position and to obtain information about the diseased segment. A hydrophilic-coated guidewire may cross the artery with greater ease. Use a steerable guidewire and probe the lumen of the artery gradually as the guidewire is advanced (Fig. 3). After the guidewire is placed, the catheter is advanced over it and is continuously observed using fluoroscopy.

PLAN OF ATTACK: Catheter Won't Follow Guidewire

1. Use gentle catheter manipulations to assess the exact location where the catheter fails to pass. Where is the hangup?
2. Is the guidewire kinked? A seemingly minor kink may be very difficult to pass with the catheter. Use a magnified view to study the guidewire. Withdraw the guidewire a few centimeters and pass the catheter again.
3. Is the guidewire subintimal? Does the guidewire itself move freely within the artery? Usually, when the guidewire is in a dissection plane, it will not advance beyond a certain point and it will appear tethered at the point of subintimal passage.
4. Is the lesion so critical that the guidewire itself has interrupted flow and there is not enough residual lumen to pass a catheter? In this case, heparin should be given. Immediate plans should be made for either treating the lesion or withdrawing from it.
5. In these situations, consider passing a smaller (4 Fr) straight catheter with side holes. After the tip of the straight catheter is passed just beyond the point of obstruction, the guidewire may be withdrawn and a puff of contrast should clarify the situation.

Negotiating Tortuous Arteries

Tortuous arteries place constrictions upon guidewires and catheters that may not be immediately obvious under the two-dimensional representation available with fluoroscopy. Anatomic segments such as iliac vessels and branches of the aortic arch may exhibit tortuosity, kinks, and loops. Despite a widely patent lumen, forces upon the guidewire–catheter apparatus may be such that they are prevented from advancing after passing through multiple turns. Oblique views of the tortuous segments are useful to identify the true angles followed by the arteries. A steerable guidewire helps to negotiate the turns. A straight or angled-tip catheter may be passed over the guidewire to help straighten some of the initial curves and provide support for the guidewire as it goes into its next turn. A sheath may also be placed at the entry site. This may be very useful for decreasing friction, even if it only reaches through the first major turn the guidewire has to make. After the guidewire and catheter have been passed, consider exchanging the guidewire for a stiffer one before initiating therapy.

Going the Distance: The Very Remote Puncture Site

A very remote puncture site may occasionally be required by a variety of circumstances. An example of this includes infrapopliteal balloon angioplasty through a brachial approach when a femoral approach is contraindicated by anatomy, infection, previous surgery, or other conditions. The approach required for arteriography is different from that required for treatment. Arteriography requires catheter positioning upstream from the lesion, whereas therapy requires guidewire and catheter placement across the remote lesion at a distance where guidewire control may be poor. The operator must be prepared to undertake multiple maneuvers to reach the intended desination several vascular beds away from the entry site.

In the example mentioned above, selective arteriography would necessitate catheter placement in the superficial femoral artery (SFA). The guidewire is introduced into the brachial artery and advanced retrograde into the subclavian artery. A straight catheter and a steerable-tip guidewire are used to advance into the aortic arch and avoid entering branches. The angle of take-off of the subclavian artery from the aorta determines whether the guidewire will preferentially enter the arch or the descending aorta. An angled-tip catheter, such as an MPB, is often required to direct the guidewire inferiorly. The guidewire is advanced into the distal descending aorta, and the catheter may be advanced over it. If a longer guidewire is required, it may be exchanged at this point. Usually a 260-cm angled-tip Glidewire is a reasonable choice. The MPB catheter may then be exchanged for a long (90 or 100 cm), straight catheter. The guidewire is advanced into the femoral artery using the steerable tip and using the catheter for support. After the catheter has reached the SFA, the guidewire is withdrawn and the arteriogram is performed.

If endovascular therapy is appropriate, the guidewire is replaced and a long (70 or 90 cm) 6 or 7 Fr sheath is placed over the guidewire. The patient is heparinized to protect the brachial access site from thrombosis and prevent thrombus formation along the lengthy sheath. The steerable Glidewire is advanced antegrade into the infrapopliteal arteries. The long sheath provides extra support for the guidewire and helps to maintain its pushability and steerability. Consider passing an angled-tip catheter, such as a Berenstein, through the sheath to assist in directing the guidewire across the lesion.

PLAN OF ATTACK: Guidewire–Catheter Buckling

A catheter–guidewire combination that buckles when the catheter is advanced (Fig. 4) has lost its pushability. This is usually because of distance or tortuosity.

1. Double check that the guidewire–catheter position is intraluminal and not subintimal.
2. Try a stiffer guidewire (e.g., Amplatz Super-stiff).
3. Use a long sheath to decrease friction over the length of the catheter.
4. Try a stiffer catheter (e.g., nylon) if catheter head shape alternatives are not limited.

Try a different approach with a shorter or straighter course, rather than force one that is not going to work.

Passing Through Aneurysms

The development of stent–graft treatment of abdominal aortic aneurysms has resulted in more frequent and aggressive catheterization of aneurysms than ever before. Passing catheters through aneurysms is associated with a risk of embolization of the compacted thrombus in the aneurysm sac. Associated occlusive disease that involves the neck of the aneurysm tends to be friable, and embolization is an even higher risk when this material is present. The usual approach is retrograde through the common femoral artery. Passing through aneurysms involves crossing the iliac arteries, which may also be aneurysmal, and then getting through the abdominal aortic aneurysm.

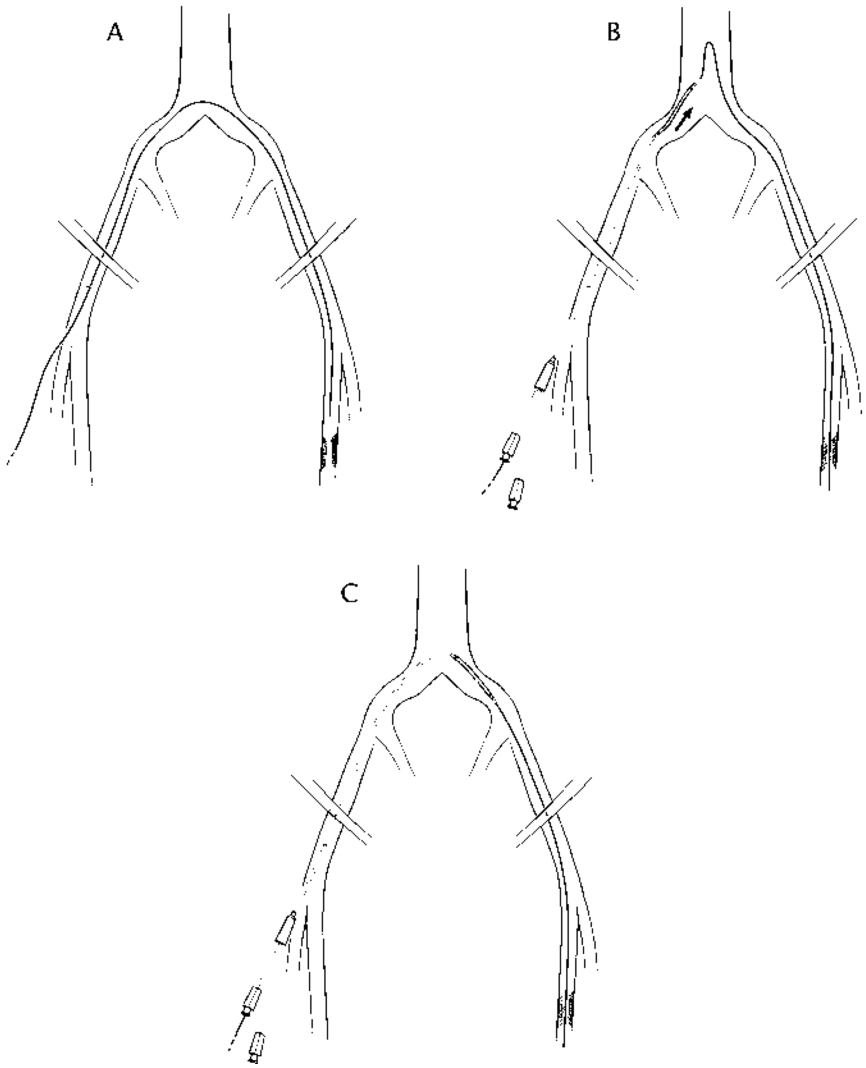

Fig. 4 Guidewire–catheter buckling. A, A contralateral approach is selected for treatment of a proximal superficial femoral artery stenosis. **B,** Advancement of the balloon catheter results in buckling of the guidewire and catheter into the distal aorta. The guidewire–catheter combination often buckles when the approach to the target is lengthy or tortuous. **C,** The standard guidewire is exchanged for a stiffer guidewire so that the catheter tracks over it. **D,** A long, curved sheath (Cook, Inc.) can be placed over the aortic bifurcation to reduce tortuosity and friction and deliver the catheter antegrade into the iliac artery. **E,** The contralateral access approach can be abandoned in favor of an ipsilateral antegrade femoral artery puncture.

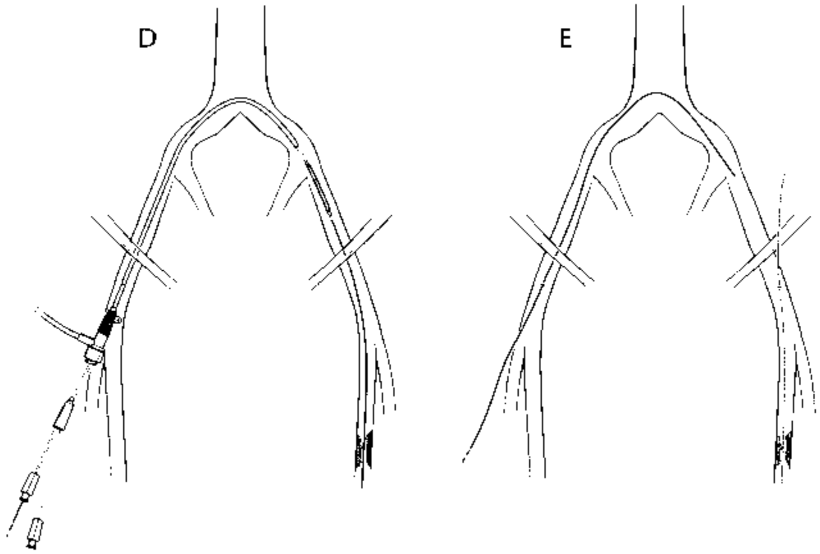

Fig. 4 (Continued)

Tortuosity of the iliac arteries may make the approach challenging, especially if there is associated occlusive disease. Because occlusive disease causes an iliac segment to be relatively fixed in configuration and less pliable, the angle of curvature is more extreme in the more compliant, juxtaposed segments. Unfortunately, this causes the occlusive lesions to be present at either end of a tortuous segment. Therefore, the operator must be prepared to use steerable guidewires and selective catheters to cross the aneurysm. Likewise, if significant tortuosity occurs in an aneurysmal common iliac artery, the guidewire may want to "pile up" inside the iliac aneurysm and the neck may be difficult to find since it is not a straight shot. Passage of a guidewire through a large abdominal aortic aneurysm can be difficult if the neck is hard to find. High-pressure contrast injection into the aneurysm to define anatomy is contraindicated. Puffing contrast in the iliac arteries may be useful but in the aneurysm it is useless since there is tremendous mixing with nonopacified blood. Multiple attempts at passage are sometimes required. Advancing the guidewire during diastole usually increases the likelihood of finding the neck. The guidewire should not be placed so redundantly into the aneurysm that it curls up within the sac. It is a counterproductive maneuver and may result in embolization of aneurysm contents or tangling of the guidewire.

It is usually best to pass a starting guidewire from the femoral artery using fluoroscopy. Often, the guidewire will pass without specific direction, despite tortuosity and nearly blind sacs. If it does not pass, place an angled-tip catheter over it, such as an MPB or a Berenstein or a Teg-T. Exchange for a steerable guidewire and advance carefully. Puff contrast into the iliac

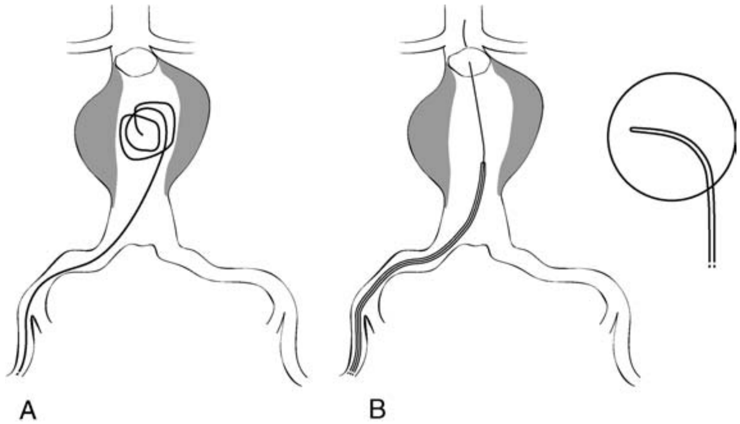

Fig. 5 Crossing an aneurysm. A, The guidewire tends to pile up in the aorta when crossing an aneurysm. **B,** A multipurpose, simple-curve selective catheter, such as an MPB, may be used to direct the guidewire past tortuous iliac and aortic segments.

arteries if necessary. If a CT scan or other imaging study is available, refer to that for clues about what to expect. After entering the aneurysm from below, advance the angled-tip catheter over the guidewire and use it to point the guidewire toward the neck of the aneurysm (Fig. 5). Always use a floppy-tipped guidewire.

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5

Imaging

How to See Where You Are Going

Are We Ready to See?
Image Quality
Generating an X-Ray Image
Digital Subtraction Arteriography Versus Cut Film Arteriography
Imaging Technique for Best Resolution
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Are We Ready to See?

The heritage of surgery provides many things of which we are proud. However, one of the things for which we have struggled needlessly is our past willingness to perform procedures blindly, or at least with less precision and guidance than we could have had. Chest tubes, central lines, paracentesis, thoracentesis, drains: we provided these services by knowing the anatomy so well that we almost always got them in the right place. When newer imaging options became available, we were slow to utilize them. Consequently, many of these procedures have been passed to other specialists who are able to use imaging for better precision. Other disciplines have established for themselves the importance of imaging and guidance in performing procedures. This explains why cardiologists and radiologists have at their disposal millions of dollars worth of imaging equipment on a 24/7 basis, and it is assumed to be an absolute necessity, and yet, many surgeons are still being forced to argue for imaging capabilities on a case-by-case basis. We did not convince ourselves early enough that imaging was important. As we have become convinced, we have been only partially successful at convincing others, such as hospital administrators. If we really want to see, we need to make it clear to everyone, both within and outside our field, that we must be able to see well and at all times.

Image Quality

The fluoroscopic image provides the equivalent of surgical exposure. High-quality images do not necessarily ensure a good result, but poor-quality images risk a bad one. Despite its importance, assessing image quality is an ambiguous task at best. How good is good enough? How do you know if there is something you are missing? The simplest way to know good imaging is to have a lot of experience with bad imaging, which many surgeons have. Will two-dimensional images of hollow, tubular, dynamic structures ever be good enough to tell us everything? Probably not! In addition, surgeons know from first-hand experience that arteriography routinely and predictably underrepresents the severity of disease at bifurcations (aortic bifurcation, carotid bifurcation), along posterior walls (common femoral, iliac), and at other locations. Fluoroscopic imaging is not perfect, even the best available, but we need it if we plan to move our field ahead.

Imaging equipment must be versatile and functional so that it does not lengthen a procedure needlessly. The operator must be prepared to work within but also maximize the capabilities of the imaging equipment that has been procured. Images must be available and adequate so that strategic decisions may be made during the procedure. Images may differ somewhat depending upon whether they are monitor images or hard copy. Many surgeons are accustomed to making decisions after studying longitudinal arterial images on hard copy. Digital arteriography affords the opportunity to have high-quality monitor images available for immediate decision-making.

The practical determinants of image quality are listed in Table 1. The mode of image acquisition usually depends upon available equipment and may be either digital subtraction arteriography (DSA) or cut film arteriography. Cut film arteriography is rapidly becoming obsolete. Although it is possible to create beautiful arteriographic images, it is not well suited for the moment-to-moment decision making required to guide an endovascular therapeutic intervention. DSA is emerging as the imaging method of choice for this and other reasons. The technology built into the imaging equipment determines its capabilities. The greater the number of pixels that contribute to the image, the higher the resolution. The higher the heating capacity, the less likely it is that the images will blur or fade during the procedure. These types of issues are under human control only at the time of purchase. The quality of the image may vary, depending upon its presentation: whether it is viewed on the television monitor or in its hard-copy form. Imaging technique is a very important factor controlled by the operator. Specific maneuvers that affect x-ray beam generation and scatter are discussed below. Contrast concentration and method of injection (automated versus hand-powered) must be tailored to the situation. The patient's size may dramatically alter the distance from the image intensifier to the target artery and will affect the resultant images accordingly.

Table 1 What Determines Image Quality?

Presentation of image	Television monitor
	Hard copy
Mode of image acquisition	Digital subtraction
	Cut film
Technology of imaging equipment	Pixels
	Post-processing
	Other
Optimizing x-ray settings	Kilovoltage
	Milliamperes
	Focal spot
Imaging technique (see Table 2)	See Table 2
Contrast injection	Timing
	Bolus size
Patient factors	Patient size
	Anatomy being imaged
	Motion

Generating an X-Ray Image

The x-ray tube emits a prescribed energy beam that passes through the patient (Fig. 1) (see Chapter 24 for a discussion of the components of imaging equipment). The level of kilovolts (usually 60 to 80 kV) sets the penetrability of the beam. The focal spot (0.15 to 1.2 mm) should be as small as possible for reasonable resolution but should still permit an adequate frame rate The x-rays emitted from the tube (beneath the table) travel through the patient. Some of the x-rays are absorbed and some scatter. Dense objects, such as bone, contrast, and surgical clips, absorb more energy. The remaining energy strikes the image intensifier (above the patient) and is converted to an image created by contrasting varying degrees of x-ray beam absorption. This is transmitted to a television system that displays a moving image. Movement of the area being imaged is avoided, since the demarcated lines of differential beam absorption are blurred by movement.

Digital Subtraction Arteriography Versus Cut Film Arteriography

The advantages and disadvantages of DSA and cut film arteriography are compared in Table 2. The resolution of DSA rivals that of cut film arteriography. In addition, DSA is cheaper, faster, and easier to work with. Continued development of digital systems and attention to variables to improve their resolution are creating images that may exceed the resolution of cut film. Currently, most angiographic suites offer both modes of image acquisition, and they are used in a complementary rather than an exclusionary manner. As DSA improves, more angiographic suites are converting to digital-only systems.

A DSA image is created by first obtaining a mask that is computerized and recorded and later subtracted from the acquired images. After the mask is subtracted, the contrast column is the primary feature of the remaining image. The digital processing system automatically divides the information transmitted from the image intensifier into a matrix, which is composed of pixels. Modern angiographic suites have matrices that are a minimum of 512 × 512 pixels. Many systems are currently available with 1024 × 1024 pixels or more. The more pixels that make up a given field of view, the smaller the pixel and the better the resolution. The images are computerized and recorded in a cineradiographic format. Prior to selecting images for hard copy, the sequences of moving images are evaluated for flow pattern and rate on the control console (Fig. 2). Information that affects decision making is available more rapidly, and the study is tailored to the patient's needs without waiting for films to develop.

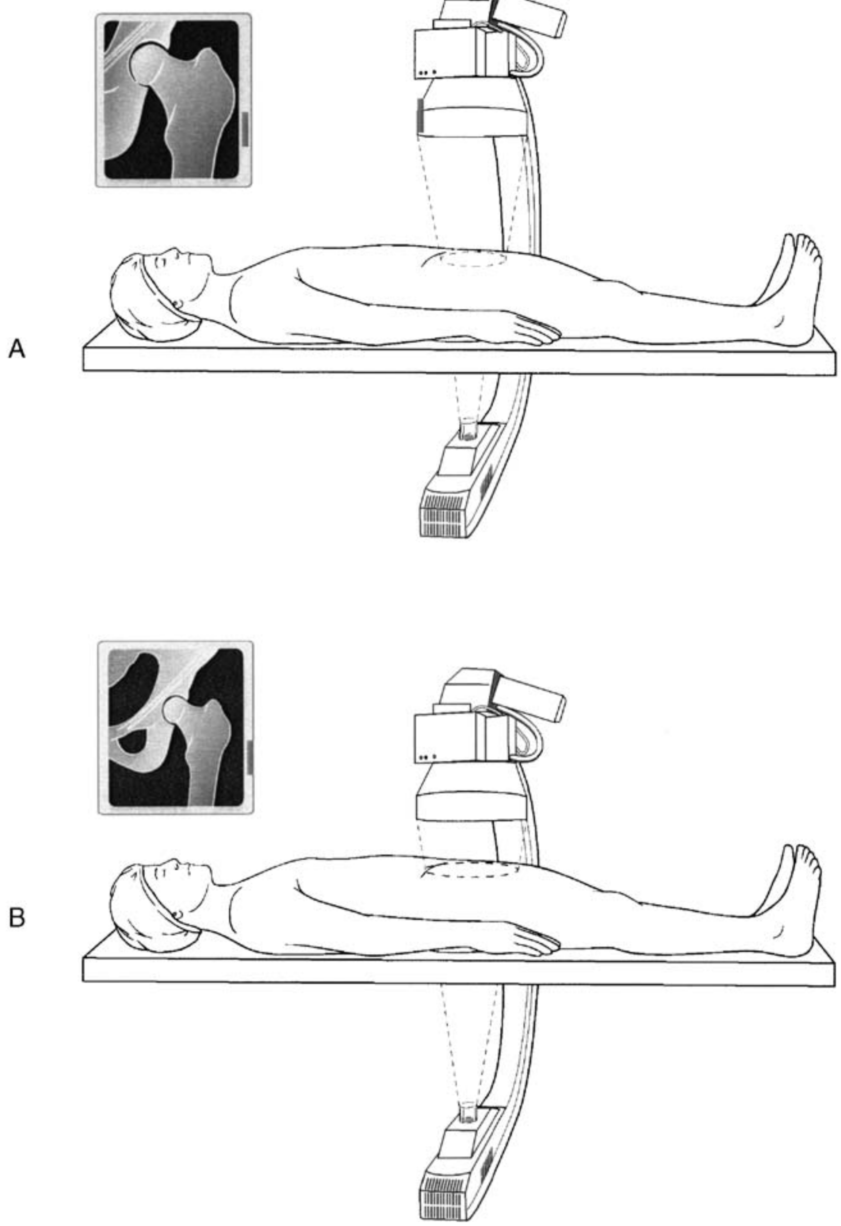

Fig. 1 Production of an x-ray image. A, The x-ray tube emits an energy beam that is partially absorbed by the patient. The remainder of the beam strikes the image intensifier and is converted to an x-ray image. **B,** Placing the image intensifier closer to the patient decreases radiation scatter and broadens the field of view.

Table 2 Digital Subtraction Arteriography Versus Cut Film Arteriography

	Digital subtraction	Cut film
Advantages	Faster	Better resolution
	Less expensive	
	Post-image processing	Unobstructed landmarks
	Continual technologic development	Accurate balloon sizing for angioplasty
	Easier image storage	
Disadvantages	Lower resolution but improving	More guesswork on timing
	Multiple injections required	Delay for films
	More intraluminal and motion artifacts	Cumbersome to view and store
		More contrast required
		Will be obsolete

Timing is simpler with DSA than with cut film arteriography. The image intensifier is placed over the desired arterial segment and image acquisition continues through the period during which the contrast passes through that segment. DSA may be performed with dilute iodinated contrast (to 50%), carbon dioxide, or gadolinium, to decrease contrast load in selected situations. DSA permits postimage processing, which helps to enhance or delineate an image further. Digital information may be accumulated at rates of up to 30 frames per second, although two to four frames per second is usually adequate. The DSA field of view is specified by the digital equipment available but is often smaller than the standard 14-in. cut film, depending upon the vintage of the equipment. Precision is essential to optimally visualize the area of interest with the field of view that accompanies the chosen film type.

DSA requires more work than cut film arteriography when an entire runoff must be obtained, unless bolus chase is available. Most digital systems require a separate mask, position, injection, and filming run for each level of the arterial tree. Newer bolus chase technology is now available that allows the runoff to be obtained in sequence as a single run. In the past, the field of view for most digital systems was smaller (9 to 11 in.) than for cut film (14 in.), but 16-in. image intensifiers are now available in digital angiographic suites, and 12-in. image intensifiers are available on portable digital units.

A cut film arteriogram must be developed and the images cannot be manipulated after exposure. Cut film arteriography relies on the movement of an exchange table and the function of a rapid film changer. The timing of contrast flow must be anticipated so that it passes through the arterial segment at the time the images are being acquired. This requires some guesswork on timing to obtain optimal films. Cut film arteriography has

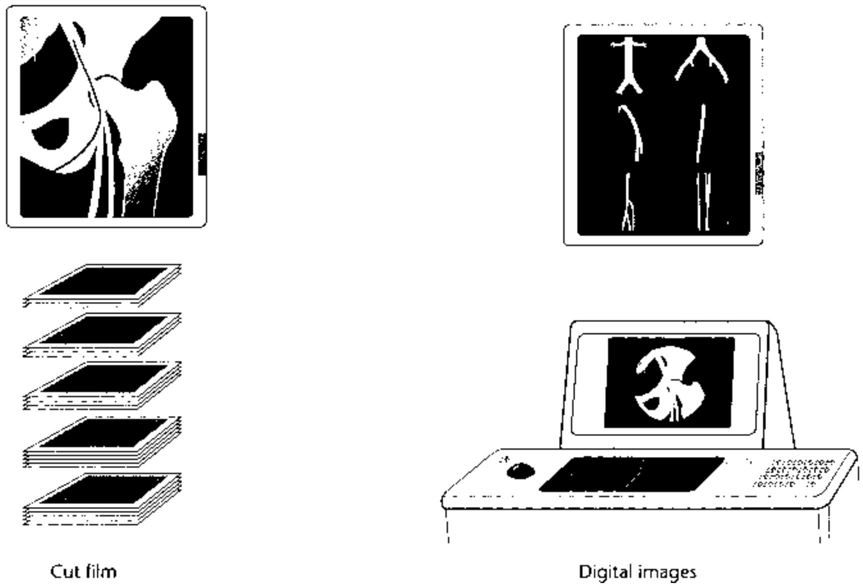

Fig. 2 The process and production of cut film and digital images. The processing and presentation of images varies significantly for cut film and digital sequences. In this example of an aortogram with lower-extremity runoff, the cut film sequence results in the accumulation of 20 films. A few images are recorded at each of five stations. The digital images can be reviewed on the control screen and post-image processing performed. Representative images are selected and committed to hard copy.

excellent resolution but is more cumbersome and expensive. There is an intraprocedural waiting time between exposure and development. Most of the films obtained at a given filming station do not contain adequate contrast density and must be sorted. These suboptimal images are usually saved and stored even though they contribute little to the study. Films are heavier, larger, and more expensive to produce and to store.

The future of arteriography depends on DSA and the continued improvement of its resolution.

Imaging Technique for Best Resolution

Imaging technique is one factor within control of the operator that significantly affects the quality of the resulting images. Specific maneuvers that improve resolution are listed in Table 3. Placing the image intensifier closer to the patient decreases x-ray scatter but also decreases magnification. Motion must be minimized by all potentially moving parts to prevent blurring of the image. Most digital imaging systems provide several

Table 3 Techniques for Enhanced Image Resolution

Center the area of interest within the field of view.
Minimize the distance between image intensifier and patient to reduce scatter.
Use a smaller field of view to provide magnification.
Filter the unimportant parts of the image to reduce scatter.
Remove extraneous objects such as leads, wires, tubes, heating blanket.
Minimize patient motion—coach breathing, use isosmolar contrast, keep patient comfortable.
Obtain appropriate obliques.

differently sized fields of view (e.g., 4, 9, or 11 in.). A smaller field of view magnifies the area of interest and improves resolution. The operator must balance the disparity between an adequately sized field in which to work and the degree of resolution that comes with it. Using the appropriate contrast type, concentration, and method of injection enhances imaging and also decreases patient movement since the contrast is better tolerated. Extraneous objects should be removed from the field. An x-ray of the operator's hand is bad form as well. Remain focused on the area of interest until it has been adequately interrogated. Oblique views or changes in patient positioning may be required. Decreasing kilovoltage improves resolution but increases radiation. A smaller focal spot improves resolution but decreases frame rate and energy available for image production. An increase in the number of frames acquired per second during DSA increases radiation exposure but also improves resolution, creating a motion picture effect, and may provide a better understanding of lesions with almost real-time observation of contrast flow. Some high-flow lesions, such as arterio-venous fistulas, may only be identified and evaluated using high frame rates (up to 30 frames per second). The object of interest should be centered in the field of view and the beam filtered to decrease scatter.

ANGIO CONSULT: How Can I Get Better Images?

1. Include as much of the area of interest in one field as possible. For example, if there is both aortic and iliac disease, include both in the appropriate field.
2. Position the patient and the image intensifier before imaging is begun.
3. Use magnification to enhance detail in a specific area of interrogation. This can be achieved by changing to a smaller field of view (e.g., 4 or 6 in. instead of 9 or 12 in.).
4. Decrease the kilovoltage to increase image contrast (see Chapter 24).
5. Use the smallest possible focal spot.
6. Move the image intensifier closer to the patient to reduce scatter.
7. Increase the resolution (and radiation) of DSA by using a higher number of frames per second.

8. Minimize motion, especially with DSA. This usually requires coaching (for breathholding during aortography), sedation, restraint (taping the leg to the angiography table if necessary), or a combination of these.
9. Filter the x-ray beam to reduce scatter.
10. Use the appropriate concentration of contrast (in low-flow situations, contrast may be diluted and still image well as a column)
11. Use contrast that is well tolerated in the awake patient, especially when imaging an ischemic limb (low osmolality).
12. Inject contrast as close to the target site as is safe. The catheter head must be positioned to deliver an adequate bolus to the area of interest, taking into account the rate of flow in the vessel.
13. Use DSA to estimate the optimal timing for contrast flow on cut film arteriography.
14. Subtract bony landmarks.
15. Use catheters and sheaths with radiopaque tips.
16. Initiate filming in the best projection (i.e., an oblique view) for a given artery.
17. Be as specific as possible about what information is required.

When to Use Road Mapping and How It Works

Road mapping is a feature of digital units that permits real-time guidewire–catheter guidance. Road mapping works by subtracting the initial noncontrast mask from the field, thus eliminating bony landmarks. Contrast is injected that opacifies the vessels in the field of interest. A new mask is digitally constructed that is added to or superimposed upon the subsequent real-time images on the television screen. Any moving items that are later passed into the field, such as guidewires or catheters, are seen on the monitor screen within the framework of the initially acquired road map (see Fig. 3).

Road mapping is often discussed but not often required. The more technically proficient an operator becomes, the less frequently this technique is useful. Road mapping is useful in (1) finding and marking the vessel origin during selective catheterization, (2) passing through a critically stenotic arterial segment, (3) encountering and crossing an occlusion, (4) guiding the puncture of a pulseless artery, (5) guiding sequential maneuvers in a complex reconstruction without multiple interval arteriograms, and (6) guiding thrombectomy or embolectomy.

Road mapping is an extra step and is only worth the extra procedure time when undertaking specific tasks. It takes time to set up. Misfires are frequent, seemingly regardless of the type of equipment. The resolution of the road-mapped images is poor and often quite grainy so they are not useful for small vessel work. The road map mask also blurs with motion

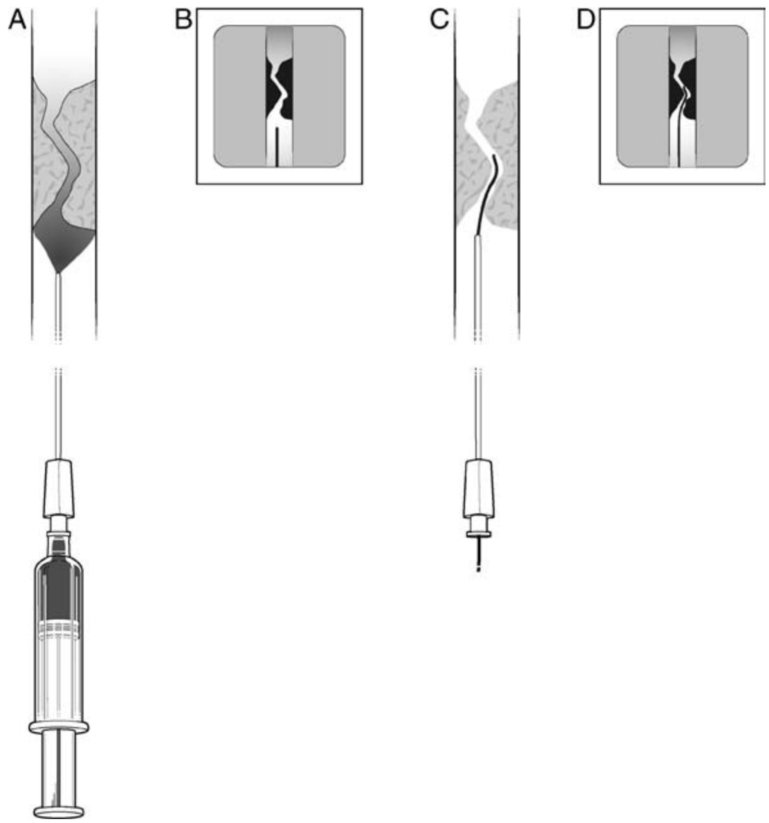

Fig. 3 Use road mapping to cross a lesion. Road mapping can be used to cross a stenosis or occlusion or assist in selective catheterization. **A,** The tip of the arteriographic catheter is placed in proximity to the lesion. Contrast is administered and an image of the opacified lesion is digitized and recorded. **B,** The road map is superimposed on the real-time fluoroscopic image. **C,** The guidewire is passed through the lesion using the road map as a guide. **D,** The guidewire is observed real-time on the monitor with the image of the lesion superimposed.

and with time so that the image quality further degrades during usage. Interval fluoroscopy or arteriography requires loss of the road map.

Automated Power Injector

When performing aortography through a 65- to 100-cm length, 4 or 5 Fr catheter, high pressure (up to 1050 psi) is required to produce an adequate bolus of contrast. It must be emitted over a short period of time against arterial pressure, and no rate of rise in pressure over time is required. Power injectors provide a pressure of up to 2000 pounds per square inch (psi). Each individual arteriographic catheter has a manufacturers' recommended limit of psi for power injection. The automated power injector can be integrated with the filming run to predetermine the timing of contrast injection. The power injector offers a constant rate and pressure of injection. Percutaneous arteriography using small catheters would not be possible without a power injector (Fig. 4). (A usual injection sequence would include a bolus of 4 to 10 ml of contrast per second for 2 to 10 sec, depending upon the type of arteriogram.) Contrast injection, filming, and arteriography sequences are detailed in Chapter 8. The power injector also represents an additional link in the arteriographic system—more connections that may leak under high pressure, more preparation time, and more potential for a misfire during a filming run. Power injection should not be performed when the contrast jet has the potential to cause arterial injury in an aneurysm, against the arterial wall, or in a lesion (Fig. 5).

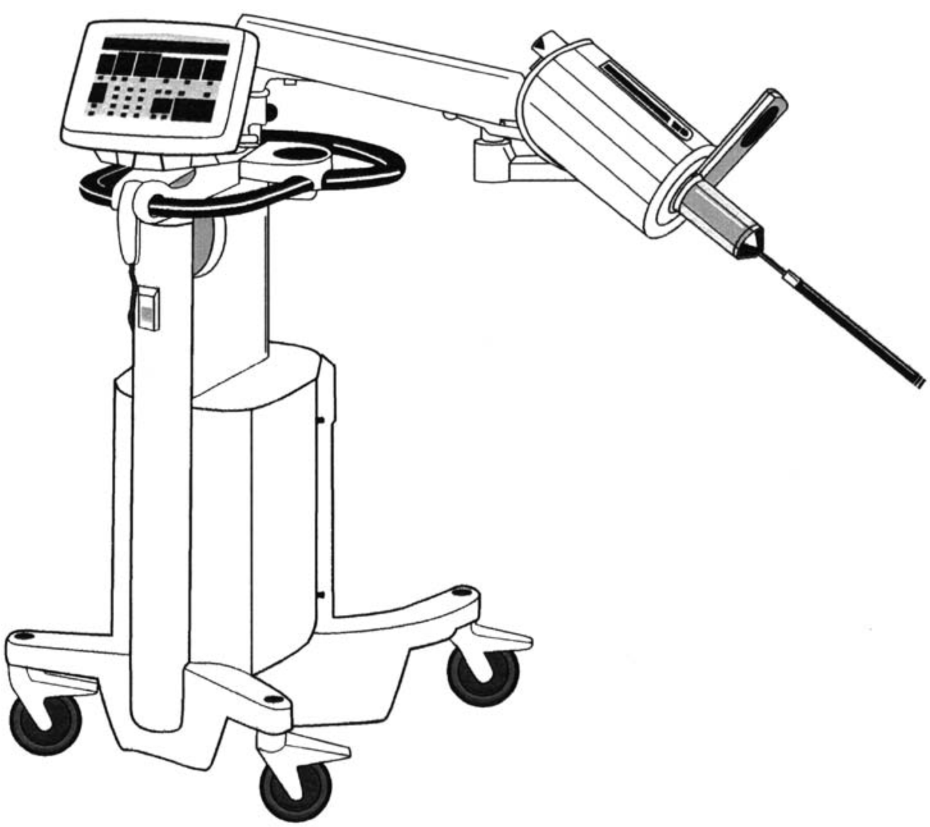

Fig. 4 Power injector. An automated power injector permits high-pressure administration of contrast. A timed bolus of contrast is delivered at a preset pressure. A rate of rise of pressure is introduced when an end hole catheter is used in a side branch.

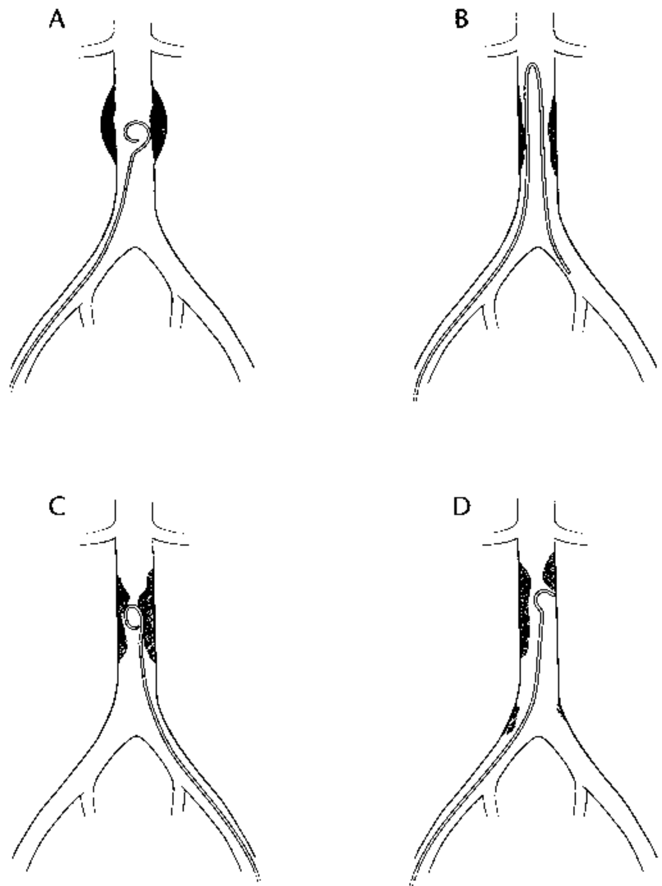

Fig. 5 Power injection is not used when an artery could be injured. A, Compacted thrombus within an aneurysm may fragment as a result of high-pressure contrast administration. **B,** Significant recoil may result from high-pressure injection. Redundancy is removed to prevent catheter whip. **C,** The catheter head may be constrained by its position within an occlusive lesion. When the catheter head changes shape under pressure, the lesion may fragment. **D,** The tip of the catheter may be against the aortic wall rather than free within its lumen.

Power Injection Versus Injection by Hand

Contrast may be injected using an automated power injector or hand power (Table 4). These two methods are often combined during an arteriographic procedure to complement each other. The high viscosity of contrast and the small caliber of catheters make contrast administration challenging at times.

When power injection is not mandatory, it is often faster and simpler to administer the contrast by hand. Hand injection can be used to puff contrast in any location and should be considered when the contrast volume required

Table 4 Contrast Administration: Automated Versus Hand Powered

Location of catheter head	Power injector	Hand power	Either
Aortic arch	X		
Innominate	X		
Subclavian artery	X		
Axillary artery			X
Carotid artery			X
Thoracic aorta	X		
Visceral aorta	X		
Visceral arteries			X
Renal artery			X
Infrarenal aorta[a]	X		
Iliac artery[b]	X		
Femoral artery			X
Popliteal artery			X
Tibial artery		X	
Infrainguinal graft		X	

[a] Hand-powered aortogram may be obtained using a ≥7 Fr sheath.
[b] Hand-powered iliac arteriography may be obtained using a ≥7 Fr sheath.

is 20 ml or less, the conduit is large (7 Fr or more), and there is lower flow (e.g., most selective arteriography or distal to a flow-limiting lesion). The smaller the syringe, the higher the positive pressure that can be achieved during injection. The accuracy of this method improves significantly with clinical experience.

Volume and flow rate in the aorta are usually enough to overwhelm pressure generated by hand. A power injector is required for performing aortography through a 4 or 5 Fr catheter. Under special circumstances (e.g., a combined procedure in the operating room), some limited aortic or iliac arteriography can be performed through a larger sheath with the tip placed near the site of interest and a hand-injected contrast bolus of 10 to 20 ml.

Selective, branch vessel arteriography and lower-extremity arteriography may be performed with either hand injection or the power injector. These situations require a smaller volume at a lower flow rate than the aorta or iliac arteries. Injection by hand may be preferable in some situations (e.g., infrapopliteal artery, vertebral artery).

Whether contrast is administered by hand power or injector, all air bubbles must be removed from the system prior to injection. This is a ritual that is followed multiple times per day in angiographic suites around the world. The catheter is aspirated and the injector tubing is purged. The sterile tubing is luer-locked to the catheter. The catheter is then aspirated (through the injector) until blood returns, and the clear injector tubing is inspected for bubbles. This maneuver is extremely important during cerebral and visceral arteriography, since a bubble, even a tiny one, is an embolus. Injection sequences are discussed in detail in Chapter 8.

Contrast Agents

There are several factors to consider in selecting the appropriate contrast solution, including osmolality, ionic charge, cost, and complications (Table 5). Standard contrast contains iodine, which is highly absorptive of x-rays. Available contrast agents are hyperosmolar (320 to 1700 mOsm) in comparison to blood (approximately 300 mOsm). Many of the complications of contrast are related to its hyperosmolarity, such as pain on injection, cardiac overload, and renal toxicity. The lower the osmolality, the better it is tolerated physiologically but the more expensive it becomes. Nonionic contrast has a lower incidence of common systemic complications but is more expensive. Life-threatening reactions, such as anaphylaxis, may occur with either ionic or nonionic contrast administration and the incidence is about the same with each. Nonionic contrast causes fewer complications since its osmolarity is about half that of the less expensive, traditional ionic contrast. Contrast concentration must be adequate for the type of imaging selected. Cut film arteriography requires 300 μg of iodine per milliliter (full strength), whereas DSA can be performed with dilutions to 150 μg/ml (50%). Total contrast loads vary substantially depending upon whether a strategic or therapeutic procedure has been performed. Patients with normal renal and cardiac function usually tolerate several hundred milliliters of contrast without complication.

More recently, gadolinium has been used as an injectable contrast agent. This was developed for use with magnetic resonance imaging but does

Table 5 Examples of Iodinated Contrast Media

	Generic name	Trade name	Iodine content (mg iodine/ml)	Osmolality (mOsm/kg H_2O)
Ionic	Sodium distrizoate	Hypaque sodium 25%	150	696
	Meglumine diatrizoate	Renograffin-60	292	1549
	Meglamine iothalamate	Conray-30	141	681
	Meglumine ioxaglate	Hexabrix	320	600
Nonionic	Iopamidol	Isovue #28	128	290
	Iohexol	Omnipaque 140	140	322
	Ioversol	Optiray 320	320	702
	Iohexol	Omnipaque 240	240	520
	Iotrolan	Visipaque[a]	320	290

[a] Author's choice. High iodine concentration increases resolution, while low osmolality decreases complications. Major disadvantage is cost.

absorb standard x-rays and may be considered for use in patients with renal insufficiency. The total safe dose is not known. The resolution is not as good as with nonionic, iodinated contrast and it is even more expensive. In vascular beds, where it becomes dilute, it is less useful. Carbon dioxide has also been employed but has some distinct disadvantages. When CO_2 encounters occlusive disease, it tends to break up into bubbles, making images difficult to interpret. Since it is a gas, it will rise. The patient must be positioned so that the CO_2 will flow and not form an airlock. Brachiocephalic arteriography using CO_2 is contraindicated since bubbles may cause stroke. Viceral, or even upper abdominal, aortic injection may result in visceral ischemia due to airlock.

ANGIO CONSULT: Is There Any Way to Limit Contrast Load?

1. Keep an ongoing tally of usage. Each bottle contains 50 or 100 ml.
2. Have a clear plan for how much arteriography is required. Be specific about which information is required and which anatomic beds require delineation (see Chapter 8 for a detailed discussion of strategic arteriography).
3. Use the clinical presentation and duplex scanning to help limit arteriography.
4. Go directly to an oblique view when treating lesions in certain areas (e.g., femoral or iliac bifurcations).
5. Dilute contrast when using DSA.
6. Puff only 1 to 3 ml of contrast at a time. Information gained from puffing contrast is usually not conclusive and is used to indicate anatomic position or to detect the presence of a major complication. An arteriographic sequence is usually required for more detail.
7. Be specific about catheter head placement for arteriographic runs (e.g., catheter head placement for an aortogram should be at the level of the renal arteries; high-pressure injection refluxes the contrast proximally despite arterial flow and if the catheter head is too high, a major portion of the contrast bolus will be lost in the visceral arteries).

Radiation Safety and Occupational Health Issues

Numerous occupational health issues require vigilant attention and preventive steps (Table 6). The maximum safe occupational whole body x-ray dose per year is 5 rems. Up to 75 rems may be absorbed by the hands and 15 rems to the thyroid. Radiation exposure causes cataracts and cancer. Leaded glasses, a thyroid shield, and lead apron are recommended. Thyroid cancer, lymphoma,

Table 6 Occupational Risks of Endovascular Work

Radiation exposure	**Watching monitor**
Cataracts	Cervical radiculopathy
Thyroid cancer	
Hematopoietic cancer	**Wearing lead**
Skin cancers/other lesions	Back strain
Other cancers	Disc herniation
Sterility/impotence	

or impotence may result from x-ray exposure. Cervical radiculopathy and low back strain and disc problems have been reported in relationship to wearing lead aprons and extending the neck to see the image monitor.

Scatter is the main source of radiation to the operator. Exposure to scatter decreases as the inverse square of the distance from the primary x-ray beam. Scatter radiation also decreases significantly as the fluoroscopic field size is decreased. Most portable and stationary systems are designed with the image intensifier above the patient and the tube emitting x-rays below. This arrangement decreases operator exposure by half. In addition, judicious use of fluoroscopy or pulsed fluoroscopy decreases exposure proportionately. Protective devices such as a lead apron (0.5 mm lead), lead shields, leaded glasses with side shields, and thyroid collars should be used.

How Do You Know Where You Are?

The best answer to this question is to go there often so that familiar appearances become internalized. Table 7 lists several methods of reminding yourself where your guidewire or catheter is located as you are starting out. As an endovascular operator, you get used to processing all these bits of

Table 7 How Do You Know Where You Are?

During guidewire passage	**Anytime during the case**
Follow guidewire progress with fluoroscopy	Internal landmarks
Road map	Vascular calcification
During catheter passage	Surgical clips
Use catheter with radiopaque tip	Bony structures, such as ribs, vertebral bodies, joints, pelvic landmarks, limb bones
Follow catheter progress with fluoroscopy	External landmarks
Puff contrast	Ruler
Road map	Stent-guide
Magnify field to visualize catheter head	Clamp

information while gazing at a fluoroscopic image, and having a sense of where you are becomes second nature.

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6

More About How to Get Where You Are Going

Selective Catheterization

Too Many Choices!

Angio Consult: What Is Your Strategy for Selective Catheterization?

Selective Catheterization of the Brachiocephalic Arteries

Selective Catheterization of the Visceral and Renal Arteries

Selective Catheterization of the Aortoiliac Arteries

Plan of Attack: Crossing the Aortic Bifurcation

Selective Catheterization of the Infrainguinal Arteries

Technique: Entering an Infrainguinal Vein Graft

Selective Catheterization of Prosthetic Bypass Grafts

Selected Readings

Too Many Choices!

Selective catheterization is a basic tool that permits more detailed and focused arteriography and allows delivery of therapeutic devices. Selective catheterization is facilitated by taking a direct approach and by gaining facility with a couple of top catheter head choices for each application. Table 1 details options for approaching selective catheterization of various arteries. Table 2 provides an example of top catheter choices for each task.

Endovascular intervention is only rarely limited by the technical ability to arrive at a remote vascular location. This is a result of improving technology that enables catheter placement in almost any location. A by-product of this improvement in technology is a broad array of selective

Table 1 Approaches to Selective Catheterization and Arteriography

Destination vascular bed	Approach: first choice	Alternative approach
Brachiocephalic		
Carotid	Either femoral	Left brachial (when femoral approach contraindicated)
Subclavian	Either femoral	Ipsilateral brachial (for endovascular therapy in some patients or when femoral approach is contraindicated)
Visceral		
Celiac/SMA	Either femoral	Left brachial (for endovascular therapy in some patients)
Renal	Contralateral femoral	Left brachial (for endovascular therapy when renal artery origin is at an acute angle or when there is severe aortoiliac disease)
Aortoiliac		
Infrarenal aorta	Either femoral	Left brachial (when femoral approach is contraindicated)
Common iliac	Contralateral femoral	Ipsilateral femoral (when endovascular therapy is planned)
Internal iliac	Contralateral femoral	Left brachial (when contralateral femoral approach is contraindicated)
External iliac	Contralateral femoral	Ipsilateral femoral (when contralateral femoral approach is contraindicated)
Infrainguinal		
Femoral Popliteal Tibial Pedal	Contralateral femoral	Ipsilateral retrograde femoral (when only arteriographic runoff is planned) Ipsilateral antegrade femoral (when there is no inflow disease and endovascular therapy is planned)

Table 2 Catheter Options for Selective Catheterization

	First choice	Second choice	Third choice
Brachiocephalic			
Innominate/right carotid	H1	Simmons	Vitek
Left carotid	Angled Glidecath	H^1	Simmons
Left subclavian	Angled Glidecath	H^1	Simmons or H3
Visceral			
Celiac/SMA	RIM	Chuang-C	Chuang-3
Renal	C2 cobra	Renal double curve	Sos-Omni
Aortoiliac			
Aortic bifurcation	Omni-flush	RIM	C2 cobra
Infrainguinal			
SFA	Berenstein	Kumpe	Vertebral
Tibial	Teg-T	Kumpe	Vertebral

catheter choices with confusing names and slight variations in shape from one to another. Some of these catheters are tremendously useful, and others were an opportunity for someone in a dimly lit lab somewhere to get their name on a piece of plastic. Nevertheless, each specialist must find what works best in his or her hands and then add additional shapes as specific needs arise. Selective catheterization adds time and complication risk to any procedure and should be reserved for necessary strategic arteriography and/or endovascular treatment.

ANGIO CONSULT: What Is Your Strategy for Selective Catheterization?

1. Complications increase with higher degrees of selectivity (e.g., embolization, occlusion, dissection). How important is the information? Is there another way to obtain that information?
2. If the anticipated catheter time is lengthy (more than 15 or 20 min) or if the catheter is passed into a small-caliber or low-flow vascular bed, heparin administration should be considered.
3. An understanding of what the different catheter heads can do is an important determinant of selective catheterization.
4. Catheter head shape may be modified in situ by passing the guidewire varying distances into the catheter head.
5. The orifice of the selected vessel should be probed with the guidewire tip and the guidewire advanced before the selective catheter is placed.
6. After the vessel is cannulated, the guidewire should be advanced past that point as far as possible (“bury the guidewire”) to prevent it from becoming dislodged during catheter advancement. This provides stable support for the advancing catheter.
7. Crossing lesions should be avoided unless treatment is planned.

8. When endovascular therapy is planned, a stiffer guidewire or a sheath (or both) should be placed if the vessel will tolerate it (e.g., in superficial femoral artery or aortic bifurcation). This enhances control of the lesion intended for treatment. If a long sheath cannot be placed, but additional support is needed, a guiding catheter (e.g., renal) should be considered (Chapter 12).

Selective Catheterization of the Brachiocephalic Arteries

The brachiocephalic arteries are usually approached through the femoral arteries or the left brachial artery. The femoral artery approach requires guidewires and catheters of adequate length to reach the arch branches from the groin. The minimum guidewire length should be 180 cm, and catheters should be 90 to 100 cm in length. A standard retrograde femoral puncture is performed and a pigtail catheter (90 cm) is placed in the ascending aorta. An anterior–posterior arch aortogram is performed (see Chapter 8). This defines the anatomy of the vessel origins and reveals whether there is significant disease in the arch. A 30 to 45 degree left anterior oblique is performed (Fig. 1). This angled view separates the aortic arch branch origins since the aorta courses posteriorly as it moves to the patient's left. The arch branches may be cannulated by using local landmarks. When diffuse or shaggy disease is present in the roof of the aortic arch, selective catheterization of the arch branches may be contraindicated. Systemic heparin is administered prior to selective catheterization of the arch branches. Based upon the vessel planned for catheterization and the angle of its origin from the arch, a selective cerebral catheter is chosen and exchanged for the pigtail. During catheter exchanges, extra care must be taken to avoid guidewire or catheter thrombus and to avoid passing any bubbles through the catheter. Guidewires are removed slowly and steadily, rather than whipped out, to avoid generating microbubbles. Because of the risk of stroke with routine cerebral arteriography, some operators advise withdrawing the catheter head to a position distal to the left subclavian artery origin prior to making catheter exchanges over a guidewire. When a critical stenosis or highly irregular plaque formation is present at the origin of the branch artery, selective cannulation may be unwise. This must be considered on a vessel-by-vessel basis. In the discussion that follows, normal arch branch anatomy is a given. When significant anomalies or unfavorable anatomy occur, additional maneuvers are required that are beyond the scope of this text.

SELECTIVE CEREBRAL CATHETERS

There are a myriad of catheter shapes used for selective cerebral arteriography (Fig. 2). Most operators develop their quiver of favorites and use two or three

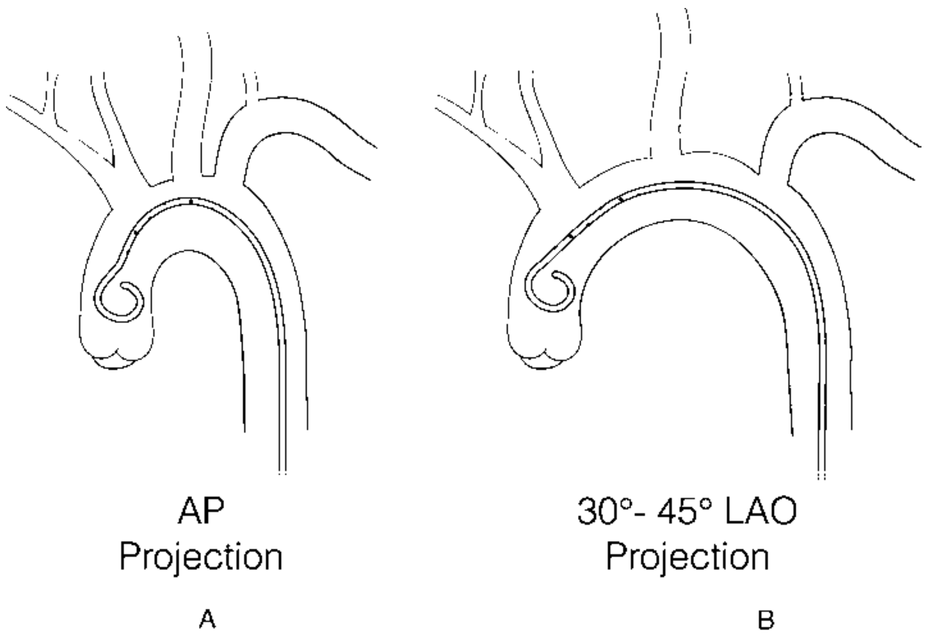


Fig. 1 Arch aortogram using AP or LAO projections. A, The flush catheter is placed in the ascending aorta in preparation for an arch aortogram. **B,** Since the aortic arch travels posteriorly as it moves from right to left, a 30-degree to 45-degree left anterior oblique (LAO) projection is required to "open up" the arch and separate the origins of the arch branches.

catheters routinely for most of the cases they do. These catheters are generally 90 to 100 cm in length, but some are available up to 125 cm The pigtail catheter used for arch aortography has an end hole and multiple side holes for large-volume contrast injection. The selective catheters have only an end hole for passing the guidewire and administering contrast after the guidewire has been removed. When a vessel origin is cannulated with the tip of a selective catheter, contrast may be puffed into the branch vessel without losing contrast into the aortic arch through side holes. However, care must be taken to assure that the tip of the selective catheter is free of the artery wall and distant from unstable lesions prior to any pressure injection, since the only outlet for the contrast is the end hole and any jet effect may cause damage (see Chapter 8).

Although there are an overwhelming number of differently shaped catheters for selective cerebral use, there are really only two major categories; (1) simple-curve catheters, which have an angled or bent tip, and (2) complex-curve catheters, which must be reshaped in the aorta for the catheter head to assume its intended shape. Commonly used simple-curve catheters include the DAV, angled-taper Glidecath (Medi-Tech), H1 Headhunter, and vertebral catheters. This type of catheter is placed into the arch just proximal to the

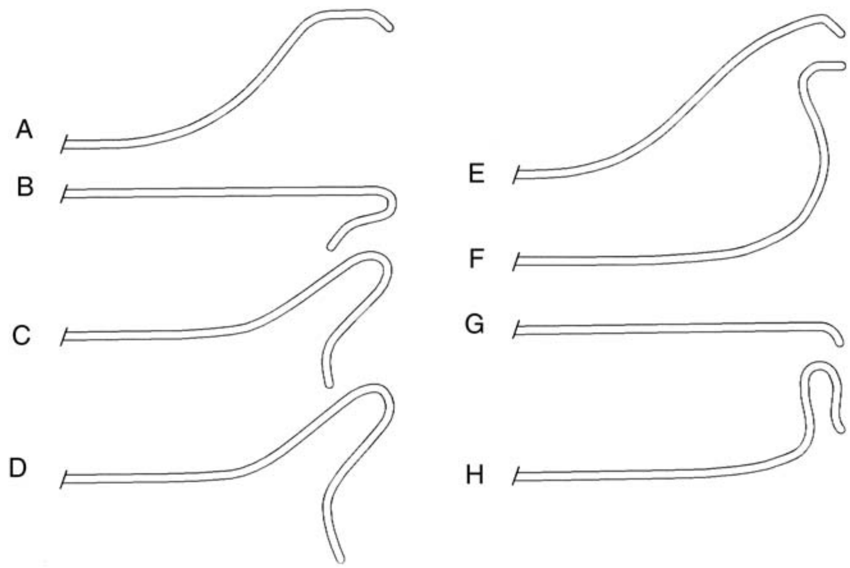


Fig. 2 Selective cerebral catheters. A few of the many examples of specially shaped selective cerebral catheters. These include **A,** H1 Headhunter, **B,** Simmons 1, **C,** Simmons 2, **D,** Simmons 3, **E,** JB 1, **F,** JB 2, **G,** Vert, and **H,** Vitek.

origin of the artery of interest and rotated toward the orifice as it is being withdrawn slightly. Complex-curve cerebral catheters include the Simmons (1, 2, and 3) the H3 Headhunter, the JB2, and the Vitek catheters. These catheters have a head that must be reshaped in either the ascending or descending aorta. The catheter head is placed proximal to the branch vessel origin, and the catheter is simultaneously withdrawn and rotated.

AORTIC ARCH BRANCHES

The image intensifier remains in the left anterior oblique (LAO) position and the approximate location of the vessel origin for cannulation is identified using bony landmarks. For example, the location of the origin of the left common carotid artery may be juxtaposed in the LAO projection to the location of the head of the clavicle. The angled Glidecath or the H1 is passed over the guidewire to the location in the arch just inferior and proximal to the vessel origin (Fig. 3). The guidewire is withdrawn and the catheter tip takes its shape. The simple-curve catheter is rotated and withdrawn slightly so that its tip approaches the origin of the arch branch vessel. The tip of the catheter must be visualized using fluoroscopy and magnified views. The tip of the selective catheter tends to pop into the origin. An angled-tip, steerable Glidewire, usually 180 or 260 cm in length, is advanced into the artery. After the guidewire has been advanced a few centimeters into the artery, nudge the catheter gently to follow the guidewire without popping out of the artery.

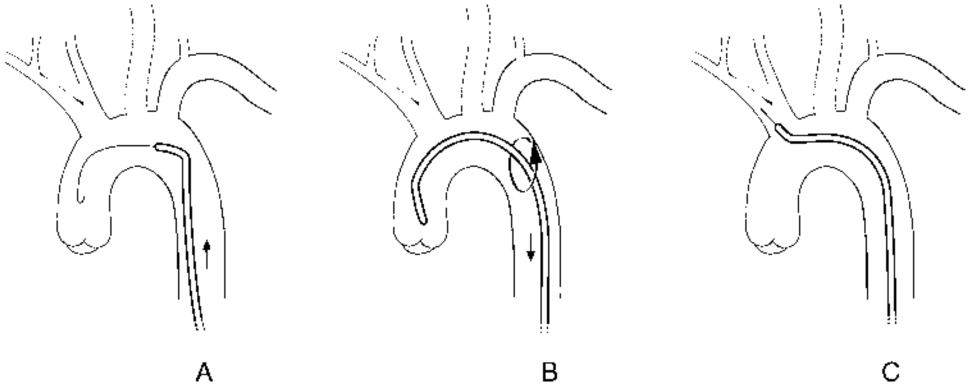


Fig. 3 Selective catheterization using a simple-curve cerebral catheter. A, A guidewire is introduced into the ascending aorta and a simple-curve selective cerebral catheter is advanced over it. **B,** The guidewire is removed, allowing the catheter head to take its shape. The catheter is gently withdrawn and rotated clockwise. **C,** The tip of the catheter pops into the arch branch and the guidewire is advanced to secure access.

Care must be taken to avoid advancing the guidewire tip into the bifurcation or across a lesion. Although this maneuver would add more purchase on the vessel for the catheter to enter the artery, it increases the risk of embolization. Watch the catheter as it is being advanced. If the guidewire does not have enough purchase within the branch artery, the catheter and guidewire together will flip out of the artery. When the catheter follows the guidewire into the artery, it tends to gather up guidewire slack and advance it forward. Care must be taken to avoid an undesired advancement of the guidewire. Refer back to the LAO arch aortogram to estimate the approximate location of the carotid bifurcation.

When cannulating the innominate artery, steer the guidewire into the proximal right subclavian artery. The catheter is advanced over the guidewire and into the right subclavian artery. Cannulation of the right common carotid artery is performed by withdrawing the guidewire into the catheter head and slowly pulling the catheter into the innominate artery. There is usually a small but perceptible jump inferiorly by the catheter tip as it is withdrawn from the origin of the right subclavian artery. The catheter head is rotated medially toward the origin of the right common carotid artery, and the steerable guidewire is advanced. Care must be taken to avoid advancing the guidewire into the bifurcation or across a lesion. The catheter is passed over the guidewire and into the right common carotid artery. If the guidewire will not enter the right common carotid artery, consider an innominate arteriogram in the right anterior oblique projection to show the innominate bifurcation. After the catheter is advanced into the appropriate position, the guidewire is removed steadily, the catheter is aspirated, and a few milliliters of contrast are puffed to check the position of the catheter tip before pressure injection is performed.

The left common carotid artery and left subclavian artery are cannulated in a similar manner. The distance along the aortic arch from the origin of one branch to the next may be short, and it is occasionally a challenge to recognize which vessel has been entered. The catheter is placed so that its tip is just proximal to the left common carotid or left subclavian arteries. The catheter is withdrawn slightly and rotated. When the catheter tip pops into the artery, the guidewire is advanced using the same principles as outlined above. In general, the simple-curve catheter functions well for cannulation of the left subclavian and left common carotid arteries since the angle of approach is usually less severe for these vessels than for the innominate artery.

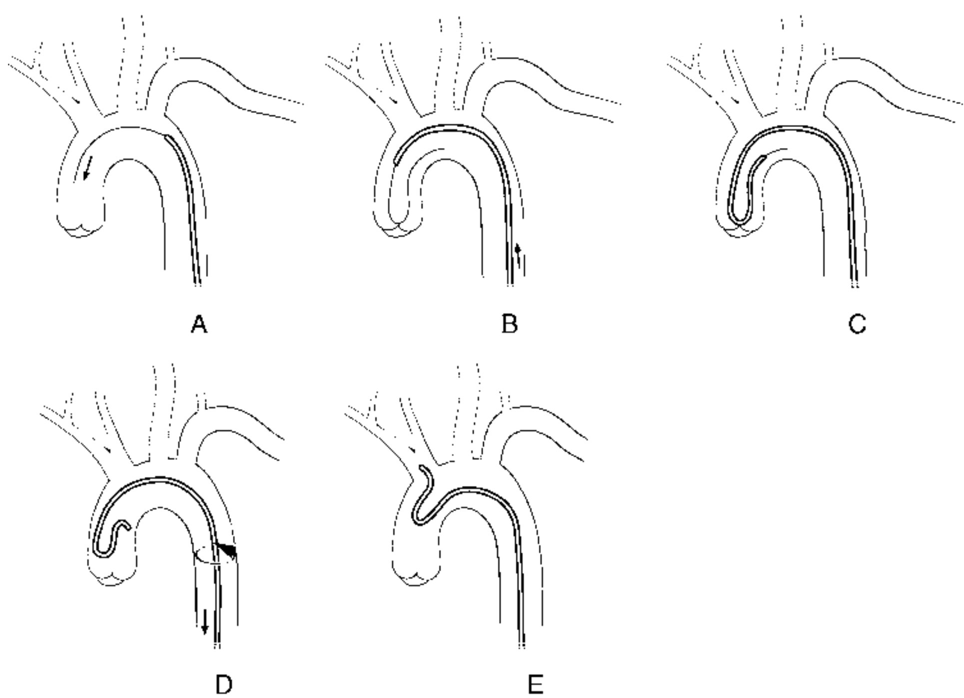


Fig. 4 Selective catheterization using a complex-curve cerebral catheter: reforming a Simmons catheter in the ascending aorta. A, A guidewire is introduced into the ascending aorta and a complex-curve (Simmons) selective cerebral catheter is advanced over it. **B,** The guidewire is allowed to bounce off the aortic valve and come back on itself antegrade in the aortic arch. The catheter is advanced into the ascending aorta. **C,** The catheter follows the guidewire antegrade into the aortic arch. **D,** The guidewire is removed and the catheter head has reformed in the ascending aorta. The catheter is gently withdrawn and rotated clockwise. **E,** The tip of the catheter engages the origin of the arch branch as the tip spins superiorly.

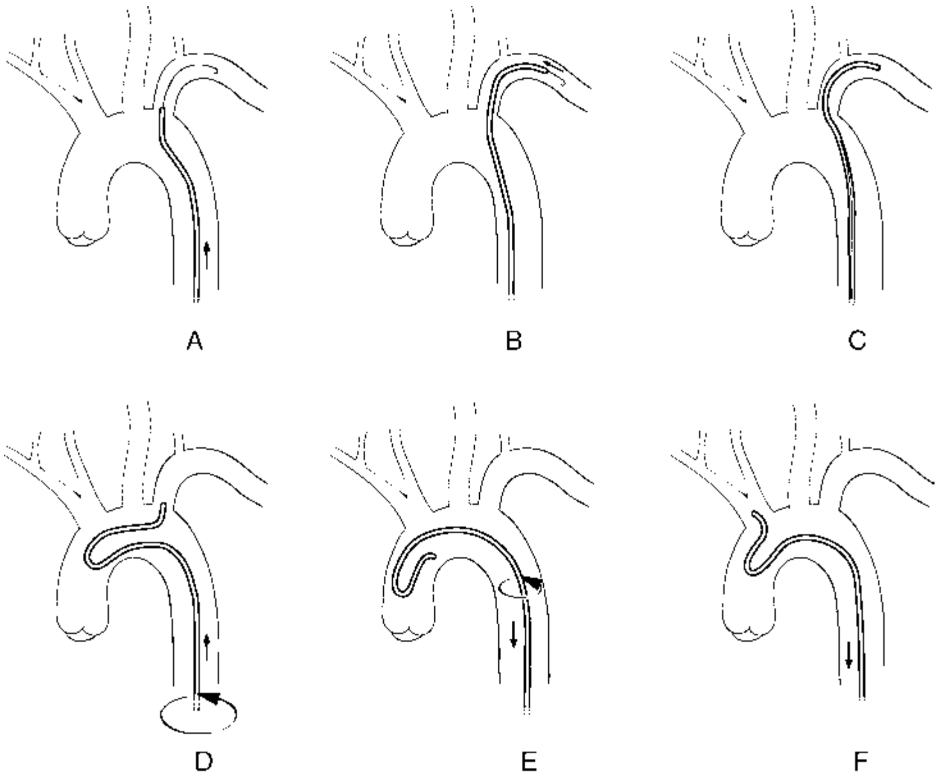


Fig. 5 Selective catheterization using a complex-curve cerebral catheter: reforming a Simmons catheter in the subclavian artery. A, A simple-curve catheter is placed in the subclavian artery and exchanged for a complex-curve catheter. **B,** As the guidewire is withdrawn, the catheter head begins to take its curved shape. **C,** The guidewire tip is withdrawn until it is just proximal to the second curve. **D,** Slight forward pressure on the catheter permits the head to reform in the arch. After reforming, the catheter is rotated and advanced simultaneously into the ascending aorta. **E,** The catheter is gently withdrawn and rotated clockwise to engage the arch branches. **F,** After the catheter tip has entered the arch branch of interest, in this case the innominate artery, slight traction on the catheter tends to advance it into the artery as the large curve begins to straighten out. Advancing the Simmons catheter tends to pull the tip of the catheter out of the artery as the large curve moves toward the aortic valve.

The complex-curve catheter may be used to cannulate any of the branch vessels but is most useful when the angle of origin of the arch branch is acute. This is often the case with the innominate artery. The multiple curvatures of the catheter head shape gives these catheters a width that must be achieved prior to approaching the vessel. The catheter head must be reshaped to its intended configuration after the guidewire is removed and before it can be used for selective catheterization. The aorta is the only vessel large enough for this task. A complex-curve catheter head may be reshaped in the ascending aorta. The catheter is passed over the guidewire into the ascending aorta, or the proximal descending aorta (Fig. 4). The guidewire is withdrawn and the catheter is advanced slightly, permitting the catheter head to take its shape.

The reformed catheter head shape is advanced into the ascending aorta. The catheter is simultaneously withdrawn and rotated so that its tip lands in the branch vessel origin. Aortic arch disease is a contraindication to this maneuver. The catheter tip is visualized using fluoroscopy as it pops into the vessel origin. The guidewire is advanced into the artery. Gently withdrawing the catheter removes some of its redundancy in the aortic arch and it tends to advance further into the selected artery. The catheter may also be reshaped using the distal aortic arch and the left subclavian artery (Fig. 5). A guidewire is placed into the left subclavian artery and a complex-curve catheter is placed over it. The guidewire is withdrawn to the location of the origin of the artery. Without guidewire in the distal portion of the catheter, the head begins to take shape. The catheter is withdrawn slightly until the large elbow takes shape in the arch. The catheter is then advanced into the proximal arch.

The subclavian artery may be approached antegrade through a femoral artery access or retrograde through a brachial artery puncture or cutdown. Through the aortic arch, the left subclavian artery may be cannulated using a simple- or complex-curve catheter (Figs. 6, 7). The retrograde approach is simple and direct and does not always require instrumentation of the aortic arch or its other branches. A floppy-tip guidewire is advanced from the brachial artery into the subclavian artery. A straight, multiple side hole arteriographic catheter is passed over the guidewire. The guidewire is removed and an arteriogram is obtained. When a subclavian artery lesion is present, contrast may be injected either distal or proximal to the lesion. High-pressure injection is usually not required distal to a significant subclavian artery stenosis and is contraindicated at the origin of the vertebral artery. Contrast usually refluxes through the lesion to delineate it. If the lesion to be evaluated or treated is at the origin or proximal subclavian artery, the guidewire is passed into the aortic arch and steered inferiorly into the descending thoracic aorta (Fig. 8). The guidewire usually advances into the proximal arch, so an angled-tip or hook-shaped catheter is usually required to steer the guidewire into the descending aorta. This is most important when endovascular therapy is planned so that a satisfactory length of guidewire may be safely deployed distal to the lesion. Injections in the aortic arch must be performed with a pressure injector. The location and detail of the left subclavian artery origin are usually difficult to visualize through a retrograde subclavian injection. High flow in the arch rapidly carries away any contrast, which refluxes into the arch. Forward flow into the subclavian artery may be minimal, and residual lumen is partially occupied by the catheter which has been passed retrograde through it. Use of a radio-paque or hot-tipped catheter helps to identify the subclavian artery origin

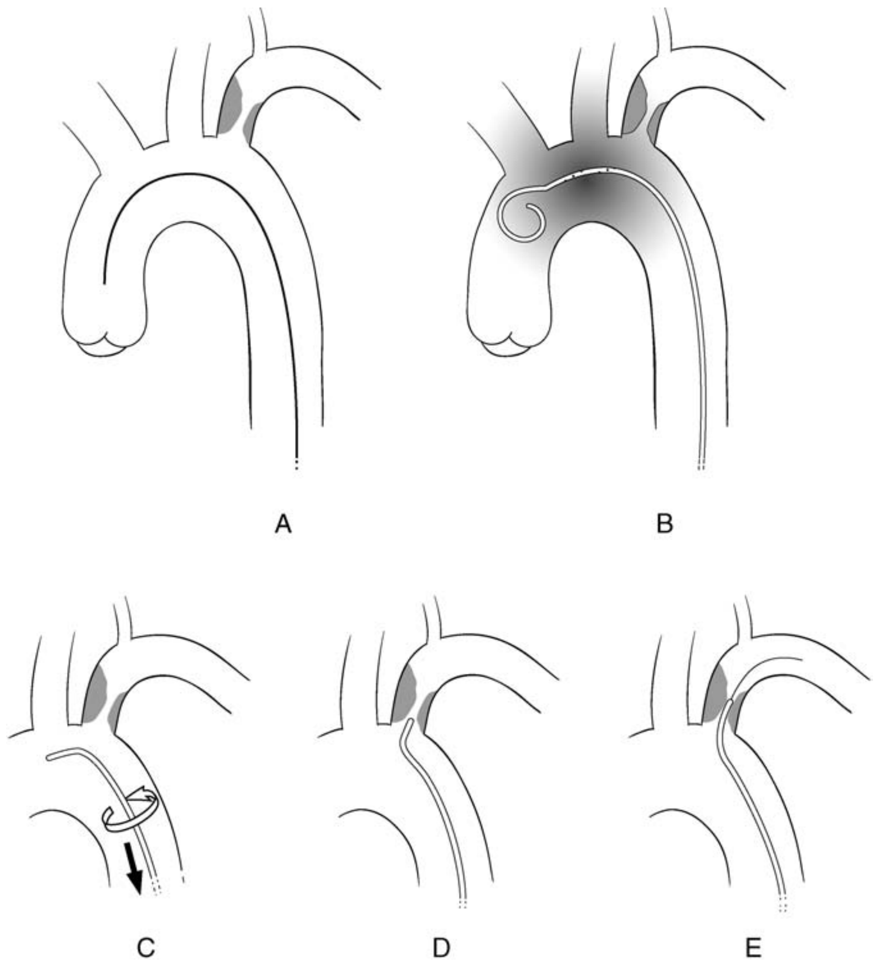


Fig. 6 Selective catheterization of the subclavian artery using a simple-curve catheter. A, A guidewire is placed in the ascending aorta. **B,** A flush catheter is placed and an arch aortogram is performed, usually in the LAO position. **C,** After the location of the origin of the artery and the lesion are identified, the flush catheter is exchanged for a simple-curve catheter. The catheter is withdrawn slightly and rotated. **D,** The catheter tip enters the origin of the artery. **E,** A selective guidewire is advanced into the artery. After a substantial length of guidewire is in the artery, the catheter may also be advanced.

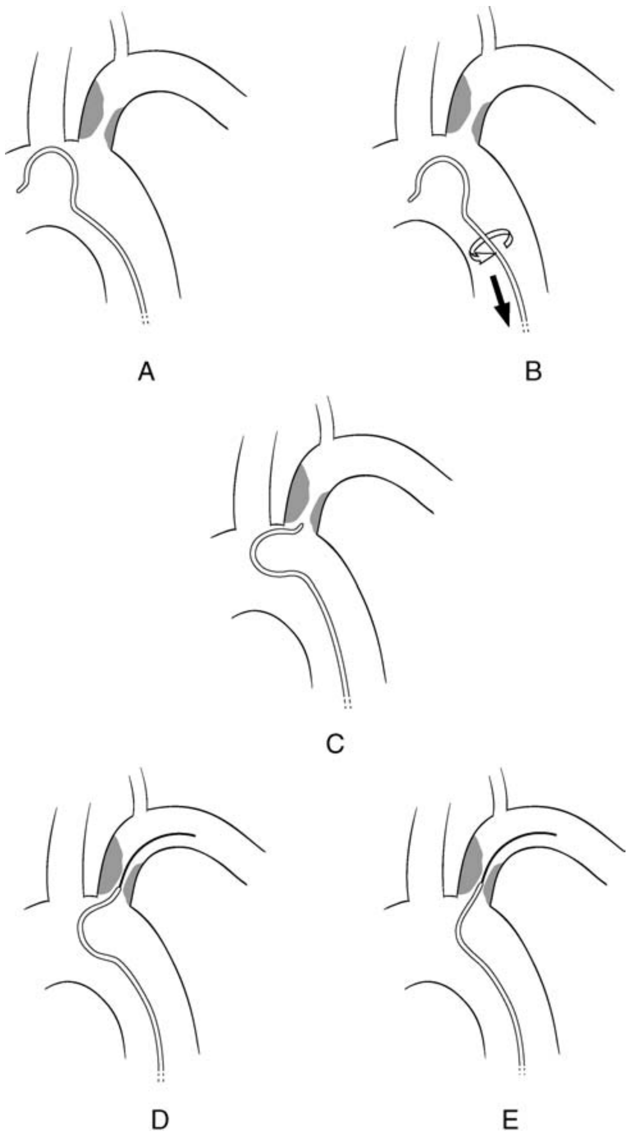


Fig. 7 Selective catheterization of the subclavian artery using a complex-curve catheter. **A,** The catheter, in this example an H3 Headhunter, is placed in the aortic arch proximal to the subclavian artery. **B,** The catheter is simultaneously withdrawn and rotated. **C,** The tip of the catheter engages the origin of the artery. **D,** The selective guidewire is passed into the artery. The guidewire must be advanced gently because if forward pressure is applied too vigorously the catheter will pop out of the artery. **E,** As the guidewire passes into the artery, the catheter head straightens and the catheter may be advanced.

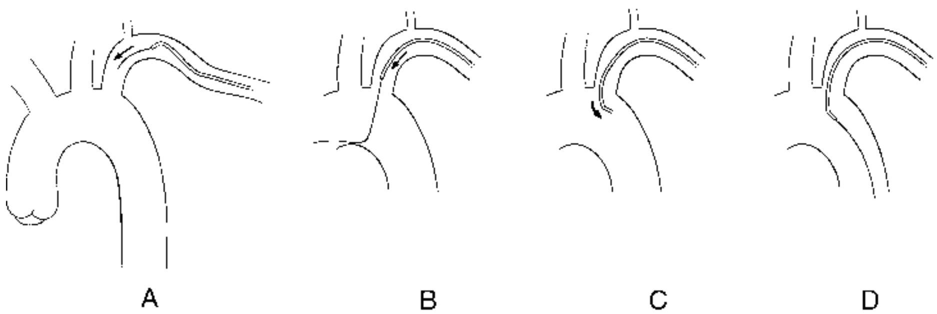


Fig. 8 Retrograde or transbrachial catheterization of the subclavian artery. **A,** After brachial puncture using a micropuncture set, the guidewire is passed retrograde into the proximal subclavian artery and a selective catheter is placed over it. **B,** The tendency of the guidewire when advanced into the arch is to proceed into the ascending aorta. A simple-curve or hook-shaped selective catheter is advanced into the distal arch. **C,** The guidewire is withdrawn and the catheter is directed posterolaterally. **D,** The guidewire is redirected into the descending aorta.

with fluoroscopy. The vertebral artery is protected somewhat when there is reversed flow.

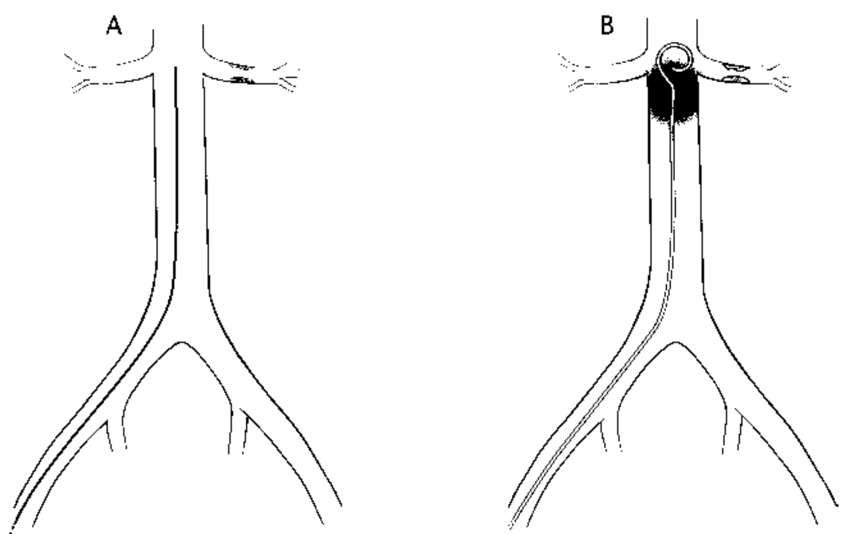
Selective Catheterization of the Visceral and Renal Arteries

CELIAC AND SUPERIOR MESENTERIC ARTERIES

The visceral arteries may be approached through the femoral or the brachial arteries. Catheterization for arteriography is usually satisfactory using a femoral approach. When therapy is indicated, a transbrachial approach should be considered, since the angle of origin of these arteries is more favorable for entry through a proximal approach. A diagnostic catheter is placed in the proximal paravisceral aorta and an anteroposterior aortogram is performed. This permits approximate localization of the arterial origins, evaluation of the integrity of the distal visceral vessels, and identification of variant anatomy. The catheter head may be adjusted slightly proximally or distally so that the side holes end at the level of the arteries' origins. The image intensifier is placed in full 90 degree lateral position and brought close to the patient's side. The arms are extended above the patient's head. The field is magnified and filtered so that the catheter head is at the top of the field of view and the posterior portion of the vertebral column is excluded from the field. The aortogram is repeated with breath-holding technique in midinspiration. Full contraction of the diaphragm may result in impingement of the visceral artery origins in some patients. The locations of the artery origins are identified using the vertebra as bony landmarks. A hook-shaped catheter is exchanged for the diagnostic catheter (Table 2). The guidewire is withdrawn, allowing the hook to take its shape. The catheter is withdrawn slowly as its tip is steered anteriorly. The tip of the catheter engages the origin of the artery. The catheter tip tends to pop into the orifice of the artery. The catheter is gently manipulated to advance it slightly into the vessel origin. An angled-tip Glidewire is advanced into the artery and the catheter may be advanced. Through a transfemoral approach, the angle of advancement of the catheter as it enters the visceral artery is acute. Therefore, the guidewire must be advanced a fair distance into the artery being selected in order for the operator to have enough purchase to advance the catheter.

RENAL ARTERY

If it is known which renal artery is desired for cannulation prior to the procedure, the catheter is passed through the contralateral groin. Aortography is performed with a flush catheter to evaluate the aorta, iliac arteries, and renal arteries. The catheter head is usually placed at the level of the first lumbar vertebral body. After the initial aortogram is assessed, the catheter head may be adjusted slightly so that it lies distal to the SMA and is unlikely to reflux a significant amount of contrast into the visceral arteries. An aortorenal arteriogram is then performed with magnification and filters. An ipsilateral anterior oblique projection of approximately 10 degrees is best for evaluating an orifice lesion if additional detail is required prior to selective catheterization. The arteriographic catheter is exchanged for a C2 cobra catheter and passed into the pararenal aorta (Fig. 9). After passage of the cobra catheter to a level just above the renal artery origin, the guidewire is removed and the catheter head takes shape. The tip of the cobra catheter is directed toward the posterolateral



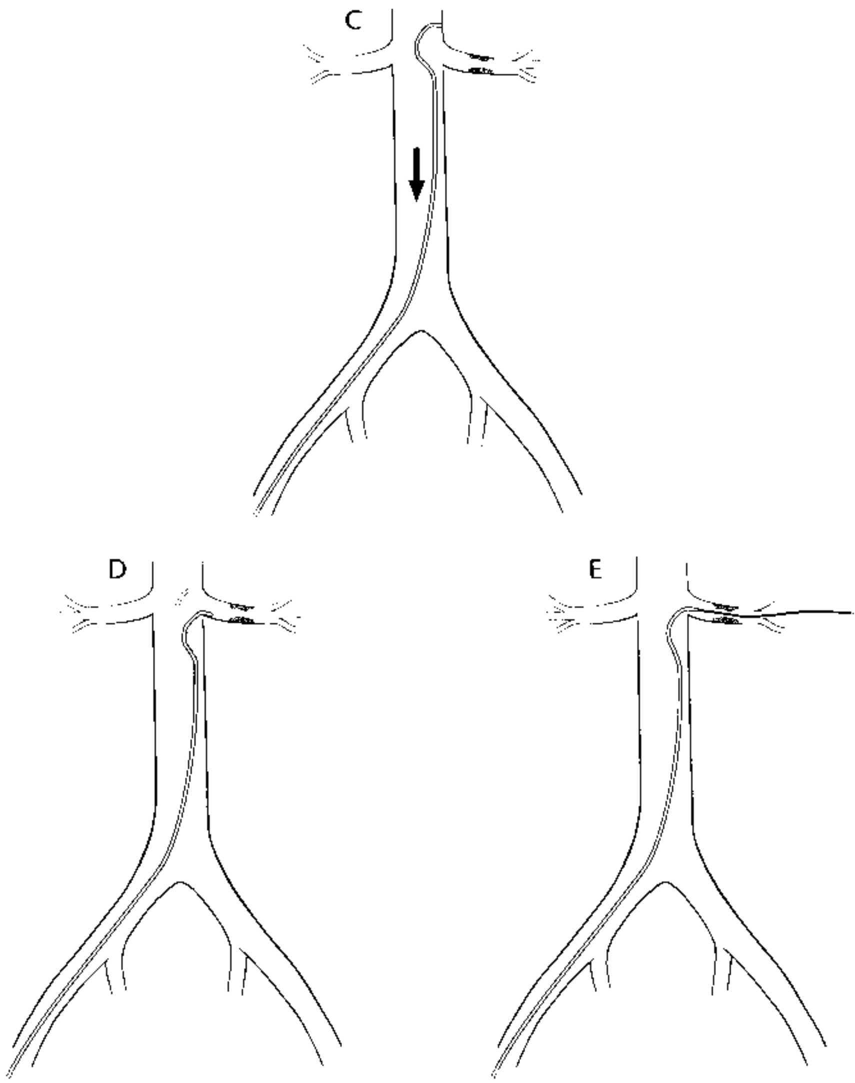


Fig. 9 Catheterization of the renal artery. A, A guidewire is placed in the aorta. **B,** An arteriographic catheter is placed and an aortogram and renal arteriogram are obtained. **C,** The arteriographic catheter is exchanged for a cobra catheter that is advanced proximal to the renal artery. The cobra catheter is slowly withdrawn with its tip along the posterolateral aortic wall. **D,** The tip of the cobra catheter falls into the renal artery orifice. **E,** The guidewire is advanced through the renal artery lesion.

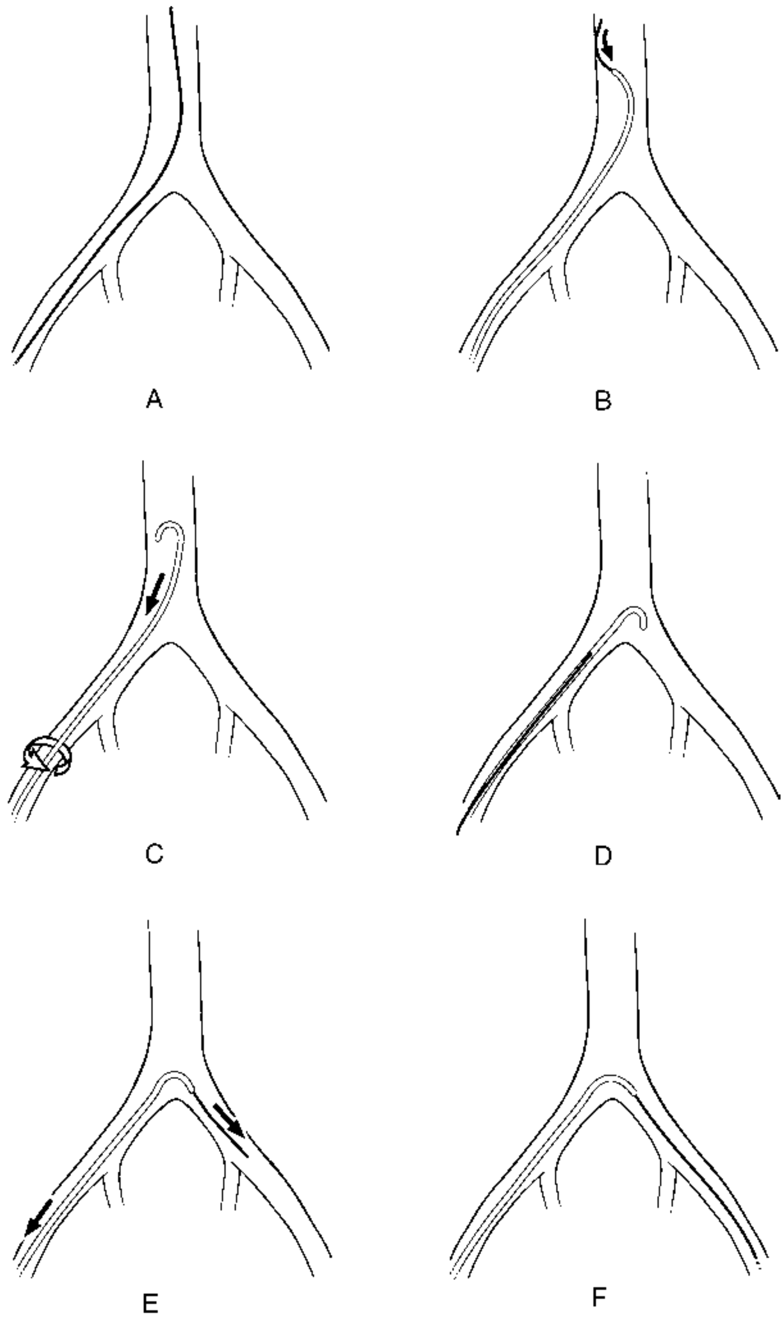
sidewall of the aorta and the catheter is slowly withdrawn. The guidewire may be maintained in the shaft of the catheter so that it can be rapidly advanced when necessary. Since the renal artery orifice is on the posterolateral wall of the aorta, other major visceral branch vessels are not encountered by the tip of the catheter but a lumbar artery may be. The tip of the catheter usually falls into the renal artery orifice with a small but perceptible jump, so that its tip appears beyond the profile of the aortic wall. The guidewire may be advanced to probe the artery. Puffed contrast confirms the location of the catheter tip and ensures that it is safe for a higher-pressure injection.

Selective Catheterization of the Aortoiliac Arteries

PASSAGE OVER THE AORTIC BIFURCATION

An aortoiliac arteriogram is performed to evaluate aortic bifurcation disease, angle, and location. The aortic bifurcation may be localized using bony landmarks or vascular calcification. It is usually located at or near the level of the iliac crest. Vascular calcification occasionally outlines the aortic bifurcation and serves as a road map. A hook-shaped catheter is passed into the infrarenal abdominal aorta (Fig. 10). The catheter should be a minimum of 65 cm in length. Some catheters such as the Omni-flush (Angiodynamics, Queensbury, NY) are designed for aortography but also have a hook-shaped head and may be used to cross the aortic bifurcation. Aortic bifurcation cannulation may also be performed with a C2 cobra (Cook, Inc., Bloomington, Ind.). In a patient with a narrow aortic bifurcation, a Rosch IMA catheter (Cook, Inc.) has a tighter hook shape and allows the guidewire to turn at a more acute angle. The catheter head is withdrawn using fluoroscopy and bony landmarks to a location one vertebral body proximal to the bifurcation. The guidewire is withdrawn so that the catheter head takes its shape. If the catheter head is not reshaped to its usual configuration after the guidewire is withdrawn, the catheter shaft must be manipulated with fluoroscopic guid-

Fig. 10 Crossing the aortic bifurcation. A, After an aortogram is performed to identify the location, configuration, and arterial disease burden of the bifurcation, the guidewire is placed in the infrarenal aorta. **B,** A hook-shaped selective catheter is passed over the guidewire. The catheter and guidewire are withdrawn until the head of the catheter is just proximal to the aortic bifurcation and the guidewire is removed. **C,** The catheter head takes its shape. The catheter is rotated toward the contralateral side and withdrawn simultaneously. **D,** The guidewire is advanced into the catheter head. **E,** As the guidewire passes through the catheter head, the catheter head becomes more firm and takes a more rounded shape. The catheter can be pulled back slightly so that its curve sits directly on the flow divider. **F,** The guidewire is then advanced from a very secure position.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ance. If the infrarenal aorta is narrow or diseased, the catheter tip may catch on the vessel wall. Give the catheter a small forward push and it usually forms the correct shape. If there is doubt, turn the catheter to be sure the head clears the sidewalls without changing shape.

The catheter is slowly withdrawn and rotated until the tip of the hooked portion of the catheter head is pointing toward the contralateral iliac artery. An angled-tip Glidewire, 150 or 180 cm in length, is advanced gently into the contralateral iliac artery, and the torque device is used to allow the guidewire tip to probe the proximal contralateral iliac artery. When a few centimeters of guidewire have been passed to the contralateral iliac system, the catheter may be withdrawn slightly to hang it on the flow divider at the bifurcation of the aorta. The head of the catheter assumes a slightly more splayed configuration when it is pulled into position where it is resting on the aortic flow divider. The tip of the guidewire frequently catches on plaque in the contralateral iliac artery and the torque device is used to steer the guidewire away and antegrade down the artery. The catheter head may not be safely pulled onto the flow divider if the guidewire is still caught on the plaque.

When the iliac arteries are tortuous, the extra turns the catheter must pass through usually make the hook of the catheter point to the ipsilateral side. This also makes the catheter head less responsive to turns performed at the catheter hub. The catheter head may not rotate in response to turning the hub and then suddenly turn 360 degrees back to its original position. The operator may have to use both hands to slowly manipulate the catheter head so that it points in the correct direction and have the assistant advance the guidewire. Another option is to withdraw the catheter just as it begins to rotate so that its tip catches the contralateral iliac origin as it comes around. Crossing the aortic bifurcation is usually performed with 0.035-in. guidewires and 4 or 5 Fr catheters. If the bifurcation is very narrow, as is the case with a prosthetic graft, a 0.025-in. guidewire may be used since it has a tighter radius of curvature.

When the catheter head hangs on the aortic bifurcation, it assumes a more broadly curved shape. If a contralateral iliac arteriogram is planned from this position, a catheter without side holes should be used since the segment with side holes extends well back into the ipsilateral iliac artery. Most often, the plan is to advance the catheter further into the contralateral side. The guidewire is advanced beyond the inguinal ligament if possible. The guidewire is pinned and the catheter is advanced. The further the guidewire is advanced, or "buried," on the contralateral side, the better purchase is obtained to permit the catheter to be advanced over the guidewire, despite the acute-angle turn at the aortic bifurcation. If the catheter is advanced by hand but the catheter tip is not advancing antegrade into the contralateral iliac system, the guidewire and catheter are usually bunching up together into the distal aorta (Fig. 11). If this is not recognized early, continued catheter insertion will drag the guidewire out of the contralateral iliac artery and into the aorta.

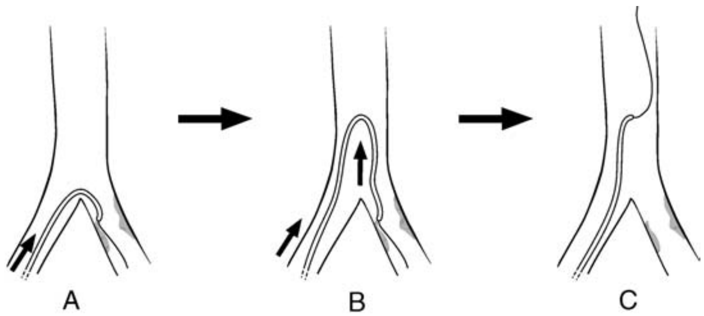

Fig. 11 Catheter pops out of contralateral iliac artery. A, Guidewire is placed antegrade into contralateral iliac system and the catheter is passed over it. If the catheter engages the wall of the proximal iliac artery, it may not advance. **B,** If continued forward motion is applied to the catheter when its tip is not advancing, the catheter begins to buckle into the infrarenal aorta. **C,** Continued forward pressure on the catheter will cause the catheter tip to pop out of the iliac artery and drag the guidewire along with it. This scenario can usually be avoided by passing the guidewire as far as possible into the contralateral iliac system as possible before advancing the catheter. When the catheter tip is passing through the proximal contralateral iliac artery, observe it carefully, especially if the artery is diseased. If the catheter tip hangs up, stop applying forward pressure.

The guidewire usually enters the internal iliac artery as it is advanced, since this is often a straight in-line direction of advance, especially with tortuous iliac arteries (Fig. 12). In that case, the guidewire usually hangs up in a branch of the internal iliac artery or progresses into a branch far enough from the intended course that it becomes clear that the guidewire has entered the internal iliac artery. The catheter may be advanced over the bifurcation and into the contralateral common iliac artery or even the internal iliac artery. The guidewire is withdrawn. Hook-shaped catheter heads shorten substantially when the guidewire is withdrawn and they are no longer forced into a straight position. The catheter is withdrawn if necessary to make sure its tip is in the common iliac artery. The steerable guidewire is passed again. The catheter may be used to direct the guidewire anterolaterally toward the external iliac artery.

Significant occlusive or aneurysmal disease of the distal aorta or the common iliac arteries are a contraindication to crossing the aortic bifurcation. Safe passage across the aortic bifurcation is more difficult if there is occlusive disease at the bifurcation, significant iliac tortuosity, or aneurysmal degeneration near the aortic bifurcation. Occlusive disease at the aortic bifurcation is usually worse along the posterior aortic wall just proximal to and extending into the iliac arteries. The anteroposterior aortogram almost always underestimates the plaque load at this location and the operator must be wary of generating emboli. Significant tortuosity of the iliac vessel through which the

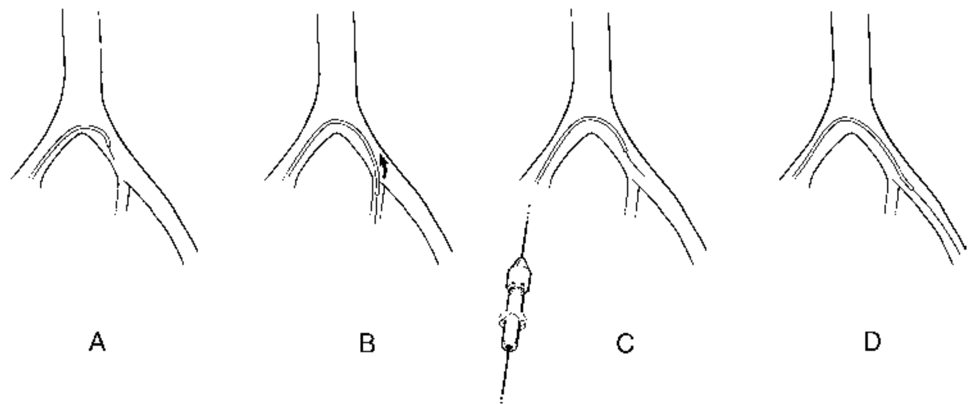

Fig. 12 Guidewire–catheter advances into the internal iliac artery. A, The guidewire frequently, almost preferentially, enters the internal iliac artery as it is advanced into the contralateral iliac artery. This is especially the case when the iliac system is tortuous. **B,** The catheter is withdrawn back toward the common iliac artery. The guidewire is pulled back to the catheter tip. **C,** A torque device is used to steer the guidewire anterolaterally. **D,** The guidewire is advanced into the external iliac artery and the catheter follows.

catheter is passed makes the torque of the catheter much less predictable. After going through several longitudinal turns, the catheter head may be difficult to rotate. A sheath may be placed with its tip in the proximal ipsilateral iliac artery. This maneuver helps counteract the effect of the tortuosity. Aneurysmal changes in the aorta or iliac arteries may add significant risk to this maneuver. When an infrarenal abdominal aortic aneurysm is present that does not involve the aortic bifurcation, the hook-shaped catheter head should be reshaped in the proximal ipsilateral iliac artery or very distal aorta to avoid dragging the hook through the aneurysm. Occasionally, it is safer to perform an additional contralateral femoral puncture to complete the intended catheterization than to cross a severely diseased bifurcation.

PLAN OF ATTACK: Crossing the Aortic Bifurcation

1. Evaluate the aortogram to determine that the bifurcation is relatively free of aneurysmal and occlusive disease so this will be a safe maneuver. The presence of significant disease in the proximal contralateral iliac artery may also be a contraindication to crossing the bifurcation.
2. Choose the catheter based on the appearance of the aorta. A bifurcation angle that is more acute requires a tighter hook to accomplish the task. Use a catheter with a radiopaque tip.
3. Advance the catheter over the guidewire and into the infrarenal aorta (Fig. 10).

4. Use bony landmarks to identify the location of the aortic bifurcation. The aortogram may be used as a guide to assist the operator in deciding how to maneuver the catheter into position.
5. Withdraw the guidewire a short distance to allow the catheter head to take its shape. The guidewire position is maintained in the shaft of the catheter.
6. Slowly withdraw the catheter and guidewire together as a single unit until the hook of the catheter head is just proximal to the aortic flow divider. Rotate the catheter so that its tip points into the contralateral iliac artery. Evaluate using fluoroscopy to be sure the catheter tip does not hook a sidewall aortic plaque. Use a smaller field of view so that the catheter and guidewire are magnified.
7. Advance the guidewire into the contralateral iliac artery as far as possible and "bury" it so that the catheter can be advanced over it. After the guidewire has passed into the contralateral iliac artery for several centimeters, readjust the catheter by withdrawing it slightly. This will allow the hook of the catheter to hang on to the aortic flow divider. This is a fairly secure position for guidewire advancement.
8. Advance the catheter antegrade into the contralateral iliac system after a long segment of guidewire has been placed.
9. After the catheter has crossed the bifurcation, withdraw the guidewire for arteriography. If larger endovascular devices such as a guiding sheath are intended for passage, place a stiffer guidewire, such as a Rosen (Medi-tech).
10. Use fluoroscopy during catheter placement to inspect the tip of the guidewire to be sure it is not migrating. Spotcheck the aortic bifurcation to ensure that redundant catheter is not accumulating in the distal aorta.
11. If there is disease at the aortic bifurcation that could be disrupted or contralateral endovascular therapy is planned, consider placing an "up-and-over" sheath (Cook, Inc.).

Selective Catheterization of the Infrainguinal Arteries

SUPERFICIAL FEMORAL AND POPLITEAL ARTERIES: UP-AND-OVER APPROACH

The selective catheter is passed up and over the aortic bifurcation as described in the previous section (Fig. 10). A 150-cm guidewire permits catheter passage to the contralateral groin or proximal infrainguinal arteries in the average-sized adult. A 180-cm guidewire is required for catheter passage to the distal femoral or popliteal level. A 65-cm catheter will usually reach the proximal to mid SFA. A 90-cm catheter is required to reach the distal superficial femoral artery (SFA) or popliteal artery levels. After the hook-shaped catheter that has been used to cross the aortic bifurcation is securely placed into the contralateral iliac artery, the guidewire may be advanced into the infrainguinal arterial segment. If it is anticipated that a longer guidewire is needed to go the distance in the contralateral lower extremity, the operator should make the exchange after the catheter has crossed the aortic bifurcation.

The guidewire tends to preferentially enter the SFA when it is passed from the contralateral side. If the guidewire enters the profunda or a collateral, the operator should remove the guidewire and puff contrast with the image intensifier in the anterior oblique position. This opens the femoral bifurcation and permits the operator to localize the SFA origin. The guidewire is advanced, using a steerable tip, and this new information and the SFA origin is cannulated. If the femoral anatomy is complex or there is significant common femoral artery disease, it may be difficult to catheterize the SFA with these maneuvers. In this case, advance the guidewire as far as it will go into the profunda or into a collateral vessel. Then advance the catheter into the distal external iliac artery or proximal common femoral artery. Withdraw the guidewire into the common femoral artery and probe the origin of the SFA. This catheter positioning provides better control and improves guidewire responsiveness.

The guidewire is advanced into the SFA as far as possible and the catheter is advanced over it. The catheter usually follows the guidewire; however, trackability may be poor because of the long distance and the acute-angle turn at the aortic bifurcation. The guidewire is pinned and the catheter is advanced firmly by pushing on the catheter shaft near the percutaneous access site. A slight twist of the catheter while advancing may also be useful. If the catheter will not advance, a stiffer guidewire, should be used. The operator may also consider removing the hook-shaped catheter used to cross the aortic bifurcation and placing a straight catheter with multiple side holes. This catheter may track the guidewire better.

SUPERFICIAL FEMORAL AND POPLITEAL ARTERIES: ANTEGRADE APPROACH

Antegrade femoral puncture is presented in detail in Chapter 2. Prior to antegrade puncture, any previous arteriograms of the femoral area should be evaluated for the location of the bifurcation relative to the inguinal ligament. The femoral bifurcation may also be localized with duplex scanning. This approach is advised only when ipsilateral aortoiliac inflow occlusive disease has been ruled out. Following antegrade puncture of the common femoral artery, a steerable-tip steel guidewire is passed through the needle (e.g., Wholey) (Fig. 13). A 145- or 150-cm guidewire is more than adequate in length for an antegrade approach. Occasionally, the guidewire enters the SFA on the first pass; however, it tends to preferentially enter the orifice of the deep femoral artery after an antegrade puncture because of the angle of approach. The guidewire should be advanced far enough so that it does not fall out of the artery, usually about 10 or 15 cm. A torque device is advanced along the guidewire until it is a few centimeters from the hub of the needle. The curved-tip guidewire is directed anteriorly and medially to enter the

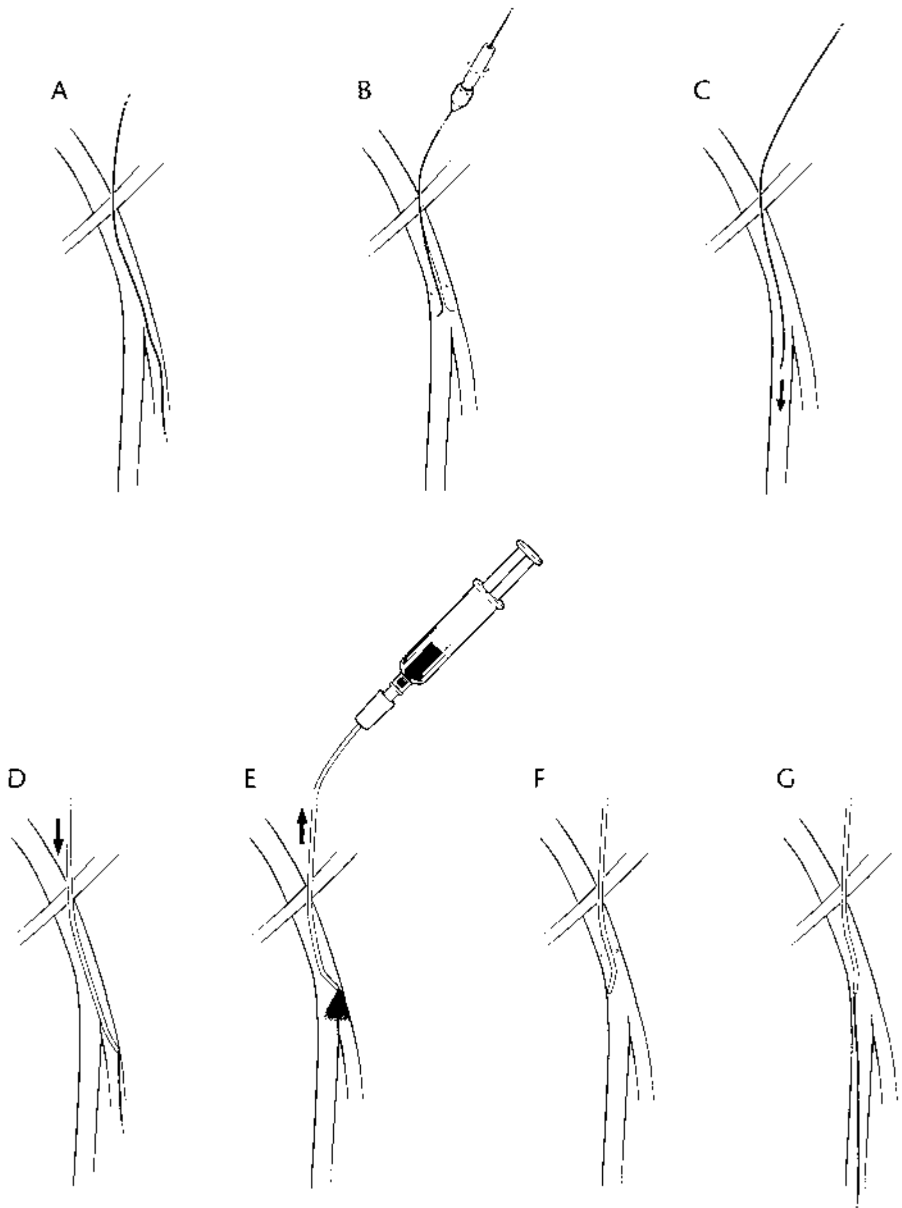

Fig. 13 Catheterization of the superficial femoral artery. A, After antegrade puncture of the common femoral artery, the guidewire tends to preferentially advance into the deep femoral artery. **B,** The initial guidewire can be exchanged for a steerable Wholey guidewire. A torque device is used to redirect the guidewire tip. **C,** The steerable guidewire rotates medially and anteriorly and advances into the superficial femoral artery. **D,** A Berenstein or cobra catheter can be passed over the guidewire in the deep femoral artery and the guidewire removed. **E,** The selective catheter is very slowly withdrawn as contrast is puffed to identify the femoral bifurcation. **F,** The tip of the selective catheter is rotated toward the origin of the superficial femoral artery. **G,** The guidewire is advanced through the selective catheter and into the superficial femoral artery.

superficial femoral artery. About half the time, the superficial femoral artery may be catheterized by directing the steerable guidewire directly from the puncture site. Care must be taken to avoid losing access since working room between the puncture site and the SFA origin may be only a few centimeters. If the guidewire cannot be directed into the SFA, advance the guidewire into the deep femoral artery until the firm portion of the guidewire crosses the arterial entry site at the common femoral artery. A short (40 cm), 5 Fr bent tip catheter (C2 cobra, Berenstein, or Kumpe) is passed over the guidewire and the guidewire is removed. The catheter is gradually withdrawn using fluoroscopy while small amounts of contrast are injected by hand. As the tip of the catheter nears the femoral bifurcation, contrast refluxes into the bifurcation. When the superficial femoral artery orifice is opacified by contrast administration, the tip of the catheter is rotated and directed anteriorly and medially to cannulate the SFA. The operator may also consider road mapping the femoral bifurcation.

Because working room is usually minimal, the catheter must be carefully secured. Catheter movements must be slow and deliberate. A few millimeters of movement in either direction can pop the tip of the catheter out of the SFA orifice or even out of the common femoral artery puncture site. The guidewire is passed through the short catheter and into the SFA orifice. The guidewire is advanced into the mid- or distal SFA. The selective catheter is exchanged for the appropriate arteriographic catheter, usually a straight, multiple side hole catheter. If the puncture site is so close to the bifurcation that the SFA cannot be catheterized, remove the guidewire and hold pressure until hemostasis is adequate. The anatomy of the inguinal ligament is reevaluated. Fluoroscopy is used to locate the superior aspect of the femoral head. A repeat attempt at the antegrade approach may be undertaken if it can be done safely.

TIBIAL ARTERIES

Optimal opacification of the pedal vessels occasionally requires tibial cannulation. However, selective catheterization of the tibial vessels is usually required only if endovascular therapy is undertaken. When this is the case, the operator should strongly consider using a 4 Fr system that employs 0.018-in. diameter guidewires and permits usage of angioplasty balloons from 1.5 to 4 mm in diameter. The guidewire is directed antegrade through the superficial femoral and popliteal arteries using either an up-and-over or an antegrade approach. Better control may be obtained with an antegrade approach due to the shorter distance and lack of major turns. The choice of approach is discussed further in Chapter 20.

If extensive catheterization of the tibial arteries is planned, continued advance of the guidewire usually results in cannulation of the tibioperoneal trunk and then the peroneal artery (Fig. 14). Anterior tibial artery or posterior

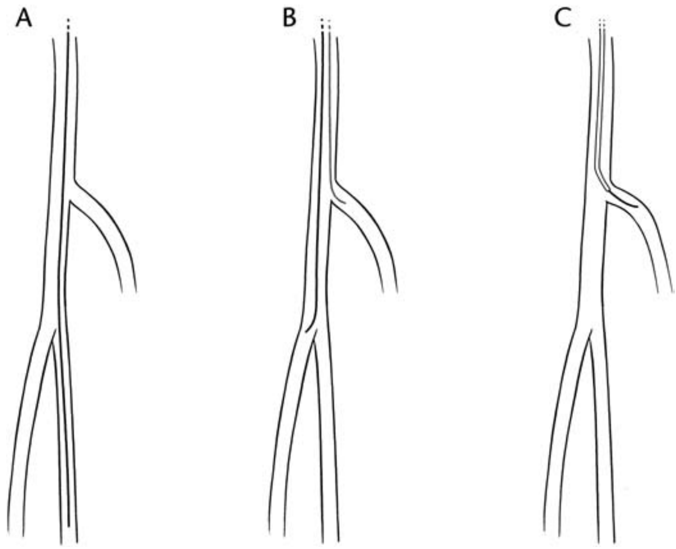

Fig. 14 Catheterization of the tibial artery. A, The peroneal artery is usually the preferential course of a guidewire passed beyond the below-knee popliteal artery. **B,** A steerable hydrophilic-coated guidewire can be used to cannulate the anterior tibial artery or posterior tibial artery. **C,** The steerable guidewire is directed by a bent-tip Berenstein catheter to enter an anterior tibial artery with a difficult angle of origin.

tibial artery catheterization is made simpler by road mapping to identify the location of origin. Arteriography is performed by injecting contrast through the sidearm of the hemostatic femoral sheath if the guidewire is already in a position that cannot be given up. Another option is to advance a straight arteriographic catheter into the distal popliteal artery. Contrast injection (5 ml) demonstrates the location of the orifice of each of the arteries. The straight catheter is exchanged for a Berenstein catheter to direct a steerable, hydrophilic-coated guidewire into either the anterior tibial artery or posterior tibial artery.

INFRAINGUINAL VEIN BYPASS GRAFTS

The most important factors influencing the catheterization of lower-extremity bypass grafts are the location of the proximal anastomosis, the volume of flow within the graft, and whether the graft has been tunneled in a superficial or deep plane. Worthwhile preoperative maneuvers include a review of the original operative report and arteriograms and a current duplex map of the vein graft.

The approach is based upon the location of the proximal anastomosis. Infrainguinal bypass grafts that originate from the superficial femoral artery, deep femoral artery, or popliteal artery may be approached through an ipsilateral antegrade femoral puncture. This ipsilateral approach provides better control of endovascular devices. A graft that has its origin in the common femoral artery must be catheterized from the contralateral side by passing the guidewire over the aortic bifurcation. The volume of flow within the graft determines how readily the graft origin is identified. If the graft is patent and functioning, contrast injection with the image intensifier in the right position will show the way to catheterization. If the graft is occluded or flow is very low, look for an outpouching or nipple of contrast extending beyond the usual confines of the artery of origin. This usually represents the hood of the graft. Grafts that have been tunneled superficially may be punctured percutaneously, usually almost anywhere along the course of the graft. Noninvasive mapping to show the location of the abnormality is useful to ensure adequate working room between the puncture site and the lesion.

An anastomosis is usually created on the anterior aspect of the inflow vessel and bypass grafts have no branches. These factors make identification of the graft orifice difficult. Flow through the proximal aspect of the graft may be minimal and is usually superimposed on the artery from which it originates. As the catheter and guidewire approach the proximal anastomosis in an antegrade direction, an oblique or even lateral view of the artery is useful to assist in identifying the location of the proximal anastomosis. Look for the presence of surgical clips to define the correct radiographic field of view. A patent but low-flow infrainguinal graft that could not be visualized upon initial contrast injection will often be seen when contrast is injected closer to the graft origin and with the image intensifier in the oblique or lateral position. A bent-tip catheter, steerable guidewire, or combination of the two may be used to enter the hood of the graft. The hood is gently probed with the steerable guidewire and a magnified field of view until the guidewire falls into the graft. When a low-flow graft is catheterized, the catheter itself may stop flow. Therefore, heparin should be administered in this situation, even if intervention is not intended.

TECHNIQUE: Entering an Infrainguinal Vein Graft

1. Find out the location of the proximal anastomosis. Hints can be found in operative notes, previous preoperative or intraoperative completion angiography, previous graft surveillance duplex studies, and fluoroscopy of surgical clips.
2. If the graft is patent, check the duplex map to see if the lesion is at or near the proximal anastomosis. It helps if the operator knows whether to expect a wide-open graft hood or a tight proximal lesion.

3. Check the graft flow rate on the duplex scan to judge the expected flow of contrast in the graft. If it is less than the adjacent native circulation, sometimes only a wisp of contrast enters the graft. Use the preoperative duplex scan to mark the location of occlusive lesions, especially if endovascular therapy is planned.
4. If the graft originates from the deep femoral artery, superficial femoral artery, or popliteal artery, approach through an ipsilateral, antegrade puncture. If it originates from the common femoral artery, use a contralateral femoral approach.
5. Use an oblique view rather than an anteroposterior view since the graft origin is almost always on the anterior surface of the artery and is superimposed upon the native circulation.
6. When the tip of the arteriographic catheter is close to where the anastomosis is located, puff contrast. If the graft hood can be seen, advance the catheter closer to it, adjust the oblique angle of the image intensifier for the best view, and road map the origin of the graft.
7. Use a steerable, hydrophilic-coated guidewire to enter the origin of the graft.
8. If the graft lesion is very tight, administer heparin because the catheter or even the guidewire alone may effectively stop flow.
9. If the graft is subcutaneous, make sure that table straps and other appliances do not impinge on the graft and impede the flow of contrast into it.
10. Manipulate and change both the leg position and the C-arm position to obtain the best views of the graft.
11. If the graft origin cannot be entered, puncture the graft directly with the assistance of real-time duplex scanning. This may be difficult in low-flow situations. If the graft is punctured and endovascular intervention does not result in improved flow, be alert to the possibility of immediate thrombosis.

Selective Catheterization of Prosthetic Bypass Grafts

Prosthetic bypass grafts may require catheterization as a strategic maneuver prior to endovascular or open revision or to evaluate end organ ischemia in the vascular bed served by the previously placed graft. Percutaneous access may be obtained by one of three methods: (1) puncture of the native artery at a site remote from the graft, (2) direct puncture of the graft near its anastomosis with the native artery, and (3) puncture of the body of the graft in a subcutaneous position. Chapter 2 includes more details about direct graft puncture for percutaneous access. In general, puncture of the native artery followed by fluoroscopic placement of a catheter into the graft is safest. Direct percutaneous, prosthetic puncture is commonly performed but is more likely to be complicated by thrombosis or infection. Antibiotics should

Table 3 Approaches to Selective Catheterization of Prosthetic Grafts Options

Bypass graft	Remote puncture	Puncture graft or native artery near anastomosis	Puncture body of graft	Comments
Carotid–subclavian	Femoral or brachial			Femoral puncture for arteriography. Brachial approach for intervention.
Axillofemoral	Brachial	Femoral	Chest or abdominal wall	Midgraft puncture is simplest.
Femoral–femoral	Brachial	Either femoral	Midgraft (over pubic area)	Can be difficult to maneuver into graft after puncture of native femoral artery.
Aortofemoral	Brachial	Either femoral		Puncture the groin opposite the side with suspected outflow problem.
Iliofemoral	Contralateral femoral (up and over)	Ipsilateral femoral		Avoid puncture of graft if possible.
Infrainguinal graft	Contralateral femoral (up and over)	Antegrade femoral (when graft originates from SFA or PFA)		Place up and over sheath if needed for better guidewire–catheter control.

be administered prior to the procedure. Prosthetic grafts are lined with pseudointima that may embolize or form an obstructive flap if disrupted. The lining of the prosthetic graft is less resistant to thrombus formation than that of an autologous graft. Catheterization of low-flow grafts may be followed by thrombosis, especially if holding pressure at a graft puncture after catheter removal further impedes flow.

Approaches to selective catheterization of prosthetic grafts are listed in Table 3. Brachiocephalic grafts, such as carotid–subclavian bypasses, usually originate at a 90-degree angle. This is a difficult angle to negotiate and there is a risk of cerebral embolization of pericatheter clot or pseudointima. If the graft is not adequately evaluated with a selective common carotid artery injection, consider approaching the graft retrograde through the ipsilateral brachial artery. The graft is best viewed using an anteroposterior (AP) or slight LAO projection.

Axillofemoral grafts may be catheterized through the ipsilateral subclavian–axillary arteries, through a puncture at the femoral level near the anastomosis or along the body of the graft. Femoral–femoral grafts may be catheterized by puncturing the hood of the graft or by a percutaneous midgraft puncture. Because the hood of the graft may be difficult to localize, duplex guidance is advised. If the puncture is in the native artery just distal to the anastomosis, it may be very difficult to enter the graft rather than the native iliac artery. Anastomoses are best evaluated with steep lateral oblique views.

Aortofemoral grafts are usually punctured directly near the femoral anastomosis. These grafts offer the advantage of relatively straight limbs for maneuvering catheters. Proceeding up and over the bifurcation of a prosthetic graft may be quite difficult due to the narrow angle of the bifurcation and the tendency for the catheter tip to catch on the fabric of the graft. Iliofemoral grafts may be catheterized through direct puncture in the groin or using an up-and-over approach from the contralateral groin. If an up-and-over approach is selected, the natural tendency of the guidewire passed over the aortic bifurcation is to remain in the native circulation, rather than pass into the graft. A steerable guidewire with a magnified, lateral oblique view will assist the operator in cannulating the proximal anastomosis.

There are many similarities between vein and prosthetic infrainguinal grafts, and the maneuvers in the previous section on vein grafts are also useful for prosthetic grafts. The location of the proximal anastomosis (common femoral artery or distal to the groin) determines the approach (antegrade or up and over). Direct percutaneous puncture of infrainguinal prosthetic grafts may be performed but is more likely to be followed by graft thrombosis since these grafts tend to be low-flow, especially if failing.

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7

Setting Up the Therapeutic Maneuver

Crossing Lesions

Why Cross a Lesion?
Three Types of Lesions
Crossing Stenoses
Plan of Attack: Crossing a Stenosis
Angio Consult: How Do You Avoid Subintimal Guidewire Dissection? What Do You Do If It Happens?
Crossing Occlusions
Plan of Attack: Crossing an Occlusion
Angio Consult: When Is Road Mapping Useful to Cross Lesions?
Selected Readings

Why Cross a Lesion?

There are only two reasons to cross an occlusive arterial lesion. The first is to set up a therapeutic intervention. The second reason to cross a lesion is because this may be the best option for evaluating that lesion (i.e., by measuring pressure) and the surrounding vasculature (e.g., no other reasonable route to perform an arteriogram). Guidewire advancement is performed deliberately but gently. The principles of guidewire handling are presented in Chapter 3. In this chapter, these principles are applied in concept and practice to the management of occlusive lesions. The ideally placed guidewire will "dance" across the lesion. Negotiating guidewire passage across a reluctant arterial segment leads to a rewarding sense of accomplishment.

Three Types of Lesions

The challenge to any endovascular operator is posed by the lesions that are encountered. There are three general types of lesions facing every endovascular surgeon, including (1) lesions that the guidewire sails across; (2) lesions that require multiple tricks to get across; and (3) lesions that are impossible, almost no matter what is done (Fig. 1). Although this is an oversimplification, categorizing lesions as such may help to shorten the learning curve by focusing our attention on the difficult ones and what needs to be done to get across them. Lesions included in each of these

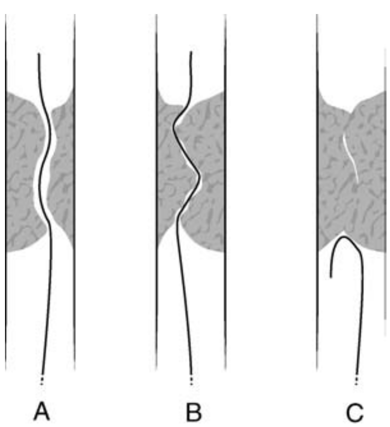

Fig. 1 Three kinds of lesions. A, A guidewire may sail across a lesion, sometimes even one that looks complicated. **B,** A lesion may require multiple guidewire–catheter tricks to traverse it. **C,** Some lesions are impossible, or seemingly so. The farther along the learning curve an endovascular surgeon progresses, the smaller this third category becomes.

categories may vary depending upon the place along the learning curve where each operator is working and how many tricks are at immediate disposal. As endovascular skills develop, the first category probably does not change much but the second category should get larger as the third category, comprised of impossible lesions, becomes smaller.

Crossing Stenoses

The stenotic lesion should be visualized with arteriography before one attempts to cross it. Oblique projections may be required for a full evaluation. The guidewire is selected on the basis of the lesion's appearance. A steel body, floppy-tip starting guidewire is satisfactory for many routine cases. If the lesion is complex, a hydrophilic-coated guidewire is a good choice. When the lesion also contains a critical stenosis, a steerable tip may be used. Lesions near branch points are best managed with steerable guidewires. Don't lead with a stiff guidewire or a catheter tip.

Encounters between guidewires and lesions are observed using fluoroscopy. When a guidewire fails to cross, its behavior as it encounters the lesion may reveal information that will assist subsequent passage using an alternative technique. Using the shortest and most direct route between the entry site and the arterial segment of interest offers the operator the most guidewire control at the site of the lesion. This approach assumes

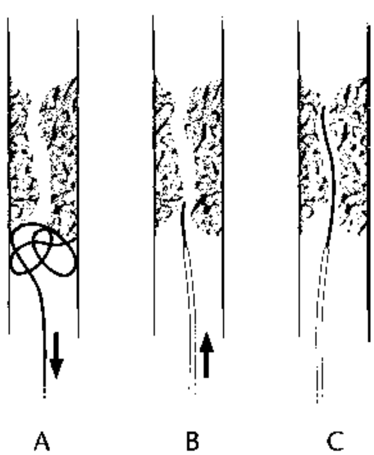

Fig. 2 Stiffen the guidewire by passing a catheter. A straight catheter passed over a guidewire gives additional stiffness and body to its shaft. **A,** The guidewire is unable to traverse the lesion and the floppy-tip guidewire piles up proximal to the lesion. The guidewire is partially withdrawn. **B,** A straight catheter is passed over the guidewire. The tip of the guidewire protrudes from the catheter and probes the lesion. **C,** The guidewire is advanced through the lesion.

adequate working room, or distance, between the access site and the lesion (usually the length of a standard access sheath, 10 to 15 cm). When distance results in poor guidewire control once it has reached the lesion, passing a catheter over the guidewire improves support and a selective catheter improves directionality.

Direct incremental advancement of a floppy-tip guidewire results in passage across most lesions. If passage is unsuccessful, the guidewire should not be forced. If the guidewire tip buckles, the leading elbow of the guidewire loop may find the lumen and pass with the guidewire doubled over on itself (see Fig. 1 in Chapter 3). This is a useful maneuver but it does work well with critical stenoses. In this case, the guidewire may enter a dissection plane and act as a loop stripper. If the guidewire begins to buckle, but continues to accumulate into several loops and piles up proximal to the lesion, withdraw the guidewire and attempt direct passage again. If the passage is still not successful, several options may facilitate guidewire passage.

A straight catheter passed over the guidewire gives additional support to the guidewire shaft and secures the access site (Fig. 2). The guidewire tip remains a few centimeters beyond the leading end of the catheter, and the guidewire is used to probe the lesion. Another option is to exchange the floppy-tip starting guidewire for a hydrophilic-coated guidewire, which

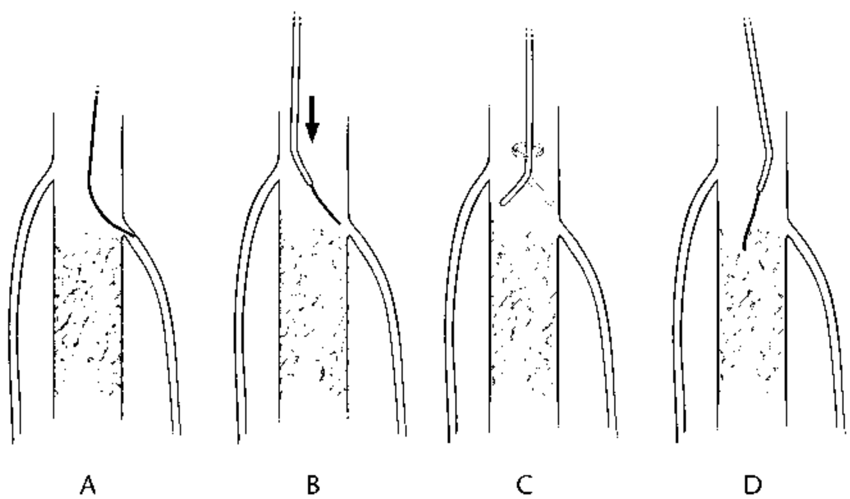

Fig. 3 Use a catheter to steer the guidewire. A Berenstein catheter (5 Fr) passed over a steerable or standard guidewire can help steer the guidewire tip into the desired location. **A,** The guidewire enters a collateral proximal to the lesion intended for passage. **B,** A bent-tip Berenstein catheter is passed over the guidewire. **C,** The catheter is rotated to redirect the guidewire. **D,** The guidewire is advanced into the lesion.

may cross the lesion, even a preocclusive stenosis, on the first pass. Hydrophilic-coated guidewires may be obtained with either a straight or angled tip. The angled tip is steerable with a torque device and may be used to find the entrance to an eccentric lesion (see Fig. 7 in Chapter 3). Road mapping facilitates this maneuver (see Fig. 3 in Chapter 5). A 5 Fr bent-tip catheter, such as a Berenstein or a Teg-T catheter, may help steer the guidewire into the desired location (Fig. 3). The catheter may be advanced as the guidewire makes forward progress, but the catheter should not be advanced into a lesion until the guidewire is across the lesion. A special exception to this is when the guidewire will not cross (usually an occlusion) and a last resort attempt is made to force a catheter across a lesion. Otherwise, the catheter tip itself, without the guidewire protruding from it, should not encounter the lesion because it is too stiff and may disrupt plaque.

Contrast may be puffed through the tip of the catheter to ensure that its position is intraluminal (Fig. 4). If significant resistance occurs, the guidewire may have passed outside the course of the artery lumen. Most of the time, guidewire does not cause pain but if the patient develops discomfort, subintimal dissection should be suspected.

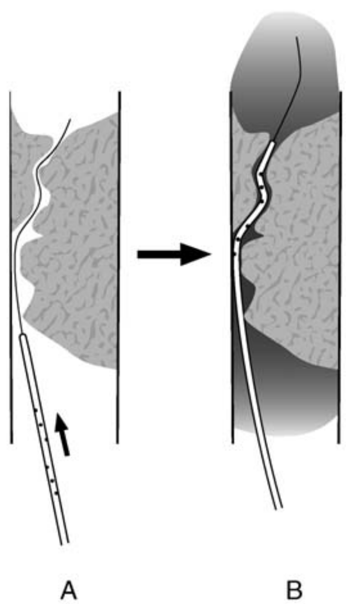

Fig. 4 Puff contrast into the lesion. A, After a difficult guidewire passage, a multi-side-hole, straight, exchange catheter may be placed over the guidewire. The catheter maintains the position through the lesion. **B,** Contrast is puffed through the catheter, and its side holes allow the lesion to fill with contrast. The guidewire may be withdrawn and contrast administered directly with the catheter tip through the lesion. Another option is to place a smaller caliber guidewire, such as a 0.018 in. or 0.025 in. and a Tuohy–Borst adapter.

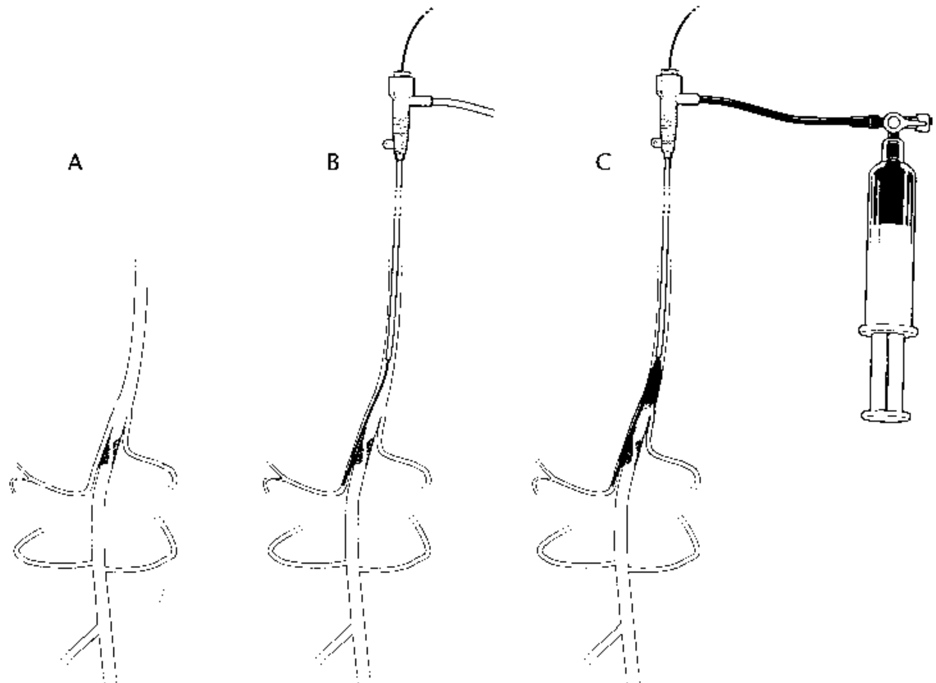

Fig. 5 Determine that the guidewire is really in the lumen. A, Large perigenicular collaterals may be the preferential course for a guidewire attempting to cross a superficial femoral artery or popliteal artery lesion. **B,** Under fluoroscopy, the guidewire appears to have crossed the proximal popliteal artery stenosis but is actually in a collateral that parallels the artery. **C,** Arteriography performed by administering contrast through the sidearm of the sheath reveals the true course of the guidewire and that the lesion has not been traversed.

Crossing lesions in well-collateralized arteries, such as the superficial femoral artery, presents an additional challenge. A large juxtaposed collateral just proximal to a critical stenosis may be the preferential course for a passing guidewire. The guidewire may be mistakenly advanced into a collateral that parallels the treatment artery (Fig. 5). Guidewire position must be confirmed before larger endovascular devices are passed over it. A steerable guidewire is useful for avoiding collaterals and maintaining position in the flow stream.

An oblique projection, as mentioned above, may be useful not only for evaluation of the lesion, but for opening up the entrance to the lesion and showing the way to cross it (Fig. 6). Occasionally, the steerable guidewire will require multiple manipulations to wind its way through a highly irregular stenosis (Fig. 7). When the approach artery is highly tortuous, it can be

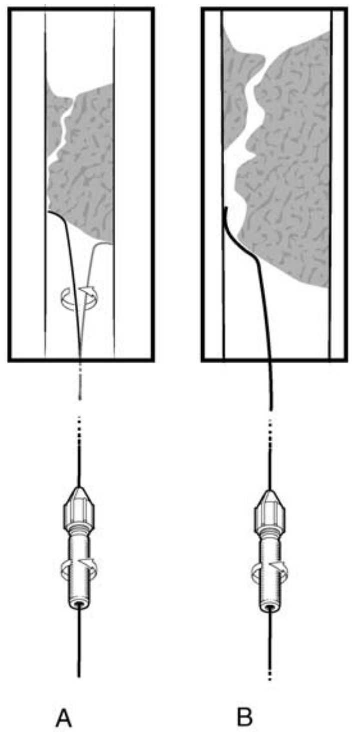

Fig. 6 Magnified oblique view. A, A complex lesion is encountered by the probing guidewire. **B,** The field is magnified and an oblique projection helps to open up the entrance to the lesion.

difficult to advance through a lesion after the guidewire has passed through several opposing curves. A straight 5 Fr catheter passed over the guidewire can lessen the curvature of some of the turns through which the guidewire must proceed.

Occasionally, a critically stenotic segment cannot be crossed in the chosen direction, and a separate puncture and an approach from the opposite direction are required (Fig. 8). After guidewire passage, control of the guidewire should not be relinquished until after treatment is completed. When guidewire control is inadvertently lost, it may be exceedingly difficult to cross the lesion a second time. Inexplicably, the same guidewire using the same technique across the same lesion may not recross easily.

Lesions at the orifice of major branch arteries, such as occur in the subclavian or renal arteries, may also be a challenge to cross. Selective catheters and steerable guidewires are routinely used to cross these. The tip of the selective catheter must provide substantial support to the guidewire despite being perpendicular to the aortic flow stream. Selective catheters appropriate for these arteries are presented in Chapter 6. The usual

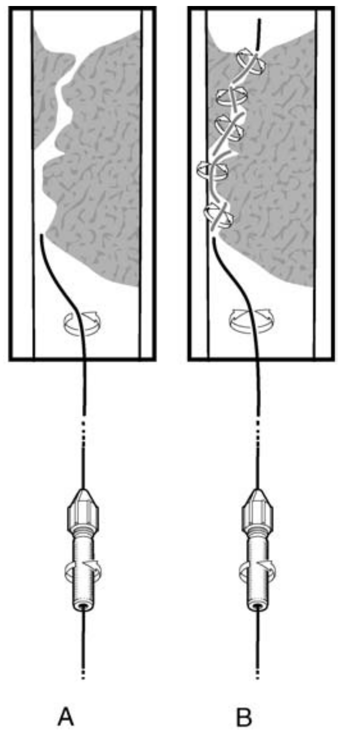

Fig. 7 Multiple maneuvers are sometimes required. A, A steerable guidewire probes a complex lesion. **B,** Multiple maneuvers are required to steer the guidewire across the lesion.

intent in crossing a lesion in one of these locations is intervention. Before the lesion is crossed, appropriate planning should be undertaken so that access for endovascular therapy with a guiding catheter or guiding sheath is prepared. Chapter 12 contains further discussion of appropriate access options for endovascular therapy. Once the branch artery lesion has been crossed, subsequent placement of a guiding sheath may pull the guidewire from its location and back into the aorta. Chapters 17 and 18 provide a step-by-step approach to the treatment of subclavian and renal lesions. After an orifice lesion has been crossed in one of these arteries, care must be taken to prevent dislodgment of the guidewire during other maneuvers. This is especially true in the renal artery, where the distance to the renal parenchyma is relatively short and the length of guidewire across the lesion is limited.

After the guidewire is in place across the lesion, the chosen catheter is advanced (see Chapter 3 for a detailed discussion of techniques for catheter placement). If there is a minimal lumen diameter at the site of the lesion, the guidewire–catheter combination may occlude it. Heparin should be administered to prevent thrombosis or the lesion should be dilated without delay so that flow resumes.

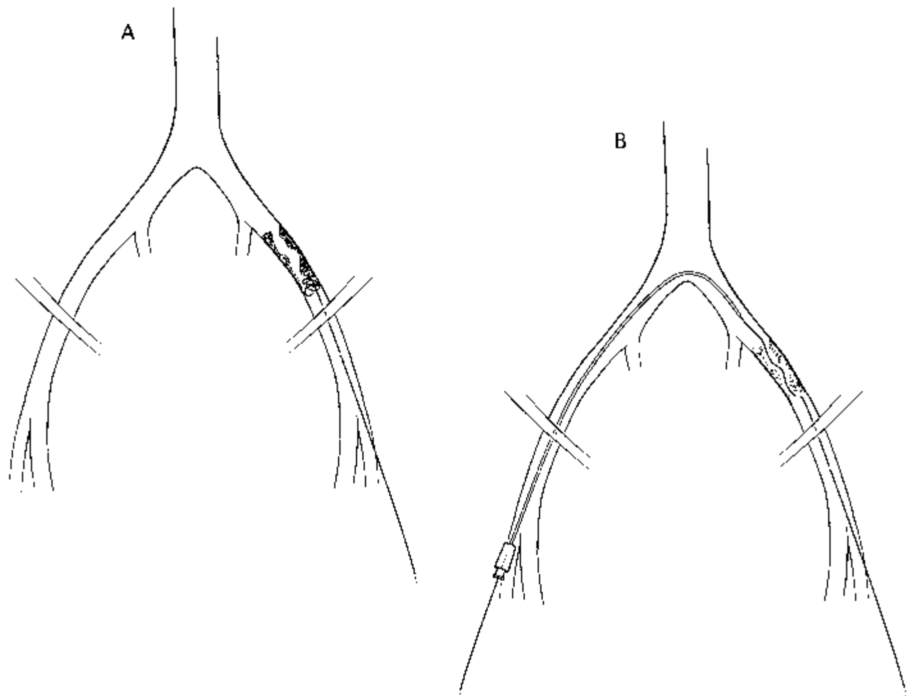

Fig. 8 Approach the lesion from the opposite direction. After attempting various maneuvers to cross a lesion, it is sometimes better to approach the lesion from the other end rather than force it and cause a complication. **A,** Ipsilateral retrograde passage of a guidewire is unsuccessful at crossing an external iliac artery stenosis. **B,** A second puncture is performed in the contralateral femoral artery, a catheter is passed over the aortic bifurcation, and the guidewire is advanced antegrade through the iliac stenosis.

PLAN OF ATTACK: Crossing a Stenosis

1. Use a floppy-tip guidewire.
2. Don't raise a dissection plane. This can be done easily by using excessive force, aggressively using a hydrophilic-coated guidewire, or attempting to advance the catheter without the guidewire (see Angio Consult).
3. Buckle the guidewire to form a leading edge (see Fig. 1 in Chapter 3). Don't force the elbow.
4. Use a straight catheter to confer stiffness to the guidewire (Fig. 2).
5. If a standard steel guidewire won't cross the lesion, use a hydrophilic-coated guidewire.
6. Exchange for a steerable guidewire (Fig. 7, see also Fig. 7 in Chapter 3).
7. Obtain oblique views of the lesion to get more information, especially if it is an eccentric or posterior wall lesion or located at a bifurcation or branch point (Fig. 6).
8. Road map the lesion to provide real-time guidance (see Fig. 3 in Chapter 5).

9. Use a selective catheter to provide additional directionality and to steer the guidewire (Fig. 3).
10. Once across the lesion, puff contrast to ensure that the guidewire did not pass through a dissection plane or into a collateral juxtaposed to the lesion (Fig. 4).
11. If the guidewire impedes flow, administer heparin.
12. If endovascular therapy is planned, advance an exchange catheter and place a stiffer guidewire to maintain control of the lesion.
13. If the lesion still can't be traversed, approach from the opposite direction and repeat these maneuvers (e.g., if a retrograde approach to an iliac artery lesion is not successful, try an antegrade approach) (Fig. 8).

ANGIO CONSULT: How Do You Avoid Subintimal Guidewire Dissection? What Do You Do If It Happens?

1. Most guidewire-induced subintimal dissections occur at the leading edge of a lesion. Care must be taken during the initial encounter with the lesion. Occasionally, even innocuous-appearing lesions will dissect.
2. Insert a low-profile angiographic catheter and puff contrast as often as is required to see where you are going.
3. "Dance" through the lesion with a steerable-tip guidewire.
4. Use continuous fluoroscopy while the guidewire is in motion.
5. Make small incremental and deliberate movements.
6. Be aware that a hydrophilic-coated guidewire may pass effortlessly along a dissection plane.
7. Anticipate where cleavage planes might be in the plaque, such as bifurcations and branch origins, and be extra careful around these areas.
8. If a dissection plane placement is suspected, advance the guidewire and twirl it to be certain that it behaves as a free guidewire should in the vasculature distal to the lesion. When the guidewire encounters unexpected obstructions or appears constrained, it may be in the wall of the artery.
9. A suspected guidewire dissection may be evaluated by advancing a 4 Fr straight catheter over the guidewire and puffing a tiny amount of contrast. If it is subintimal, the contrast will be stationary in the arterial wall.
10. If a dissection occurs, remove the guidewire.

Crossing Occlusions

Crossing occlusions is more challenging and less reproducible than crossing stenotic lesions. The only reason to cross an occlusion is in preparation for an attempt at recanalization. An ill-fated attempt at crossing and recanalizing an occlusion that results in distal embolization can be one of the most costly complications of endovascular intervention because of the potential that relatively stable chronic ischemia will be converted to acute ischemia. Acute ischemia due to embolization may also be untreatable if it is due to plaque contents rather than thrombus. Along the length of an occluded arterial segment, there is usually a critical stenosis from atherosclerosis with an accumulation of compacted thrombus proximal and distal to the lesion that extends to the next substantial collateral. When the occluded artery is tortuous or the underlying atherosclerotic lesion is diffuse, the risk of perforation or dissection is increased. The dual antegrade and retrograde approach to a lesion is more often required for occlusions than for stenoses.

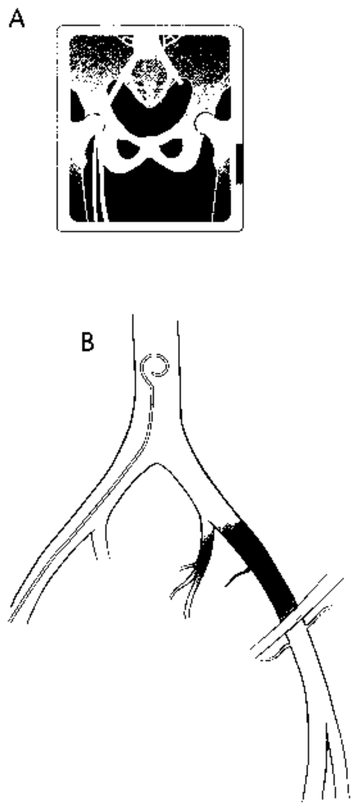

Fig. 9 Use delayed filming to show the true length of an occlusion. The length of an occluded segment can affect the decision as to whether recanalization should be attempted. **A,** Cut film arteriography tends to overestimate the length of an occlusion. The late filling of contrast into the distal, underperfused segments is usually missed by a multistep filming sequence. **B,** The length of an occlusion is best determined by placing the image intensifier over the area of interest, injecting contrast, and performing delayed filming as contrast slowly fills the segment immediately distal to the occlusion. This is most simply accomplished with DSA.

When endovascular recanalization is being considered, adequate arteriography includes delayed films to assess the length of the occlusion and its runoff (Fig. 9). The durability of a recanalized occluded segment is inversely proportional to its length. The length may affect the decision to attempt to cross and recanalize it. For iliac artery occlusions, digital subtraction arteriography (DSA) with delayed pelvic filming is required. For superficial femoral artery occlusion, extended DSA is performed in the area where reconstitution is expected. Cut film arteriography tends to overestimate the length of an occlusion.

A steerable steel but somewhat firm guidewire (e.g., Wholey) or a J-tip guidewire (tight 1.5 mm J tip) can be used to cross occluded arteries.

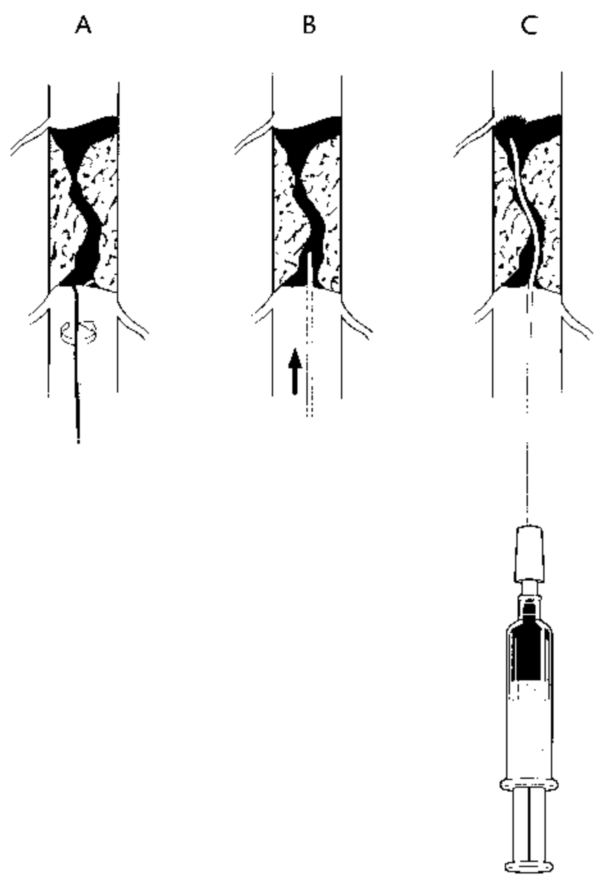

Fig. 10 Crossing an occlusion. A, A Wholey guidewire approaches the occlusion. The guidewire tip enters the thrombus but advancement stops. **B,** A straight catheter is passed over the guidewire. The guidewire is advanced while its tip is rotated. **C,** The catheter is advanced gradually and intermittently over the guidewire. Occasionally the guidewire is removed and contrast is puffed through the catheter to check progress and position.

One of these guidewires passed through a straight or Berenstein catheter often forms an effective combination (Fig. 10). Hydrophilic-coated guidewires are a second choice because they have the propensity to enter and slide along dissection planes. Once a dissection plane is raised in juxtaposition to an occluded arterial segment, it is difficult to redirect the guidewire into the lumen.

It is usually undesirable to pass the guidewire into a dissection plane. In some cases, however, if the occlusion is short and in a fairly large artery, such as the iliac artery or the superficial femoral artery, an angioplasty in the subintimal space can be performed. This procedure is more technically demanding because of the challenge of reentering the true lumen at the optimal location. In addition, long-term patency has not been evaluated as thoroughly as the patency of standard balloon angioplasty of the infrarenal arteries. Although subintimal balloon angioplasty is a second choice to angioplasty within the true lumen of the artery, it has gained increasing usage at some centers in the past few years.

In general, the shorter the occlusion and the less calcified, the easier it is to cross. Once the guidewire is through the most narrowed segment with the heaviest plaque formation, it usually slides through the compacted thrombus. If additional resistance is met and the operator is convinced that the guidewire is within the true lumen, a long, straight catheter is passed over the guidewire nearly to its tip. The guidewire is pushed ahead while performing a rotating-type maneuver to drill the tip of the guidewire into the occluded segment. As progress is achieved, the catheter is gradually and intermittently advanced. Contrast is puffed through the tip of the catheter to monitor progress and rule out subintimal passage.

If a short but difficult segment of the occlusion remains to be crossed or the entire lesion is short (2 cm or less) but heavily calcified, a straight catheter is advanced to the base of the J tip and the guidewire–catheter combination is advanced together. Endovascular treatment cannot be achieved unless the guidewire is completely across the occluded segment.

PLAN OF ATTACK: Crossing an Occlusion

1. Assess proximal and distal patent arteries arteriographically to measure occluded distance and to ensure that the plaque load is small enough that a recanalized occlusion has a reasonable likelihood of continued patency. DSA is best for this task. Cut film tends to overestimate occlusion length.
2. Road map the lesion. An extended road mapping run usually allows both ends of the occlusion to be visualized simultaneously (Fig. 9, see also Fig. 3 in Chapter 5).

3. Try a steerable steel guidewire (e.g., Wholey). If the lesion contains a significant amount of soft thrombus, this may be all that is required.
4. Try a J-tip guidewire (1.5 mm).
5. Advance a Berenstein or straight catheter over the shaft of the guidewire to give it more body, but do not advance it past the tip of the guidewire.
6. Drill and push the guidewire using a torque device. For each centimeter the guidewire advances, advance the overlying catheter also.
7. Assess the course of the guidewire and the distance from the other end of the occlusion with oblique views or with continued use of a road map.
8. Puff 1 to 3 ml contrast through the catheter to identify the location of the catheter tip, whether it is subintimal, and how far it has to go to clear the occlusion.
9. If a short distance remains or the lesion is short but calcified, advance a straight catheter to the base of the J tip on the guidewire and advance both together.

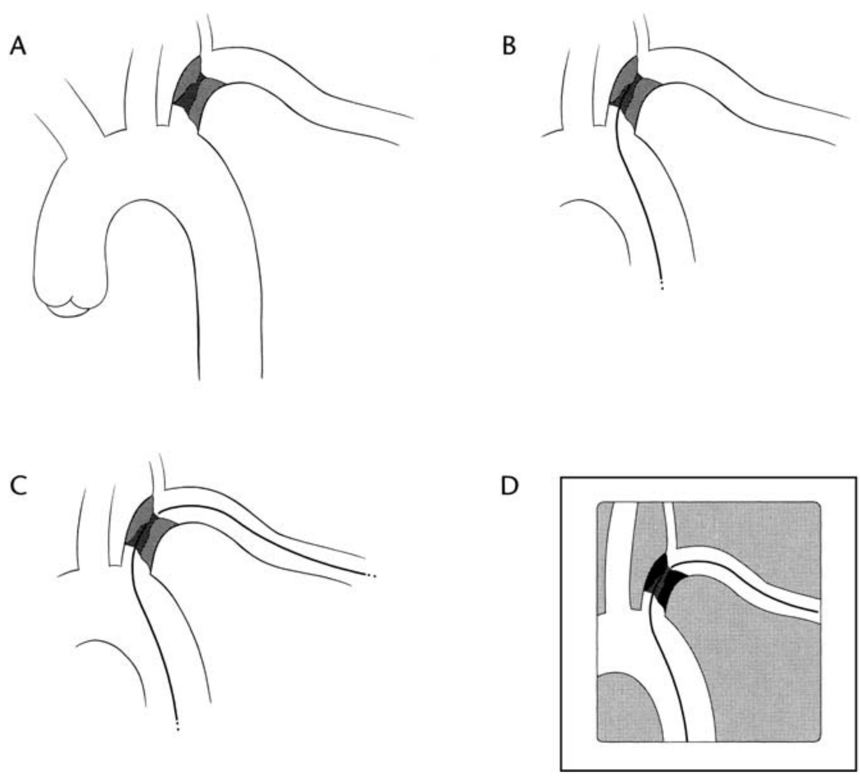

Fig. 11 Leave guidewire that won't cross occlusion as a marker. A, A proximal subclavian artery occlusion can be approached either antegrade (transfemoral) or retrograde (transbrachial). **B,** An unsuccessful antegrade approach results in the partial passage of a guidewire tip across the occluded segment. **C,** The first guidewire is temporarily left in place and serves as a marker for an alternate retrograde approach to the same lesion. **D,** Using fluoroscopic guidance, the distance between the tips of the two guidewires can be assessed.

10. If the guidewire won't cross the occlusion completely, leave it in place as a marker and approach the lesion from the opposite direction (Fig. 11).

ANGIO CONSULT: When Is Road Mapping Useful to Cross Lesions?

1. Road mapping is most useful for managing occlusions. Both ends of the occlusion may be visualized simultaneously. The progress of the guidewire across the occluded segment may be monitored in real time.
2. Road mapping is overrated as a tool for crossing stenoses. Most operators use many other tricks before going to the time and effort required to construct a road map.
3. Consider a road map for approaching complex lesions that could not be crossed after many different maneuvers have been attempted. The road map provides another option for attacking the lesion.
4. Road mapping simplifies the approach to lesions near the origins of branch arteries since it permits simultaneous visualization of the location of the branch that must be entered and the lesion that must be crossed.

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8

Arteriography

Arteriography Is Strategic, Not Diagnostic
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Arteriography Is Strategic, Not Diagnostic

Rarely does arteriography yield a new diagnosis. "Diagnostic arteriography" is a misnomer that will take a long time to disappear. This misconception is understandable since most departments performing arteriography were intended to provide assembly line style imaging, not individualized therapy. Except for an unusual case of vasculitis, most patients who undergo arteriography already have a diagnosis based upon history, physical exam, and noninvasive vascular evaluation.

Modern arteriography has two major purposes: strategic planning and guiding endovascular interventions. Arteriography presently provides much of the information used for the strategic planning of vascular reconstruction. It is still the most common strategic method with which most vascular specialists are familiar and comfortable. Arteriography permits the vascular specialist to evaluate disease patterns and the lesions that make them up and decide which should be treated with open surgery, which should undergo endovascular techniques, and which are best treated with a combination of the two. Once endovascular therapy has been selected as the treatment approach of choice, arteriography is the best way to guide the intervention. Intermittent periprocedural arteriography is crucial to guidewire and device passage and assessment of the results of treatment.

The Future of Arteriography

The development of duplex mapping, computed tomography (CT), angiography, and magnetic resonance arteriography (MRA) is likely to obviate the future need for much, if not most, of the strategic arteriography performed today. This will be a tremendous advance for vascular specialists and their patients for several reasons. Standard, percutaneous contrast arteriography has puncture site, end organ, and systemic complications associated with it. Among patients who avoid these complications there is obligatory cost, discomfort, and inconvenience experienced with each procedure. Over the next 5 to 10 years, arteriography will be performed less often for the purposes of identifying disease patterns and planning therapy. Standard catheter-based arteriography is likely to remain stable in terms of quality, cost, and risk while other vascular imaging modalities continue to improve.

A substantial disadvantage of catheter-based strategic arteriography as it is commonly performed by nonclinician technicians is that the information required from the arteriogram is often not well understood by the person performing the study. In angiographic suites throughout the world there are technicians performing strategic arteriograms who may not have familiarity with the patients' problems or the various options that may be reasonable to treat them. There are a substantial number of images being acquired and a substantial amount of contrast being administered that will not influence the patient's treatment. Because these procedures are not standardized, some patients leave the angiographic suite without all the information required to plan treatment.

The primary future role of arteriography is in real-time guidance of therapeutic endovascular procedures.

Supplies for Arteriography

Arteriography requires that specific supplies be readily available, whether the procedure is done in the angiography suite or the operating room. These include the contents of an "arteriography pack," items to be opened at the operator's discretion, and protective gear (Table 1).

Planning for Strategic Arteriography

Treatment strategy is developed as a result of information gained from arteriography The role of arteriography in clinical management is determined by patient presentation: (1) the location of symptoms (which vascular bed is involved), (2) the severity of symptoms, (3) probable etiologic factors, and (4) comorbid medical conditions. Arteriography is most efficient and successful when its purpose and scope are determined prior to the procedure and driven by an understanding of the patient's presentation and spectrum of treatment options.

Table 1 Supplies for Arteriography

Arteriography pack	Specialist's choice	Protective gear
No. 11 scalpel blade	Starting guidewire	Leaded apron
4 × 4 gauze	Angiographic catheter	Thyroid shield
Mosquito clamp	Heparinized saline flush	Leaded eye shields
Drapes	Contrast	
Gown		
Gloves		
Sterile cover for image intensifier		
Entry needle, 18 gauge		
Several 10- and 20-ml syringes		
Local anesthetic		
22-gauge needle		
Basin for discards		

Location of symptoms. The vascular bed involved determines the type of arteriogram required and to some extent the degree of selectivity involved.

Severity of symptoms. This factor influences the urgency of the study, the degree of detail required, and it may prompt additional views. Patients with claudication and patients with gangrene require different degrees of filming detail.

Etiology. Embolic, thrombotic, aneurysmal, and chronic occlusive disease each requires some modification of the approach to angiography. Oblique views and additional runs are required to find a source if embolic disease is suspected. Acute thrombotic occlusive disease requires enhanced images of the site of the lesion and the operator may consider converting the procedure to a therapeutic one for the delivery of thrombolytic agents. Evaluation of patients with aneurysms focuses upon the integrity of the arteries proximal and distal to the aneurysm where suture lines or stent may be placed. Other vascular beds may require evaluation for associated aneurysms. The integrity of the inflow and the quality of the distal target site are the main concerns in patients with chronic occlusive disease.

Comorbid medical conditions. Obesity adds time and decreases image quality. Cardiac and renal diseases limit contrast load and increase its complications. Patients with prohibitive risk for surgery may be better treated with endovascular intervention, even if the lesions are not particularly favorable for this approach.

Questions to Consider Before Arteriography

1. Can the patient be treated without arteriography?
2. What is the crucial information that arteriography will provide?
3. Is an aortogram necessary?
4. Is contralateral runoff needed?
5. How much contrast can the patient tolerate?
6. Could this be embolic disease?
7. Is selective catheterization required?
8. Is conversion to endovascular therapy likely?

Evaluation Before Angiography

Before performing arteriography the medical status of the patient must be evaluated. Potential puncture sites are checked to be certain the skin is free of infection. Current medications are reviewed. Those taking Glucophage should stop it several days prior to the procedure. Insulin dosage should be decreased appropriately for NPO status on the day of the arteriogram. Intravenous hydration is begun when the patient arrives. Coumadin should be held for 5 days before the arteriogram to permit the INR to normalize. If anticoagulation must be continuued, the patient may be hospitalized and converted to intravenous heparin administration. Another option is to continue the coumadin through the procedure and take extra care to obtain hemostasis afterward. This is most appropriate when only arteriography is planned, especially if it can be performed with a 4 Fr catheter. A closure device may be used to manage the arteriotomy, especially if it is larger than 4 Fr.

Allergies to medications should be clearly noted, as for any procedure. Patients with contrast allergies should be asked about what type of reaction occurred and what the circumstances were. A previous anaphylactic reaction is a contraindication to contrast administration. Patients with dermatologic or other systemic reactions may be pretreated with prednisone and benadryl. Management of contrast allergies and medication dosing is discussed in Chapter 13.

Cardiac and pulmonary insufficiency may also present difficulties in performing arteriography. The patient must be able to lie in the supine position for a lengthy period of time. Breath holds are often required to obtain reasonable images of any part of the body cavities. Patients with severe congestive heart failure, poor cardiac output, diastolic dysfunction, or a history of flash pulmonary edema may not be able to tolerate the osmotic load presented by the contrast.

Renal insufficiency may be worsened by contrast administration, and precautionary maneuvers should be undertaken to minimize nephrotoxicity (Table 2). Alternative imaging methods, such as duplex, MRA, or CT angiography should be considered, either to replace the arteriogram or to minimize the amount of contrast required for a more limited arteriographic study. If an arteriogram is still required, iodinated contrast may be minimized or possibly eliminated by using alternative contrast agents, such as CO_2 or gadolinium. When iodinated contrast is required, preprocedural hydration is performed,

Table 2 Preventing Contrast-Induced Renal Failure

Use alternative imaging methods	Use duplex or magnetic resonance arteriography
Minimize iodinated contrast during arteriography	Obtain imaging studies to complement and minimize extent of arteriogram (duplex, MRA) Use alternative contrast agents (CO_2, gadolinium)
Hydrate	Before, during, after procedure with normal saline
Premedicate	Mucormyst, 600 mg po bid on day before procedure, 600 mg po on day of procedure and 600 mg po on day after procedure

usually with normal saline. Patients should also be treated with mucormyst. Fenoldapam may also be considered. These medications are discussed in more detail in Chapter 13.

Informed consent is best obtained in the office well before the arteriogram or intervention so that the patient has time to become educated about the procedure and family members may ask questions and be reassured. It does not make much sense to sit with the patient as crew members and expensive high technology equipment sit idle while the patient ponders what may occur next.

Deciding Where to Puncture

Selecting a puncture site is similar to planning an incision. Puncture site choice is based upon where the operator believes the pathology is located. This is another substantial reason why the person performing the procedure should understand the patient's problem well. The correct puncture site location decreases the likelihood of complications and shortens the length of the procedure. The essential data for choosing the best puncture site are derived from the physical examination and supplemented by noninvasive studies. Table 1 in Chapter 2 includes a detailed list of which puncture sites are best for access to various anatomic segments. Puncture in an area of significant plaque formation, such as a bulky common femoral artery lesion, should be avoided when possible. Substantial femoral artery lesions may often be identified by palpation and further evaluated by duplex scanning.

When the area of interrogation is proximal to the renal arteries, most operators choose to perform a retrograde femoral puncture on the side that is easiest to reach with forehand positioning because of ease of guidewire and catheter placement. If the femoral pulses are equal, a right-handed operator usually punctures the right common femoral artery. If femoral pulses are diminished, the least diseased side is punctured.

If a renal catheterization and/or balloon angioplasty is likely, the approach to the renal artery of interest may be slightly simpler and the angle of approach more favorable with a puncture performed in the common femoral artery on the opposite side. This avoids turning the catheter or sheath back on itself, as occurs with an ipsilateral puncture. When the angle of origin is acute, as occurs often with mesenteric arteries and commonly with renal arteries, the best approach may be through a proximal puncture site.

Infrarenal occlusive disease is usually approached with a retrograde femoral artery puncture on the side contralateral to the worst disease (Fig. 1).

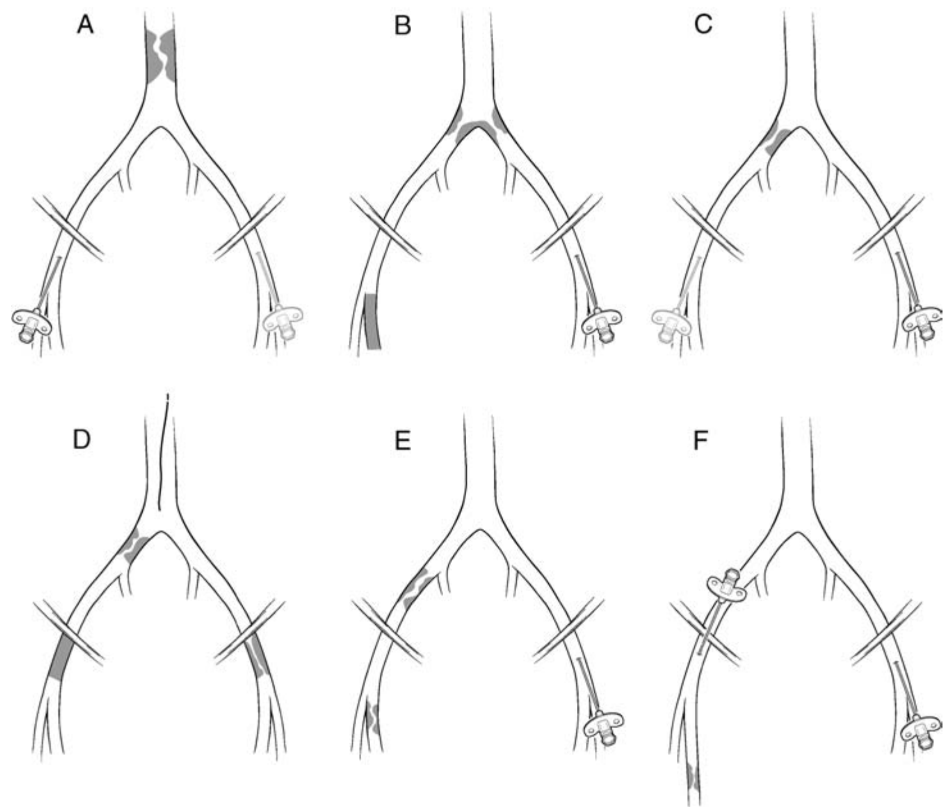

Fig. 1 Puncture site selection for infrarenal occlusive disease. A, Aortic disease may be treated with access through either femoral artery. When the two sides are relatively equal, the operator usually goes to the side where the forehand approach is easier. The right-handed surgeon would likely go to the patient's right side. **B,** When aortoiliac disease is similar bilaterally, the side with the least infrainguinal occlusive disease is punctured. This can usually be ascertained using physical exam, ankle–brachial indices, and/or other noninvasive studies. **C,** A focal iliac artery stenosis can be evaluated through a puncture of either femoral artery. Usually the side contralateral to the disease is used as access for arteriography. If endovascular therapy is planned, an ipsilateral retrograde approach may also be used. **D,** Severe common femoral artery occlusive disease is an indication for a proximal approach. **E,** Infrarenal occlusive disease is usually approached with a retrograde femoral artery puncture on the side opposite the worst disease. **F,** Isolated infrainguinal occlusive disease may be approached through an ipsilateral antegrade femoral puncture or a contralateral approach and up-and-over guidewire passage.

This location provides maximum flexibility if the procedure is converted to balloon angioplasty and avoids a puncture site in an area of low flow. If a contralateral femoral artery approach is not possible, puncture on the same side as an iliac lesion may still be considered, but it is best if other imaging has been performed to be sure that it is not a distal external iliac artery lesion. A proximal approach, through the brachial or axillary arteries, may also be considered. Focal iliac artery lesions, identified by duplex scanning or MRA, which are likely to be reasonable candidates for endovascular therapy, can be reached with an initial ipsilateral retrograde femoral artery puncture and undergo immediate treatment. If an iliac lesion is located in the distal external iliac artery, a contralateral puncture should be performed, whether endoluminal therapy is planned or not.

When the presence of aortoiliac disease can be ruled out by physical examination and noninvasive studies, only femoral arteriography may be required. This can be performed through an ipsilateral antegrade or retrograde femoral puncture or a contralateral retrograde puncture and passage of the catheter over the aortic bifurcation. If noninvasive data demonstrate infrainguinal occlusive disease and endovascular treatment is reasonable, an antegrade femoral artery approach is appropriate. An antegrade approach is also very useful when the infrainguinal disease is very distal in location; this permits distal contrast delivery and if endovascular treatment is required, it provides better guidewire and catheter control. A contralateral femoral artery puncture with the catheter passed over the aortic bifurcation and into the superficial femoral artery (SFA) may also be

Table 3 When to Use a Proximal Puncture Site Access Through the Axillary or Brachial Arteries

Severe infrarenal occlusive disease
Aortic occlusion
Bilateral critical/diffuse iliac occlusive disease
Bilateral common femoral artery disease
Common femoral artery occlusion
Severe common femoral artery stenosis
Femoral puncture contraindicated
Recent surgery
Infection
Aneurysm
Pseudoaneurysm
Angle of approach more favorable
Selective catheterization of or endovascular intervention in mesenteric arteries
Acute angle at origin of renal arteries
Retrograde approach to endovascular therapy
Subclavian lesions
Axillary lesions

performed. This approach is especially indicated if there is a proximal SFA lesion, which would render working room inadequate with an ipsilateral, antegrade puncture.

Since proximal approach arteries are smaller and more prone to spasm and thrombosis, and the risks of neurologic and other complications are higher, these are usually a second choice for routine access. Nevertheless, there are several situations in which proximal access is advised (Table 3). These indications include severe bilateral infrarenal or common femoral occlusive disease; hostile groins; a more favorable angle of approach to aortic branches through a proximal approach; and a retrograde approach to subclavian or axillary artery lesions.

ANGIO CONSULT: How Can Duplex Scanning Help in Choosing a Puncture Site?

1. The integration of hemodynamic information from duplex scanning into the planning of strategic arteriography and endovascular therapy permits better decision making on the patient's behalf. Choices of puncture sites, approaches, and therapy can be focused and specific.
2. Use duplex scanning to rule out lesions in the common femoral artery that may contraindicate puncture of that vessel.
3. When duplex scanning shows an isolated, focal iliac artery stenosis and therapy is intended, consider an ipsilateral, retrograde femoral artery puncture for arteriography and angioplasty.
4. When duplex scanning shows extensive aortoiliac occlusive disease and it is unclear whether an endovascular or an open surgical technique will be required, consider a retrograde femoral artery puncture on the side with the least amount of inflow disease.
5. When duplex scanning shows severe common femoral artery disease, puncture the least diseased side or use a proximal puncture site.
6. When duplex scanning shows a tight, proximal superficial femoral artery stenosis, avoid puncture of the adjacent common femoral artery.
7. When the superficial femoral artery is occluded and duplex scanning shows a significant proximal stenosis of the deep femoral artery, avoid puncture of the adjacent common femoral artery.
8. When an antegrade femoral artery puncture is considered, use duplex scanning to ensure that there is no large femoral bifurcation plaque.
9. Identify a high origin of the deep femoral artery before performing an antegrade femoral artery puncture.
10. Evaluate an infrainguinal vein graft with duplex scanning to identify the proximal anastomotic site and its distance from a common femoral artery puncture site. This is one factor in deciding whether to use an ipsilateral antegrade or an alternative approach.

Catheter Placement

The technique of arterial puncture is described in Chapter 2. After the optimal puncture site is selected, access is obtained and the guidewire is placed in the desired location. The usual initial guidewire choice for routine strategic arteriography is a floppy tip, 0.035-in. diameter, 145-cm length, starting guidewire (see Table 1 in Chapter 3). The guidewire is advanced to a location where the floppy tip is several centimeters beyond the intended location of the catheter head. Aortography is usually performed with a pigtail or tennis racket catheter. Catheter types and lengths are discussed in Chapter 3. Some common catheter choices for flush aortography are listed in Table 4 in Chapter 3. Catheter placement for aortography is based upon fluoroscopically visible landmarks (Fig. 2). Arch aortography is performed with the catheter head in the ascending aorta, well distal to the coronary ostia but proximal to the innominate artery. Thoracic aortography is performed with the catheter head placed just distal to the left subclavian origin, usually at the location where the aorta begins to straighten to descend into the thorax. The paravisceral segment of the aorta is seen best when the catheter is placed at or just proximal to the level of the diaphragm. A lateral projection is required to evaluate the celiac and superior mesenteric arteries in profile. Aortorenal arteriography requires catheter head placement at or just below the level of the renal arteries, usually over the first lumbar vertebral body or at the junction of the first and second lumbar vertebral bodies (Fig. 1 in Chapter 4). More details about catheter head placement are provided in the sections below that describe different types of arteriograms.

Following removal of the guidewire, the flush catheter head takes its preformed shape. Contrast may be puffed through the catheter to confirm the correct location. The catheter is flushed with heparin–saline solution. The catheter is permitted to backbleed momentarily while the sterile tubing of the automated power injector is purged. After the air bubbles are removed from the system, the catheter is connected to the sterile tubing. The catheter is again aspirated through the power injector to check the system for microbubbles.

Contrast Administration and Image Acquisition

The power injector and its usage in arteriography are described in Chapter 5. Power injection causes contrast to reflux several centimeters before the contrast bolus moves forward with the flow stream. During routine abdominal aortography, for example, contrast refluxes proximally

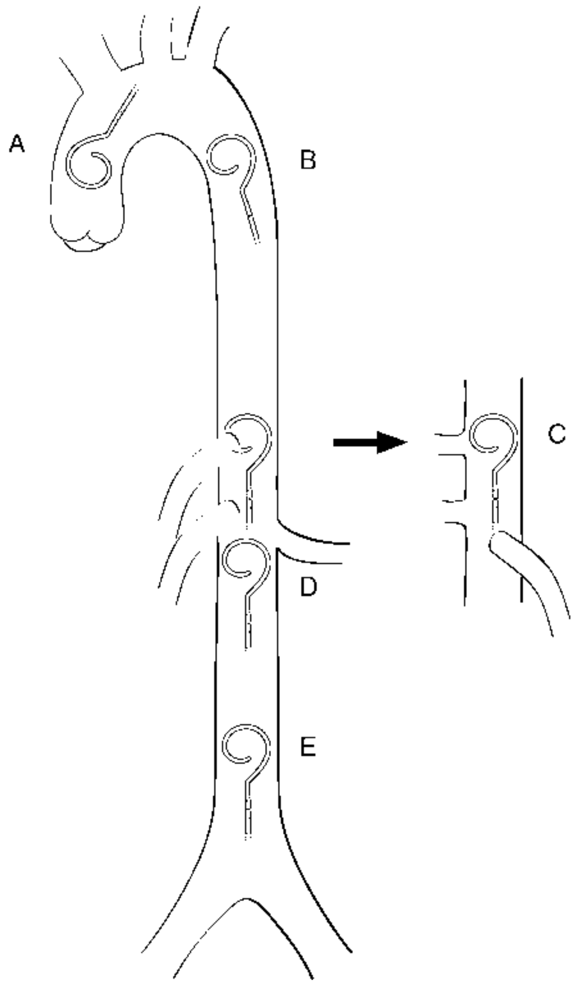

Fig. 2 Catheter position for aortography. A, Arch aortography is performed with the catheter head in the mid-ascending aorta. **B,** A thoracic aortogram is performed with the catheter head positioned in the proximal descending aorta. **C,** The paravisceral aorta is evaluated in the lateral projection with the catheter head at the level of the celiac artery. **D,** Catheter head placement at the level of the renal arteries provides reflux of contrast into the renal arteries and a flush of contrast into the infrarenal aorta. **E,** When the side holes are placed just proximal to the aortic bifurcation, pelvic and bilateral lower extremity arteriographic runoff can be performed.

the distance of approximately one vertebral body. If severe occlusive disease is present in the aorta or iliac arteries, contrast may reflux further and run off through the visceral arteries. Reflux during arch aortography is usually less since it is higher flow, there is more mixing with nonopacified blood, and juxtaposed occlusive disease is much less common. The injection (volume and rate) and imaging of contrast depend on the size of the patient, the expected rate of blood flow, the type of filming selected (digital subtraction or cut film), and the area of arterial anatomy to be surveyed (trunk, neck, or extremity).

Digital subtraction arteriography (DSA) is often performed one station (field of view) at a time. A mask is created for later subtraction, contrast is injected, and the image intensifier and the object are held in a constant position. Motion artifact is detrimental to digital images because the computer attempts to subtract the static image from the contrast column after the images have been acquired. DSA within a body cavity requires that the patient perform breath holding during image acquisition to minimize motion artifact. Digital images are acquired at rates of 1 to 30 per second, depending upon the type of arteriogram and the lesion being interrogated. Aortography is usually performed at 3 to 4 images per second. High-flow aortic branches such as subclavian or renal arteries require at least 3 images per second for evaluation. Very slow pedal artery flow may be well evaluated with images acquired at 1 per second. A high-flow arteriovenous fistula may require up to 30 frames per second to capture the detail.

Newer bolus chase technology is available for lower extremity runoffs. Contrast is injected and the table moves the patient as the image intensifier is maintained in a fixed position and images are acquired. After the run, the table returns to its starting position and the filming sequence and table movement are repeated to create a mask that is then subtracted from the initial contrast run to produce the final arteriogram.

Cut film arteriography uses a rapid film changer (puck) and an exchange table that permits different steps (fields of view) to be acquired following a single injection. The exchange table moves through five stations in sequence so that once the contrast has been administered, the filming and table movement follow in the prescribed manner. The exchange table allows an overlap of approximately 1 in. between each filming station.

Arteriography Sequences

Strategic arteriography requires specific contrast injection and filming or image acquisition sequences depending on the vasculature being studied (Table 4). The clinical and arteriographic pictures should be reconciled to determine when the study has yielded adequate information and may be concluded. A clear understanding of the patient's clinical problem prevents the continued accumulation of noncontributory views and filming runs. DSA and cut film are compared in Chapter 5. In the discussion that follows, DSA techniques are described primarily. Cut film arteriography was the standard for many years, but there are fewer endovascular specialists working with this type of arteriography. Table 4 includes contrast injection and filming sequences for both DSA and cut film.

Arteriography of the Brachiocephalic Arteries

Brachiocephalic arteriography differs from many other types of arteriography for two reasons: (1) it is fairly remote from femoral artery puncture sites and longer guidewires and catheters must be used than for many other types of arteriography (see Tables 2 and 3 in Chapter 3); and (2) there is a small but real risk of stroke, which may be caused by guidewire–catheter manipulation, microbubbles, or catheter thrombus.

ARCH AORTOGRAPHY

The guidewire is introduced and its floppy tip is placed in the ascending aorta. Care must be taken to avoid placing the guidewire in the left ventricle or into the coronary arteries and causing arrhythmias. A 90-cm pigtail catheter is placed over the guidewire and the catheter head is placed in the distal ascending aorta, just proximal to where the aorta begins to turn to the left to form the arch (Fig. 2). The guidewire is removed, and the catheter is flushed and then connected to the power injector. Care must be taken to avoid the injection of microbubbles. The catheter hook-up process is described in Chapter 5 and in the previous section on catheter placement. The image intensifier is positioned so that the aortic arch and the extracranial carotid and vertebral arteries are within the field of view. The catheter crossing the arch provides a marker for the inferior aspect of the field. The patient is asked to breath hold and avoid swallowing during image acquisition. Contrast injection for DSA is usually 15 for 30, or 15 ml/sec for two consecutive seconds (Table 4). Image acquisition is variable, but a common sequence would be 4 images per second for 6 to 8 sec or until contrast washes out.

After the anteroposterior (AP) arch aortogram, 30- to 45-degree oblique views of the arch and its branches are obtained using the same injection and filming sequence. If contrast must be limited, the operator has the option of performing a left anterior oblique (LAO) projection first and omitting the anteroposterior (AP) and right anterior oblique (RAO) views. The LAO view is used to establish the landmarks required for selective catheterization of the aortic arch branches. Figure 1 in Chapter 6 demonstrates the LAO projection.

Table 4 Strategic Arteriography: Contrast Administration and Image Acquisition

Type of arteriogram	Catheter placement	Type		Imaging mode	Contrast Administration			Image Acquisition	
		Flush	Selective		Volume (ml)	Time (sec)	Rate[a]	Delay (sec)	Sequence (images per sec/ no. of sec)
Brachiocephalic									
Arch aortogram	Ascending aorta	X		DSA	30	2	15 for 30	0	4/8
				Cut film	40	2	20 for 40	0 or 1	2/3 then 1/6
Innominate arteriogram	Innominate artery		X	DSA	15–30	3–4	6 for 18	0	3/6
				Cut film	15–40	3–4	8 for 24	0	2/3 then 1/6
Carotid arteriogram	Common carotid artery		X	DSA	6–15	2	5 for 10	0	3/6
				Cut film	10–20	3	5 for 15	0	2/3 then 1/3
Subclavian arteriogram	Subclavian artery		X	DSA	10–15	3	4 for 12	0	3/6
				Cut film	10–20	3	5 for 15	0	2/3 then 1/3
Axillary arteriogram	Axillary artery		X	DSA	10–15	3	4 for 12	0	3/6
				Cut film	10–20	3	5 for 15	0	2/3 then 1/3
Thoracic									
Descending thoracic aortogram	Proximal descending aorta	X		DSA	30	2	15 for 30	0	3/6
				Cut film	40	2	20 for 40	0 or 1	2/3 then 1/3

Visceral									
Paravisceral	Distal descending	X		DSA	30	3	10 for 30	0	3/6
aortogram	aorta			Cut film	40	3	12 for 36	0	2/3 then 1/3
Celiac/SMA	Visceral artery		X	DSA	12–18	3	5 for 15	0	3/6
arteriogram				Cut film	12–24	3	6 for 18	0	2/3 then 1/3
Renal arteriogram	Renal artery		X	DSA	8	2	4 for 8	0	3/6
				Cut film	12	3	4 for 12	0	2/3 then 1/3
Aortoiliac									
Aortoiliac	Pararenal aorta	X		DSA	18–24	3	8 for 24	0	3/6
arteriogram				Cut film	45	3	15 for 45	1 or 2	2/3 then 1/3
Abdominal aortogram with runoff	Pararenal aorta	X		Cut film	60–90	6–12	8 for 72	1 or 2	
Infrainguinal									
Bilateral runoff	Infrarenal aorta	X		Cut film	60–70	6–8	8 for 64	3 or 4	1/3, 1/4, 1/4, 1/4, 1/6
Femoral arteriogram	External iliac or femoral	X	X		DSA	2	5 for 10	0	3/4 repeat at multiple (4 or 5) stations
				Cut film	20–30	4–6	6 for 24	1–2	1/4, 1/4, 1/5, 1/6
Tibiopedal	Femoral or	X	X	DSA	10–20	2–3	5 for 15	3–15	2/20 if necessary
arteriogram	popliteal			Cut film	10–20	2–3	6 for 18	3–15	1/20 if necessary

[a] Commonly used injection rates are shown. They are described in terms of the amount of contract administered per second and the total volume injected.

CAROTID ARTERIOGRAPHY

The arch is inspected for evidence of occlusive disease at the origins of its branches and for evidence of disease within the arch that may cause embolization. If either of these are present, the risk of stroke from catheter manipulation is substantial and the operator may consider alternative methods of imaging. If the operator decides to proceed with selective catheterization and arteriography of the cerebral arteries, heparin is administered.

Chapter 6 contains a discussion of selective catheterization of arch branches. The arch aortogram is used to assist in choosing a selective cerebral catheter. The pigtail catheter is withdrawn to a position distal to the arch branches. The catheter is flushed, the starting guidewire is placed through the pigtail catheter, and the pigtail catheter is removed. The selective cerebral catheter is introduced over the guidewire. The image intensifier is maintained in its LAO position so that landmarks may be used to guide selective catheterization. The starting guidewire is removed and the catheter is aspirated, assessed for microbubbles, and gently flushed with heparinized saline. A long (180 or 260 cm), steerable, hydrophilic-coated guidewire is inserted into the catheter. The cerebral catheter is advanced into proximity to the origin of the artery intended for selective arteriography (Fig. 3, see also Figs. 3 to 5 in Chapter 6). The steerable guidewire is advanced into the artery for a few centimeters. The guidewire is not advanced into the carotid bifurcation. The catheter is advanced over the guidewire while the guidewire is maintained in a stationary position. Because of the large caliber and curvature of the aorta, extra slack may be present along the length of the

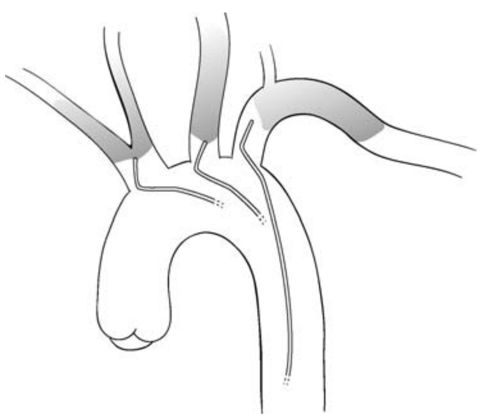

Fig. 3 Cerebral arteriography. A simple-curve selective cerebral catheter is advanced into each of the arch branches. The tip of the catheter must be a few centimeters or more into the artery to prevent the catheter from popping out of the artery and into the arch. There is some recoil of the catheter during contrast administration. See also Figs. 3 to 7 in Chapter 6 for more about selective arch branch catheterization.

guidewire and care must be taken to avoid advancing the guidewire while the catheter is placed into the cerebral artery. After the catheter is a few centimeters within the origin of the intended artery, the guidewire is removed and the catheter is aspirated and gently flushed again.

Contrast is puffed into the artery to confirm correct positioning of the catheter tip. The catheter tip should not be placed into the sidewall of the artery or near a lesion. The selective catheters have an end hole but no side holes. Pressure injection should not be performed until the position of the catheter is confirmed within the lumen of the origin of the branch artery. Because there is only an end hole for contrast administration, there may be recoil of the catheter under pressure, so the catheter must be placed at least a few centimeters into the artery to prevent it from popping out. The catheter is aspirated, flushed with heparinized saline, and connected to the power injector tubing. The catheter is aspirated through the injector and the tubing is checked again for microbubbles.

Injection rates and filming sequences are summarized in Table 4. Injection of contrast into the innominate artery should be 5 to 8 ml/sec over 3 or 4 sec. An example sequence is 6 for 18, or 6 ml/sec for 3 sec. Image acquisition should be at 3 or 4 images per second. The pressure limit is usually decreased to about 300 psi, and a 0.3 to 0.5 rate of pressure rise is programmed into the injector as a safety maneuver. Oblique views of the innominate artery are usually required to open the bifurcation to evaluate the origins of the right subclavian and right common carotid arteries. Injection into the common carotid artery is usually performed with 3 to 5 ml/sec over 2 or 3 secs. Example sequences include 4 for 8 (4 ml/sec for 2 secs), 3 for 9 (3 ml/sec for 3 secs), or 4 for 12 (4 ml/sec for 3 secs).

The carotid bifurcation is usually evaluated in the AP and lateral projections. Since the bifurcation and proximal internal carotid artery disease is worst along the posterior wall, addition steep oblique views may be required to demonstrate the most significant segment of the stenosis in profile. During image acquisition the patient is coached to breath hold and to drop the shoulders and lengthen the neck.

SUBCLAVIAN ARTERIOGRAPHY

The first step in transfemoral subclavian arteriography is an arch aortogram (Figs. 6 and 7 in Chapter 6). It is often possible to evaluate either subclavian artery with an arch injection. After arch studies are performed, the need for selective arteriography is assessed. The same steps are followed for selective subclavian arteriography as have been discussed in the previous section on carotid arteriography. A selective catheter with either a simple curve or a complex curve is chosen and advanced into the origin of the subclavian artery using a steerable guidewire and anatomic landmarks. Selective subclavian artery catheterization is discussed in detail in Chapter 6. The selective catheter is positioned a few centimeters within the origin of the subclavian artery. The catheter is aspirated, checked for microbubbles, irrigated with heparinized saline, and connected to the automated power injector. Contrast administration is usually at 4 to 6 ml per second for 3 or 4 seconds. An example sequence is 4 for 12, or 4 ml per second for 3 seconds with image acquisition at 3 or 4 frames per second. Injection within the subclavian artery should not be performed in proximity to the origin of the vertebral artery to avoid dissection. Most of the time, adequate information about the vertebral artery can be obtained with subclavian artery contrast injection. When detailed vertebral anatomy must be delineated, the vertebral artery may be selectively cannulated and a lower pressure injection may be performed. Heparin is administered when vertebral artery catheterization is performed. When subclavian steal is present, extended filming is required to demonstrate reversed flow in the vertebral artery ipsilateral to the lesion.

The subclavian artery may also be approached through an ipsilateral brachial puncture or cutdown. Brachial punctures are described in Chapter 2. The upper extremity approach may be useful for arteriography and interventions in a variety of situations (Table 3). Transbrachial catheterization of the subclavian and axillary arteries is described in Chapter 6 (Fig. 8 in Chapter 6). After access is secured, and a straight catheter is placed, a hand-powered injection of 10 ml of contrast is usually adequate to obtain a subclavian arteriogram, especially if antegrade flow is reduced because of a proximal subclavian artery stenosis or occlusion. However, keep in mind that a brachial puncture ipsilateral to a significant lesion is more difficult to perform. In addition, there is a higher likelihood of thrombosis if the lesion is not treated to improve inflow.

Thoracic Aortography

A 90-cm pigtail catheter is introduced into the proximal thoracic aorta. When aortic arch or left subclavian artery anatomy are important, an arch aortogram may be performed initially and the location of the left subclavian artery may be identified. The catheter head is withdrawn and positioned at a level just distal to the origin of the left subclavian artery (Fig. 2). The catheter is connected to the sterile tubing for the power injector using the same routine. The patient is instructed to breath hold. Thoracic aortography requires 12 to 20 ml of contrast injection per second for 2 to 3 seconds. An example sequence is 15 for 30, or 15 ml per second for 2 seconds, with filming at 3 or 4 frames per second. There is some debate about the safety and efficacy of selective arteriography of the spinal cord blood supply. This is beyond the scope of this text.

Arteriography of the Visceral and Renal Arteries

Arteriography of the visceral and renal arteries is characterized by factors that differentiate it from other types of arteriography. These include: (1) these arteries are more prone to spasm during manipulation, which may lead to end organ complication, (2) the anatomy of these arteries may be significantly altered by ventilatory motion and diaphragmatic movement, and (3) the angle of approach from the femoral artery to the visceral and renal arteries is usually fairly acute.

ARTERIOGRAPHY OF THE CELIAC AND SUPERIOR MESENTERIC ARTERIES

A starting guidewire is introduced through the femoral artery and a 65-cm length, 4 or 5 Fr pigtail or Omni-flush catheter is placed over it. The catheter head is placed at or just proximal to the level of the diaphragm (Fig. 2). Aortography of the paravisceral segment is performed using the power injector to administer 8 to 12 ml of contrast per second over 3 seconds. An AP aortogram is performed, the catheter head may be adjusted slightly, and a magnified lateral view is obtained. The lateral is performed with the patient's arms extended above the head. Chapter 6 details selective catheterization of the visceral arteries. The selective catheter must be placed 1 to 2 cm within the origin of the artery to avoid having the catheter pop out with diaphragmatic excursion or high-pressure injection (Fig. 4). The

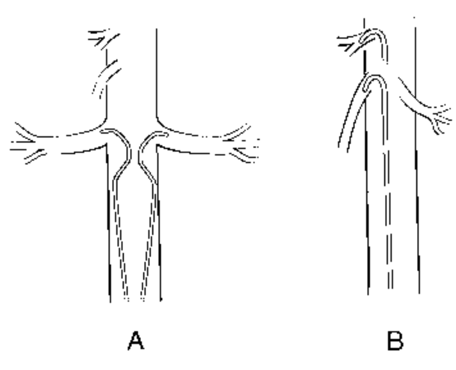

Fig. 4 Selective visceral and renal arteriography. A, A C2 cobra catheter is used to cannulate the renal artery. Contrast may be puffed from the position shown. There is some catheter recoil with pressure injection, and the catheter tip must be inside the artery to perform detailed arteriography. **B,** A hook-shaped catheter is used for selective arteriography of the celiac and superior mesenteric arteries.

catheter is connected to the power injector tubing after the system is irrigated and purged of microbubbles. Selective arteriography of either the celiac or superior mesenteric arteries may be performed with 4 to 6 ml of contrast injected per second over 3 sec with image acquisition at 3 or 4 frames per second (Table 4). The origins of the celiac and superior mesenteric arteries are best visualized in the lateral position. The more distally located branches of each of these arteries are best evaluated in the AP position or at a slight oblique.

If the catheter is in the artery for more than a few minutes, consider administering nitroglycerine to prevent spasm. If there is very slow flow due to a lesion at the origin of the artery, it is usually not advisable to cross it unless therapy is planned to follow immediately. In that case, consider systemic heparinization prior to crossing the lesion.

ARTERIOGRAPHY OF THE RENAL ARTERY

Renal arteriography begins with a pararenal aortogram if the patient can tolerate the contrast load. The catheter head is placed at or just below the renal arteries (Fig. 2). Reflux of contrast into the superior mesenteric artery is undesirable because its image frequently obscures the left renal artery orifice. The image acquisition is extended for several seconds so that bilateral nephrograms may be evaluated. The catheter head may be adjusted slightly, based upon the contrast flow pattern seen on the initial AP aortogram. If one renal artery origin is of particular interest, consider a repeat aortogram using a smaller field of view to provide a magnified arterial image. Since the renal artery origins are posterolateral, the orifice of the artery is often obscured by the aortic wall (Fig. 5). A 10-degree ipsilateral anterior oblique projection is performed. The images are inspected and selective catheterization is considered. Selective renal artery catheterization is detailed in Chapter 6. The flush catheter is exchanged for a selective

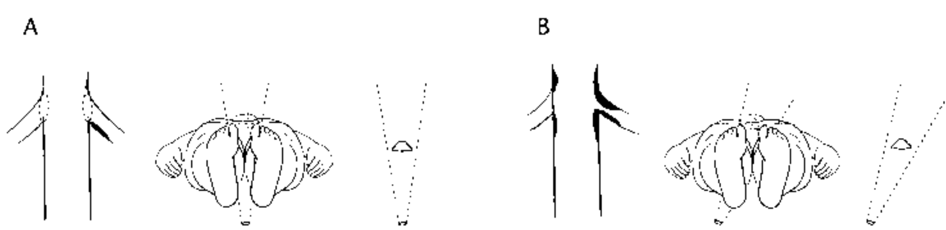

Fig. 5 Oblique projection for renal arteriography. Renal artery origins are posterolateral. **A,** Origin lesions may be obscured by aortic plaque or contrast on the standard anteroposterior projection used for aortography. **B,** An ipsilateral anterior oblique projection permits enhanced visualization of the renal artery origin.

catheter, usually a 65-cm C2 cobra catheter (Fig. 9 in Chapter 6). The tip of the selective catheter is directed into the origin of the artery (Fig. 4). Selective renal arteriography may be performed with 3 to 6 ml per second for 2 or 3 seconds (Table 4). If the catheter remains in the artery for more than a few minutes or therapy is planned, consider systemic heparin administration prior to entering the artery and local nitroglycerine administration after crossing the lesion.

Arteriography of the Infrarenal Arteries

Occlusive and aneurysmal diseases involving the infrarenal arteries comprise a significant proportion of contemporary vascular practice. Because there are many competing options available for treatment of lesions in these arteries, the operator's understanding of the patient's clinical problem has a direct impact upon the quality and appropriateness of the study. This is also a vascular bed where arteriography is likely to progress to endovascular therapy during the same intervention, so the arteriogram must be planned to dovetail with therapy.

ARTERIOGRAPHY OF THE ABDOMINAL AORTA AND ILIAC ARTERIES

Aortoiliac arteriography is usually performed with a 65-cm length, 4 or 5 Fr flush catheter, such as a pigtail, tennis racket, or Omni-flush catheter. The catheter head is placed at the level of the renal arteries (Fig. 2). When the patient is under consideration for stent–graft placement, a calibrated catheter with 1-cm markers is used, and the first marker should be placed just below the renal arteries in the stent–graft landing zone. The catheter is aspirated, flushed, and connected to the injector. The field of view should extend superiorly to the T12–L1 disc space. Laterally, the field should be wide enough to include both nephrograms. The patient is coached at breath holding. A DSA is obtained with 6 to 15 ml of contrast injected per second over 2 to 3 seconds (Table 4). A common sequence would be 8 for 24, or 8 ml per second for 3 seconds. Image acquisition is at 3 or 4 frames per second until contrast washes out. Whether evaluating occlusive or aneurysmal disease, 30-degree anterior oblique projections may also be performed to provide additional anatomic detail. The inferior aspect of the field of view for the obliques should include the common femoral arteries and their bifurcations so that these arteries may also be assessed.

Aortoiliac arteriography may also be performed using cut film. Cut film aortography is usually performed with 15 ml per second for 2 seconds (15 for 30). Image acquisition is at 2 films per second for 3 seconds, and 1 per second for 3 seconds, usually after a 1- or 2-second delay.

INFRARENAL AORTOGRAPHY WITH LOWER-EXTREMITY RUNOFF

An aortogram with runoff may be obtained using either DSA or cut film aortography. An aortogram with lower-extremity runoff may be accomplished by placing the catheter at the level of the renal arteries and performing a sequence of films that covers the distance from the aorta to the feet. This is the standard method used with cut film and is also now available with DSA systems using "bolus chase." Another option is to perform an aortoiliac arteriogram, withdraw the catheter to the distal aorta, and follow with a filming sequence from the aortic bifurcation to the feet. When using DSA, a common method is to perform the runoff at one station, or field of view, at a time with a separate contrast injection at each level.

A digital aortogram with bilateral runoff using bolus chase is performed in the following manner. The locations of the patient's hips, knees, and feet are put into line using fluoroscopy and moving the angiographic table only cephalad and caudad, without side-to-side motion. The beginning and ending locations of the sequence are determined and locked into place. The contrast is administered. A hand-held table motion device is used by the operator to move the table to keep the contrast bolus within the field of view as it is followed toward the patient's feet. After the sequence is completed, the patient remains still and the sequence is repeated without contrast to obtain a mask. Contrast is usually administered at 7 to 10 ml per second for 8 to 12 seconds.

A cut film aortogram with lower-extremity runoff is demonstrated in Fig. 6. Injection is performed over 8 to 12 seconds, usually with 6 to 12 ml per second. A standard program is 8 ml per second for 8 seconds, or 8 for 64, but the specific rate and amount must be individualized. A delay of 1 to 2 seconds following the start of injection and prior to filming is usual. Five steps are usually required to film from the costal margins to the feet. These are performed in rapid succession with a rapid film changer. Before beginning the run, the patient is positioned so that the arterial system is centered within the field of view at each step along the filming sequence. Scout films are taken at each step. Films are acquired at 1 per second with a 1-second interval when the table moves. Generally, three films are acquired of the aorta and proximal iliac system, three films of the distal iliac and proximal femoral system, three or four films of the superficial femoral artery and popliteal arteries, four films of the popliteal–tibial segment, and five to six films of the lower tibial and pedal segments. Up to 20 films may be acquired in a single runoff sequence. The number of films acquired at each level is modified according to the level of expected disease as determined by physical examination and noninvasive data. For example, if superficial femoral artery occlusion is expected, the films at that level are increased by one or two and the films at the distal levels are delayed by obtaining a film every other second rather than every second.

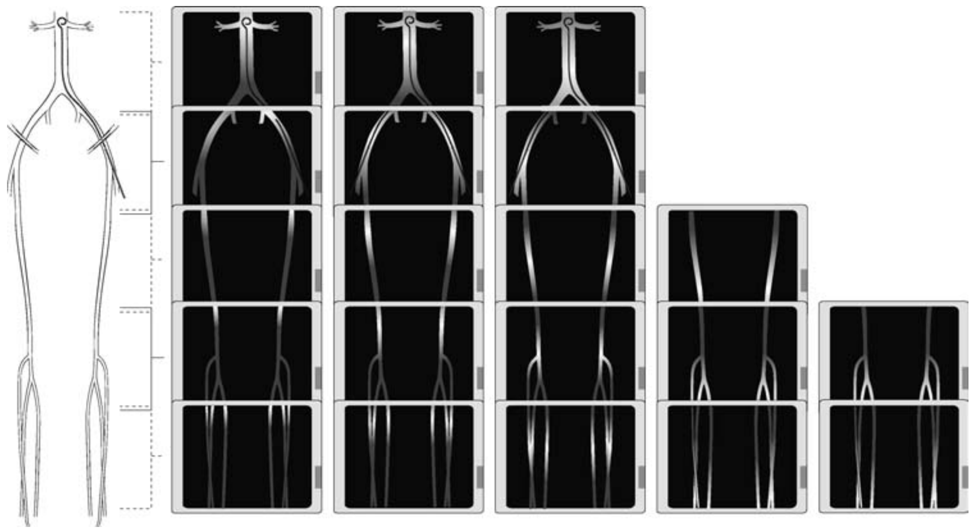

Fig. 6 Cut film sequence for aortogram with runoff. The cut film sequence includes up to 20 films at as many as five stations. The number of films at each station and the amount and timing of contrast injection are modified to suit the individual patient. The catheter head is placed at the level of the renal arteries. This filming sequence includes three films of the aorta and iliac arteries, three of the distal iliac and proximal femoral segment, four of the superficial femoral artery, five of the popliteal and proximal tibial arteries, and five of the middle to distal tibial arteries. Timing of the sequence must be estimated in anticipation of the flow of the contrast bolus. Although this example shows unilateral runoff, bilateral runoff is often obtained by centering the patient carefully while obtaining scout films prior to contrast injection.

Cut film bilateral lower-extremity runoff is obtained after aortography by withdrawing the catheter head to the distal infrarenal abdominal aorta. The second through fifth steps from the aortogram with runoff sequence are performed while injecting 6 to 10 ml of contrast per second for 6 to 8 seconds.

The ability to perform an aortogram with bilateral runoff, using either cut film with the rapid film changer or DSA with the bolus chase technique, provides the opportunity to cover a long distance within the arterial system by following a single large bolus injection. However, when the pattern of occlusive disease is significantly different from one leg to the other, the contrast may travel at different rates in each limb, making the resultant study suboptimal in one of the limbs. In this case, additional unilateral views will be required to supplement the study. Another disadvantage of this type of study is that in patients with multiple levels of disease, sufficient concentrations of contrast may not reach the feet to obtain adequate pedal arteriograms after an injection of contrast in the aorta. Subsequent study is then required, usually with contrast administered in a more distal location.

FEMORAL ARTERIOGRAPHY

Femoral arteriography may be performed with a catheter placed either up and over the aortic bifurcation or in a retrograde or antegrade direction through the common femoral artery ipsilateral to the lesion (Fig. 7). Femoral arteriography may be performed using a standard angiographic catheter or a dilator.

Using a contralateral approach, a straight or curved arteriographic catheter is placed over the aortic bifurcation for an injection at the level of the distal iliac artery or common femoral artery. An ipsilateral approach is performed using a short, straight catheter or dilator placed either retrograde or antegrade. Contrast is administered by hand or power injector. The simplest method for performing a DSA femoral arteriogram is to obtain one field of view at a time with a separate small injection of 6 to 12 ml of contrast at each of several stations (usually four or five to the foot) while filming at two to four frames per second. Cut film may also be used with a runoff arteriographic sequence that usually includes 20 to 40 ml of contrast injected and four steps of the table to delineate the anatomy from the femoral artery to the foot.

In patients with inflow to the knee but with severe tibial and/or pedal occlusive disease, as often occurs in diabetics, selective infrapopliteal arteriography may be required. The catheter is placed as distally as possible using an antegrade approach, either up and over the aortic bifurcation or as an ipsilateral antegrade femoral puncture (Fig. 7). A long, straight, multi-sidehole catheter is used, and 3 to 10 ml of contrast are administered directly into the popliteal artery.

PEDAL ARTERIOGRAPHY

It is not usually possible to obtain detailed pedal arteriography with contrast administered through an arteriographic catheter placed in the aorta. Inadequate pedal arteriography may lead to the subsequent surprise of the "angiographically occult" outflow artery in the foot. When detail is required at the ankle and foot, such as target site identification, either selective catheterization with injection in the popliteal artery is required or an extended filming sequence must be performed after a femoral artery injection (Fig. 8).

Contrast displaces what little blood is flowing to an ischemic foot, so arteriography causes discomfort, which prompts movement. This movement diminishes film quality but also indicates the timing of the contrast flow to the foot. If a cut film magnification lateral is desired, the timing is estimated by (1) evaluating the rate of contrast flow on the runoff films, or (2) performing DSA of the foot after a small proximal injection and timing the flow distally. Once the transit time for contrast to flow from the injection site to the foot has been quantified, the delay can be programmed into the cut film sequence. Patients with very ischemic limbs may require a 20-second delay after administration of contrast into the femoral artery. The foot is

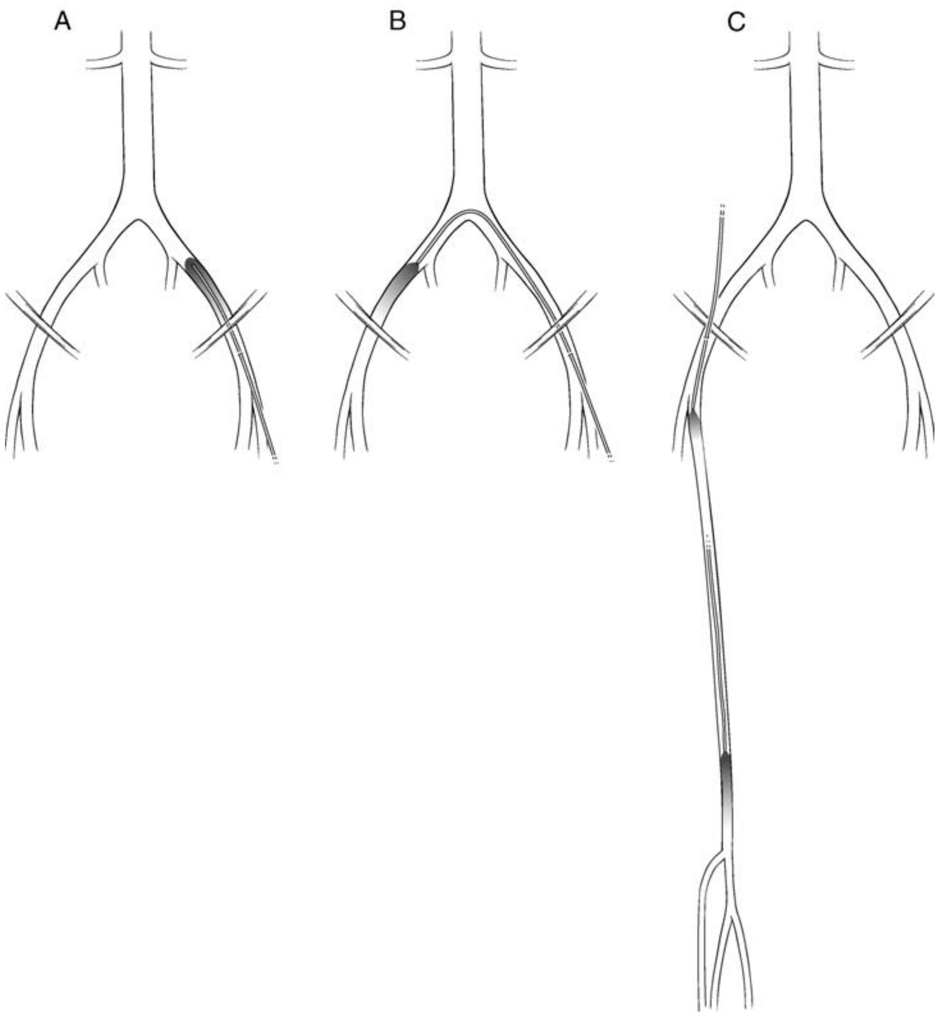

Fig. 7 Catheter placement for femoral arteriography. A, An ipsilateral retrograde femoral puncture can be performed for femoral arteriography. A 4 Fr dilator can be used as the catheter. This approach is not well suited to endovascular therapy. **B,** Contralateral access with catheter passage over the aortic bifurcation is a reasonable approach for arteriography, and it is easily converted to a therapeutic approach. **C,** If aortoiliac disease has already been ruled out, an ipsilateral antegrade femoral puncture provides excellent control and pushability, especially if infrageniculate disease is the focus of the investigation.

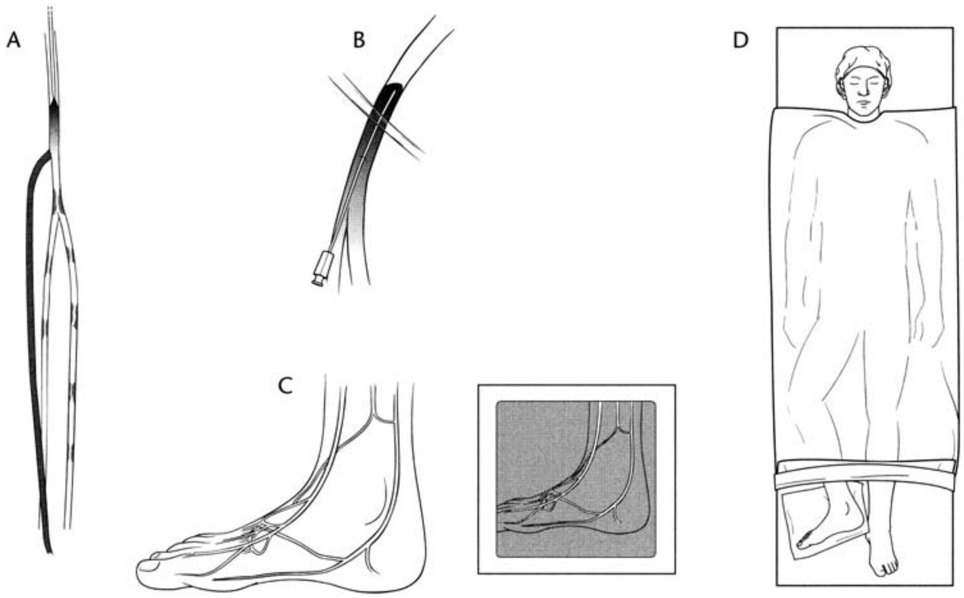

Fig. 8 Pedal arteriography. A, Antegrade placement of the arteriographic catheter is optimal to evaluate infrageniculate occlusive disease. **B,** When antegrade catheter placement is not possible, a straight 4 or 5 Fr dilator can be placed retrograde in the femoral artery and contrast administered. Delayed filming is performed. **C,** The foot is imaged in the lateral position. The image intensifier is placed over the area of interest. Contrast may require 20 to 30 seconds to flow from the femoral segment to the foot. **D,** The foot must be completely immobilized to prevent motion artifact.

padded and taped in the lateral position (hip externally rotated and knee flexed). The pain of contrast reaching an ischemic foot can be a memorable and upsetting experience for the patient, and sedation should be administered prior to selective pedal arteriography. Hand-powered injection of 5 to 10 ml of contrast over 1 or 2 seconds is performed with the catheter tip placed in the popliteal artery if possible. When there is an ipsilateral SFA occlusion, contrast is administered into the common femoral artery. A larger bolus of contrast may be required since there is more mixing of contrast with unopacified blood from collaterals prior to reaching the foot.

ANGIO CONSULT: What Can I Do to Identify Arteriographic Fakeouts?

1. **Posterior wall lesions.** Obtain oblique or lateral views. Posterior wall plaque and bifurcation stenoses may appear insignificant in the anteroposterior projection, but sometimes a decrease in the density of

the contrast column gives it away. Occlusive or embolizing lesions commonly occur along the posterior wall of the artery.

2. **Juxtaposed aneurysmal and occlusive lesions.** Filling an aneurysm with contrast can obscure the inflow and outflow arteries. Occlusive lesions are commonly present in these arteries and may be hidden.
3. **Flow artifacts.** These may occur at the leading edge of the contrast column. Flow artifacts usually result from incomplete mixing of blood and contrast and resolve on subsequent images.
4. **Layering of contrast.** If contrast is administered at inadequate pressure or volume, the contrast may layer within the artery and provide an image where the vessel is only partially opacified. This may create the impression that there is a filling defect. The contast envelope is usually very smooth and contrast usually settles posteriorly.
5. **Standing wave.** Occasionally, contrast administration results in a standing wave. Although it represents only another mode of contrast flow, the artery may appear to be involved with fibromuscular disease because of a beaded appearance. This occurs in conduit arteries that travel at a regular rate over a distance of many centimeters without interruption by major branch points. The beads appear too regular and uniform to actually be lesions.
6. **Parallax.** This describes the differences in orientation and length measurement that may be expected when the image intensifier is moved either toward or away from the patient. The radiographic image presents a three-dimensional subject in two dimensions. When bony landmarks are used to guide therapy, for example, movement of the image intensifier changes the relative relationship of the location of the arterial lesion and its bony landmarks. These landmarks must be rechecked before precise treatment may be undertaken.
7. **Gas artifacts.** If bowel gas mimics the appearance of an aortic or iliac lesion, obtain an additional view for clarification. Look for the same pattern on the mask to see if it was present and whether it was consistent with intestinal gas.
8. **Catheter occlusion of the artery.** If the residual lumen in a preocclusive stenosis is minimal enough that the guidewire or catheter occludes it, there may be no flow into the distal artery.
9. **Spasm.** If spasm occurs as a result of muscular reactivity to manipulation, administer vasodilators (e.g., nitroglycerin or papaverine) to reverse the effects. The infrapopliteal, renal, and upper-extremity arteries are most susceptible.
10. **Filming error.** If opacification of the vasculature is inadequate, there may have been a poor estimation of timing (flow), inadequate pressure or volume of contrast injection, or too much delay in filming. Determine that contrast was actually administered.
11. **Patent "occlusion."** If filling is very slow and filming is not extended adequately, patent arterial segments may appear to be occluded. This occurs commonly in the superficial femoral artery distal to an occlusion, especially when using cut film.

12. **Viable foot/no outflow.** If a foot is viable, but there is no outflow target vessel, pedal arteriography may have been inadequate.
13. **Short-necked aneurysm.** If the anteroposterior aortic view makes an aneurysm neck appear short (the aorta often turns anteriorly distal to the renal arteries), locate the neck on the video images as the place where the contrast column "stops." The contrast bolus dilutes with swirling blood in the aneurysmal sac. Obtain a lateral or lordotic view for additional detail.

Lesion Interrogation: Special Views

The aortic arch is demonstrated en face when a left anterior oblique projection is used (Fig. 1 in Chapter 6). This helps to separate the origins of the arch branches. If an area of expected critical stenosis appears only mildly diseased, additional interrogation such as oblique views should be considered. The degree of stenosis at the carotid bifurcation and proximal

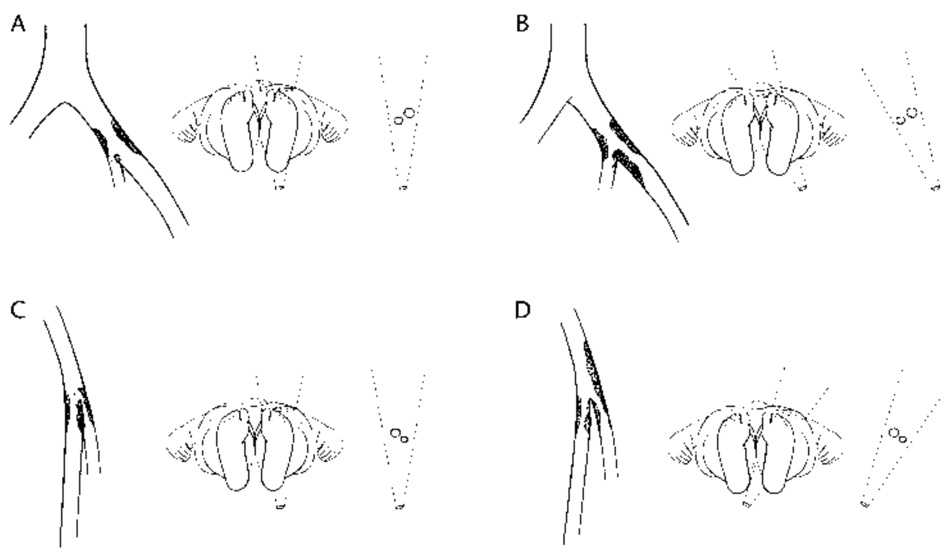

Fig. 9 Oblique projections of the iliac and femoral bifurcations. A, Occlusive disease at the common iliac artery bifurcation is not clearly delineated with the standard anteroposterior projection used for aortoiliac arteriography. **B,** A contralateral anterior oblique projection permits the iliac bifurcation to be viewed en face. **C,** Occlusive disease at the femoral bifurcation is sometimes difficult to visualize because of overlap between the proximal superficial femoral artery and deep femoral artery. **D,** An ipsilateral anterior oblique projection allows the femoral bifurcation to "open up" so that the proximal portions of the branches do not overlap.

internal carotid artery is best evaluated with lateral or steep oblique views. The celiac artery, superior mesenteric artery, and paravisceral aorta require lateral views to evaluate branch artery orifice lesions and posterior wall aortic plaque or aneurysm (Figs. 2, 4) The origins of the renal arteries are best evaluated with a slight ipsilateral anterior oblique (Fig. 5).

Disease at iliac and femoral bifurcations often requires visualization with oblique views (Fig. 9). The common iliac bifurcation and posterior wall external iliac disease are best delineated using a contralateral anterior oblique projection. The common femoral bifurcation and common femoral artery posterior wall are investigated using an ipsilateral anterior oblique projection. Popliteal and tibioperoneal occlusive disease is often diffuse, and an accurate assessment of severity sometimes requires oblique views of these arteries. The proximal to middle tibial vessels are best evaluated with an anteroposterior view of the lower leg in slight medial rotation. The distal tibial and pedal arteries are evaluated with a lateral projection that separates the tibial and pedal arteries.

Pressure Measurement

Pressure measurement is time-consuming, and tedious, and should only be performed selectively. However, it is the only quantitative physiologic data that may be yielded by the arteriographic study. Pressure measurements are required only when the results will influence the treatment plan. This situation arises most commonly with moderate degrees of stenosis where the decision about whether to treat depends on the hemodynamic significance of the lesion. Decisions about the treatment of either critical or mild degrees of stenosis can usually be made on the basis of the images alone.

Pressure may be measured through a selective or diagnostic catheter or a sheath. The transducer is placed at the level of the right atrium. The shortest adequate extension tubing is flushed with heparin–saline solution, zeroed, and connected to the catheter hub. Blood does not come into contact with the pressure transducer.

Pressure measurements vary from one cardiac cycle to the next. The systolic or mean values are observed until stable and then averaged over five readings. The catheter head is moved to the other end of the lesion and the process is repeated. If the catheter has been placed through a sheath at least one French size larger than the catheter, the distal pressure can be measured through the sidearm of the sheath. During measurement, pressure may continue to fluctuate. If a small gradient is present (less than 10 mm Hg systolic) or if the lesion in question is potentially physiologically important, papaverine (1 ampule, 30 mg) is administered through the catheter and into the limb. Diminished peripheral resistance exacerbates any gradient across

Table 5 Pitfalls Associated with Pressure Measurements Across Occlusive Lesions

Systemic pressure fluctuation	Variations in systemic blood pressure during the few minutes it takes to measure pressure influence the results of pressure measurement proximal and distal to a lesion.
Pressure in end organ arteries	Measuring pressure in an end organ artery, such as the renal artery, presupposes that the lesion must be crossed. The catheter used to measure pressure must occupy a portion of the residual lumen. In a tight stenosis, this may falsely lower the distal pressure.
Poor outflow	If outflow distal to a lesion is poor, pressure tends to equalize proximal and distal to the lesion.
Pressure does not equal flow	Although pressure measurement provides hemodynamic quantitation, it does not provide what is really required, which is an assessment of flow across a lesion.
Pressure is not measured under physiologic conditions	Occlusive lesions often become hemodynamically significant only with exercise. Although vasodilators may mimic this, it is usually not an accurate representation of physiologic conditions.

the lesion and is revealed by immediately repeating the measurements. Pitfalls associated with pressure measurement across lesions are listed in Table 5.

Arteriography of Aneurysms

Arteriography has some distinct advantages and disadvantages with respect to the assessment of aneurysms. Arteriography is not useful in determining the size of an aneurysm or the configuration of an aneurysmal segment. However, arteriography is a very good option for evaluating inflow and outflow arteries, flow surface contour, and associated aneurysm or occlusive disease in juxtaposed arteries. Full strength, iodinated contrast should be used in the arteriography of aneurysms. There is usually slow flow and substantial mixing of the contrast bolus with nonopacified blood. Larger contrast volumes administered over a longer period of time are often used. The proximal neck is the location where the contrast bolus seems to stop on the cine loop during DSA. Contrast is administered proximal to an aneurysm, since injecting within an aneurysm may cause thrombus disruption and embolization. Oblique views or special angles may be required to fully evaluate the proximal and distal necks of the aneurysm. Evaluation of runoff distal to an aneurysm may be difficult since the contrast bolus becomes so diluted. Additional contrast injections may be required distal to the aneurysm.

ANGIO CONSULT: How Can I Use Duplex Scanning to Limit the Amount of Arteriography Required?

1. Unilateral lower-extremity ischemia and a normal femoral pulse. Obtain femoral waveform and femoral acceleration time and evaluate aortoiliac segments directly with duplex scanning. If these are normal, consider unilateral femoral arteriography without aortography.
2. Diabetic with gangrene and normal femoral artery and popliteal artery pulses. Evaluate aortoiliac and femoral segments with duplex scanning. If these are normal, consider an antegrade femoral artery approach and infrageniculate arteriography only.
3. Diminished femoral artery pulse and no tissue loss. Evaluate aortoiliac and femoral–popliteal segments with duplex scanning. If a focal iliac artery lesion is identified and the femoral–popliteal segment is without significant disease, consider proceeding to aortography and balloon angioplasty without performing arteriographic runoff.
4. Patient with an abdominal aortic aneurysm, indications for arteriography, and palpable pedal pulses. Evaluate popliteal arteries with duplex scanning if any enlargement is suggested by physical examination. If these are normal, consider aortoiliac arteriography only without runoff.
5. Recurrent lower-extremity symptoms after a previous reconstruction. Identify the flow-limiting lesion with duplex scanning. If a focal lesion is identified, consider either very limited arteriography for lesion anatomy or no arteriography at all.
6. Suspected occlusion in the aortoiliac segment that requires therapy. Assess the location and length of the lesion with duplex scanning to help determine whether an effort at recanalization is reasonable. If not, detailed arteriographic interrogation of occluded arteries is not necessary.
7. Superficial femoral artery occlusion that requires therapy. Identify the length of the occlusion and the location where flow reconstitutes with duplex scanning. If it is a short occlusion and not at the superficial femoral artery origin, consider an antegrade approach and recanalization. If it is a long occlusion with reconstitution above the knee, consider an above-knee femoral–popliteal bypass without arteriography.
8. Use noninvasive methods to evaluate the lower extremity contralateral to the symptomatic limb to avoid performing bilateral runoff studies.

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9

Introduction to Endovascular Therapy

Endovascular Therapy Requires Basic Skills
Impact of Endovascular Therapy
Steps to Endovascular Therapy
A Loaded System
The Future of Endovascular Surgery

Endovascular Therapy Requires Basic Skills

Endovascular therapy has prompted an ongoing reinvention of vascular care that has permanently changed the spectrum of vascular practice. As in so many other disciplines, a basic set of skills comprise the foundation upon which complex therapy is provided, thus making endovascular skills integral to vascular patient care. Part I (Chapters 1 through 8) provided an overview of basic endovascular skills. Part II presents techniques in endovascular therapy that build upon the basic skills. Endovascular therapy is performed with fairly simple tools, such as guidewires and catheters. However, guidewire–catheter skill development is a dynamic process. As the years go by and techniques and devices are refined, the capability of the catheter and its attachments to render treatment will continue to expand.

Impact of Endovascular Therapy

Balloon angioplasty has offered an alternative to open surgery for several decades. This technique was initially complementary to bypass operations and was reserved primarily for lower-extremity revascularization in patients with focal occlusive disease in larger arteries. Since the widespread introduction of noncoronary stents in the first half of the 1990s, endovascular therapy of both occlusive and aneurysm disease has advanced rapidly. These advances include an increase in the severity of occlusive disease that can be treated, a broadening of endovascular therapy to include all vascular beds, and the development of stent–graft treatment of aneurysmal disease. Endovascular therapy has had a huge impact upon vascular practice. This impact will continue to increase as techniques and devices become more refined and more data becomes available to guide treatment. Table 1 offers a summary of one practitioner's view of the impact of endovascular therapy upon the management of vascular disease in various vascular beds. Endovascular intervention has traditionally provided an option for treatment in patients with mild forms of occlusive disease or those who are not surgical candidates. The scope of endovascular intervention has increased to replace surgery in some vascular beds and to be a more competitive adjunct in others. Endovascular intervention has become the treatment of choice in most patients with aortic, iliac, and renal artery occlusive disease and has become a prominent part of treatment for subclavian and infrainguinal occlusive disease and aortoiliac aneurysm. The future of endovascular therapy is bright, and this approach may become the treatment of choice in many vascular beds. The impact of carotid bifurcation balloon angioplasty and stent placement remains to be seen. It is highly likely that it will play a role but the impact of that role depends upon the results of studies.

Table 1 Overall Impact of Endovascular Intervention in Various Noncoronary Vascular Beds Upon Vascular Therapy Practice

	Current		
	Provides treatment option for patients who are not surgical candidates	Replaces surgery for patients who were candidates for operation	Likely to be future treatment of choice
Carotid bifurcation	**	*	*→****[a]
Common carotid[b]	**	**	***
Innominate	**	**	**
Subclavian	**	***	***
Axillary	O	*	*
Brachial	O	O	O
Celiac/superior mesenteric artery	***	**	***
Renal	****	****	****
Infrarenal aorta	***	****	****
Iliac	*	****	****
Femoropopliteal	*	***	***
Tibial	*	*	*
Pedal	*	O	O

O, no impact on vascular therapy; *, minimal impact; **, moderate impact; ***, substantial impact; ****, profound impact.

[a] Depends upon the results of prospective randomized trials of endoarterectomy versus balloon angioplasty and stent.

[b] Isolated common carotid artery stenosis.

Steps to Endovascular Therapy

Performing endovascular therapy is a multiple-step process (Table 2). The conduct of the intervention is important but is only one of the many steps required. Actually pulling the trigger of an endovascular device takes skill, but patient selection, management, and follow up also require judgment and vigilance that require enthusiasm and years of effort to develop. Vascular therapy is ideally practiced as a continuum: a long-term commitment to prevent, diagnose, treat, and follow patients with vascular problems. The person performing the procedure is effective only if there is a clear understanding of where a given patient is along the treatment curve and what the other treatment options are. The operator must also be focused on short-term results and longer term outcomes if continuous quality improvement is to be possible. When a piece of the care, such as pulling the trigger on an endovascular device, is farmed out to another specialist, the opportunity for discontinuity in care is profound. There may have been a previous era when this concept seemed to make sense, but it is difficult to justify using current paradigms of care which emphasize efficiency, seamlessness, and best possible outcomes.

Table 2 Steps to Endovascular Therapy

Step	Physician responsible
Identify symptoms and signs of vascular disease	Primary physician; vascular specialist
History and physical exam of vascular system	Vascular specialist
Order appropriate laboratory and noninvasive tests	Vascular specialist
Interpret results of testing	Vascular specialist
Assess treatment options	Vascular specialist
Obtain nonvascular studies to assess medical risk of intervention	Vascular specialist, primary physician
Counsel patient and family with recommendations	Vascular specialist
Admit patient (if necessary)	Vascular specialist
Endovascular operation	Vascular specialist or nonclinical interventionist
Periprocedural management	Vascular specialist
Manage complications	Vascular specialist
Discharge patient, arrange follow-up, provide results	Vascular specialist
Manage postprocedure outpatient issues as they arise	Vascular specialist
Long-term clinical and noninvasive follow-up	Vascular specialist

A Loaded System

Open surgery for vascular problems is a 'front loaded system'. Open surgery is expensive and has an inescapable risk of morbidity. The short term costs and complications have the potential to be substantial. However, open surgery also offers the best long-term results among the various treatment options for most vascular problems. Conversely, endovascular intervention is generally less expensive and has lower associated perioperative morbidity, but it is also a "pay as you go system." The additive costs are high, with greater surveillance required, and higher rates of failure, readmission, and repeat therapy. Since almost any lesion may now be treated with endovascular intervention, it is important to be readily aware of the long-term consequences of the chosen therapy. In this context, understanding when not to do a particular procedure will take on greater value as technology progresses.

The Future of Endovascular Surgery

Endovascular therapy is here to stay and the likelihood is high that it will assume an expanded role over the next few years. There are applications in every vascular bed for the management of both aneurysmal and occlusive disease. Although the durability of many procedures is not yet known, technology and innovation will likely lead to further improvements. There will be many patients requiring vascular care but it is not clear who will be delivering that care or what the constraints will be from a standpoint of resource expenditure. The vascular specialist is well advised to gain expertise in all applications of endovascular therapy and be able to justify those procedures from a risk/benefit standpoint.

10

Therapeutic Strategies

Choosing Treatment: The Endovascular Therapy Curve
Endovascular Decision Tree
Plan and Control the Procedure
Converting a Strategic Arteriogram to
Endovascular Treatment

Choosing Treatment: The Endovascular Therapy Curve

Deciding who gets what can be a challenge. Wrong choices are usually revealed only after the damage is done. When intervention is indicated, the choice of endovascular or open surgery is based upon the clinician's understanding of the balance in a given patient between medical comorbidities (perioperative risk) and lesion severity (likelihood of endovascular success). This is represented in a stylized graphical version in Fig. 1. Endovascular therapy is most beneficial in patients with more severe medical comorbidities or with lesser forms of vascular disease. Open surgery is more successful when the risk is low and when the disease is severe enough that the results of surgery are likely to be durable in comparison to endovascular intervention. Theoretically, every patient can be placed somewhere on this graph. There is an enlarging group of patients in the middle who could be considered for either type of treatment. Advancing technology and patient demand for less invasive procedures is pushing the curve downward toward a decrease in open surgery and an increase in endovascular surgery.

Endovascular Decision Tree

Figure 2 shows an endovascular decision tree. This diagram helps to categorize the important decisions which must be made to carry out therapy. The concept that multiple different specialists could be involved in this

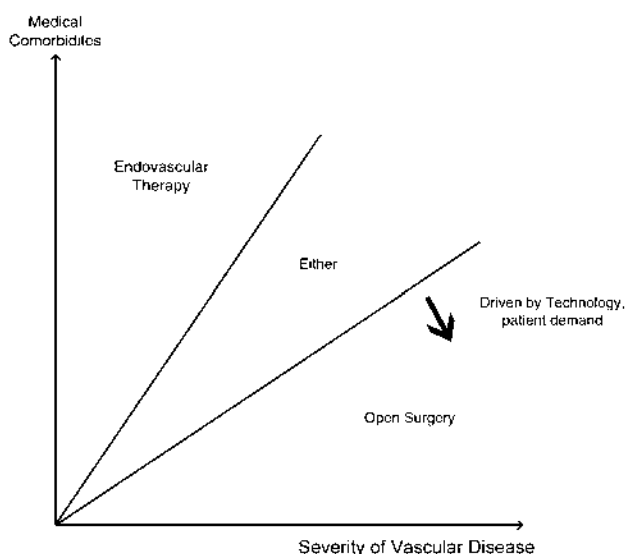

Fig. 1 Endovascular therapy curve.

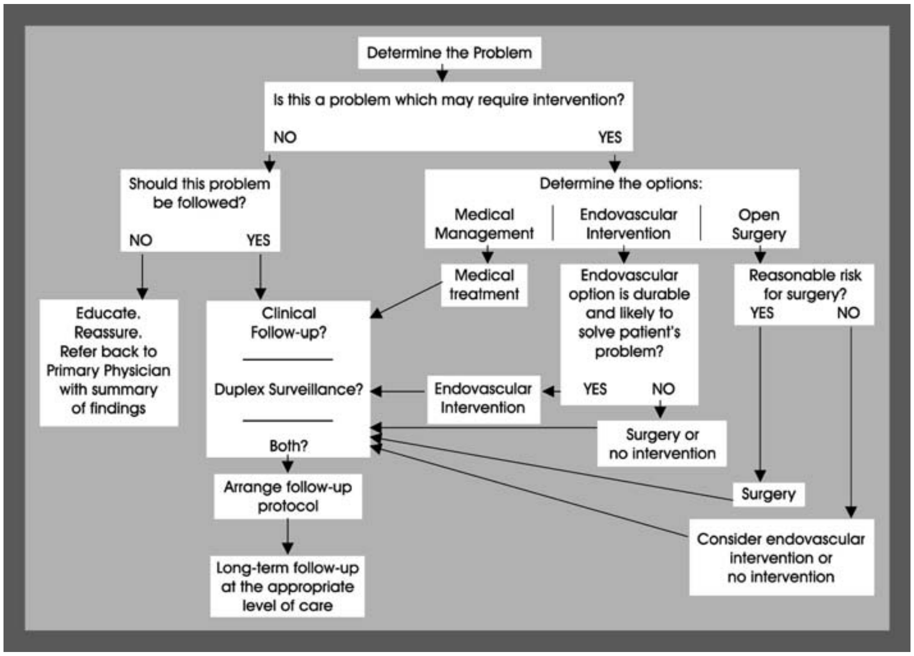

Fig. 2 Endovascular decision tree.

decision tree and each take responsibility for some small part of the process is an invitation to failure. Ideally, the physician who knows the patient and understands the problem is best suited to guide the patient through the decision-making process.

Plan and Control the Procedure

When an approach is selected, the procedure should be planned and controlled in the same way as an open operation. The case should be prepared in advance with a thorough understanding of the patient's desires and expectations, a careful physical exam, and noninvasive imaging to evaluate the location and severity of lesions. In that way, the scope of endovascular therapy can usually be determined ahead of time.

Converting a Strategic Arteriogram to Endovascular Treatment

Strategic arteriography should be planned so that when conversion to an endovascular operation is indicated, it can proceed with stepwise progression. Expectations generated by history, physical examination, and noninvasive studies as to the location and severity of disease determine not only the puncture site and arteriographic approach, but also the likelihood that the procedure may be converted to an endovascular operation. A contralateral or proximal approach for strategic arteriography permits maximal flexibility. Occasionally, a well-placed second puncture site in proximity to the area intended for therapy is a simple solution. Performing endovascular surgery from a very remote location increases catheter and procedure time, contrast load, and the number of exchanges necessary for longer guidewires and catheters.

11

Where Do We Work?

Where We Work Determines What We Can Do!
Operating Room Versus Special Procedures Suite
Stationary Versus Portable Imaging Systems
The Ideal Vascular Workshop
Converting an OR to a Vascular Workshop
Selected Readings

Where We Work Determines What We Can Do!

Dramatic developments in endovascular intervention have lead to the common dilemma about where the modern vascular specialist should be working to get the best results: the operating room or the special procedures suite. The rise in clinical importance of endovascular therapy has outpaced the ability of most institutions to create the right environment in which to perform these procedures. As this issue plays itself out in institutions everywhere, it is unfortunately settled more often on the basis of politics and economics than patient care. The facility where the work is done can either promote or hamper success. Vascular specialists must be clear about what is required to provide high-quality care. Fixing vascular problems is already complicated without the case being placed at a disadvantage before the procedure starts. High-resolution imaging, endovascular inventory, and uniquely trained personnel are all required to deliver modern vascular care.

Operating Room Versus Special Procedures Suite

Operating rooms (ORs) are well suited to the sterile technique of open surgery, handling blood vessels, and implanting prosthetic material. Special procedures suites, such as angiographic suites and cardiac catheterization laboratories, are designed to support percutaneous interventions and generally have the best fluoroscopic imaging available in any given hospital. Table 1 compares these two environments. Special procedures suites were

Table 1 The Operating Room or the Special Procedures Suite

	Operating room	Special procedures suite
Advantages	Best sterile technique Handle blood vessels Manage bleeding Implant prosthetic material Better anesthetic capability	Best imaging quality Broader inventory of devices Personnel trained in interventions Personnel trained in imaging technique
Disadvantages	Lower imaging quality Smaller endovascular inventory Poor staff support for interventions	Poor sterile technique Poor environment for open surgery Inadequate equipment, lighting, and staff support Poor anesthetic capability

designed for what they are each named to do, either angiography in angio suites or cardiac catheterization in cath labs. The fact that these facilities usually have a high volume of foot traffic, poor lighting, poor air flow, marginal sterile technique, and excellent imaging makes sense. They were designed to accumulate images, not perform therapy or insert vascular implants. As more procedures are developed that combine components from each of these workshops, the design of the place where vascular treatment is carried out becomes a crucial issue. Ultimately, the unsatisfactory choice of multiple suboptimal facility options must be resolved in each institution by designing a better location.

Operating rooms were designed to meet the standards required to provide therapy; in terms of sterility, quality control, planning for contingencies, managing sick patients, and performing procedures efficiently. The primary advantage of special procedures suites over operating rooms, as they exist in most institutions, is radiographic imaging. There is a substantial trend toward recognition of high-resolution digital arteriography as an essential component of vascular procedures of all types, including open vascular operations. There is some validity to the concept that quality imaging is required in the OR, regardless of whether the majority of endovascular interventions are performed there.

Stationary Versus Portable Imaging Systems

Table 2 compares stationary and portable fluoroscopic imaging equipment. Angiographic suites are constructed with stationary imaging equipment, including a ceiling- or floor-mounted C-arm or U-arm configuration (Fig. 1).

Table 2 Stationary Versus Portable Fluoroscopic Imaging Equipment

	Stationary	Portable
Advantages	Better resolution Easy to use Versatile positioning Bolus chase	Less expensive Can be used in different locations Best units available simulate quality of stationary equipment-resolution, road mapping, post-image processing, storage
Disadvantages	More expensive Usage restricted to single location Some units difficult to adapt to use with open surgery Requires room renovation	Inconvenient and cumbersome to move and position Resolution inferior to fixed unit Impractical for survey arteriography Often no dedicated personnel

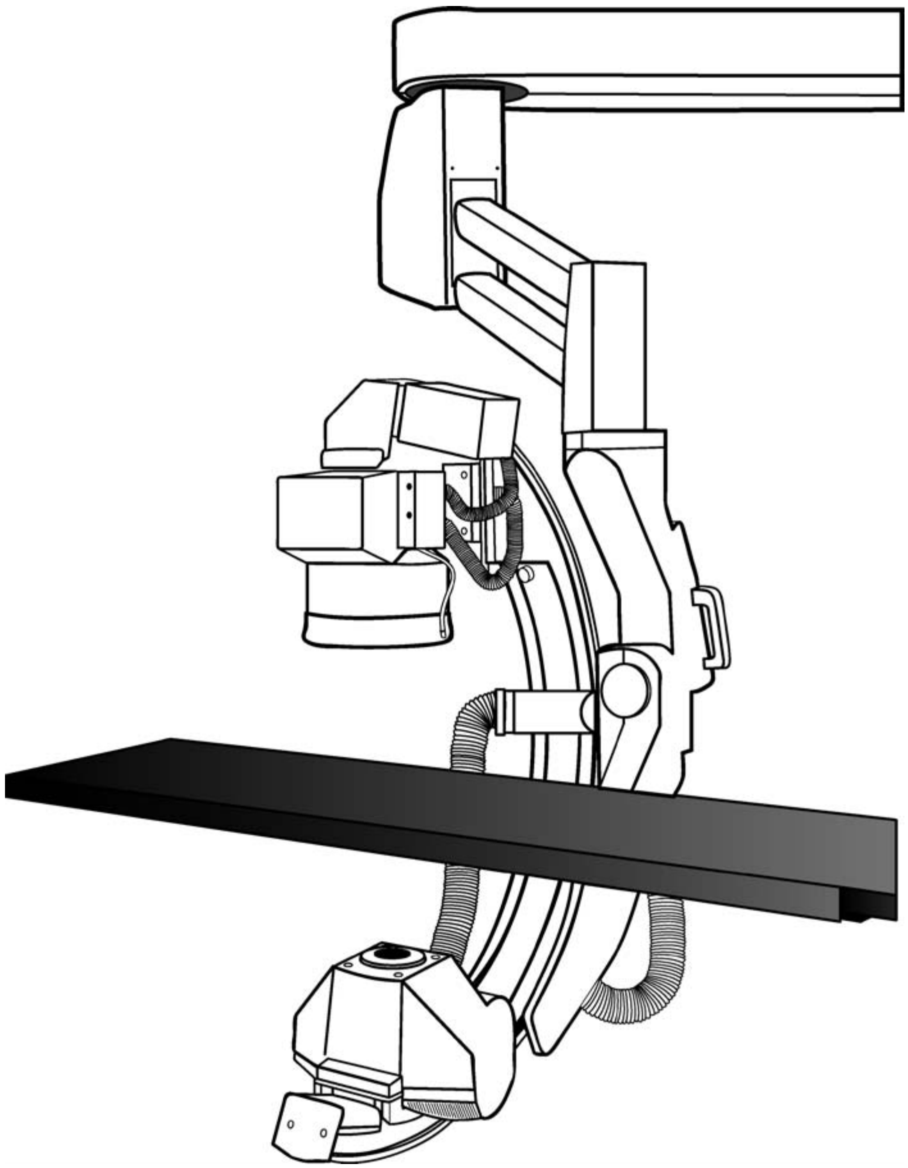

Fig. 1 Stationary imaging system. The C-arm may be either ceiling mounted, as in this example, or floor mounted. Monitors are usually ceiling mounted on booms. These systems usually have larger generators for better image quality. A floor-mounted table on a pillar provides imaging access to the entire body.

In most surgical operating rooms, portable C-arm digital arteriographic imaging can be obtained when necessary (Fig. 2).

Stationary equipment offers high resolution and maximal C-arm mobility for multiple views. Portable, digital arteriographic units have been developed that produce adequate images for completing complex endovascular procedures. Available features include multiple frame rates, digital storage, road mapping, video playback, last image hold, post-image processing, and variable fields of view. The portable fluoroscopic unit lacks the convenience of a specially designed room. It is more cumbersome to position and use portable equipment and more setup time is required. The hard copy obtained with a portable imaging system is frequently not as good as the visual image on the monitor at the time of the arteriogram. However, portable units are cheaper and can be used (and therefore justified) by many different services in the same institution. The most complex procedures in endovascular intervention, such as endovascular aortic grafts, have been performed in the OR with portable digital imaging systems, and with very acceptable results. Nevertheless, this approach is more challenging than it would be with improved imaging capabilities.

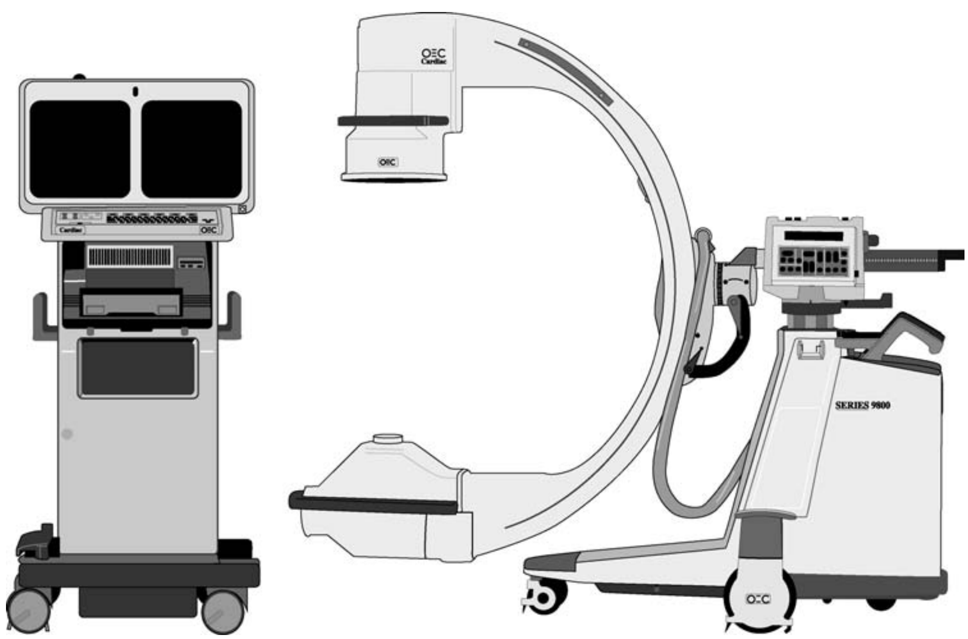

Fig. 2 The portable imaging system provides more flexibility and can be moved from room to room. It consists of a portable C-arm (image intensifier and x-ray tube) and a portable monitor. These generally have a smaller generator and lower heat capacity.

The Ideal Vascular Workshop

Important components that should be included in a vascular workshop are listed in Table 3. There are facility, equipment and personnel requirements to consider.

Facility requirements. The facility should have a minimum of 750 square feet. It will need lead-lined walls. The regulations that govern this vary from one state to another. The structure should be able to support the mounting of ceiling-based fluoroscopic and monitoring units. Further requirements that are standard for open surgery include the availability of anesthetic gases, adequate overhead lighting, appropriate air flow, and limited foot traffic.

Equipment requirements. A stationary, preferably ceiling-mounted, digital fluoroscopy unit with high-resolution capability, road mapping, post-image processing, digital storage, last-image hold, variable frame rates, multiple fields of view, and versatile image intensifier positioning is desirable. A radiographic table that permits positioning for open surgical cases and the placement of self-retaining retractors is also important. A pressure injector is necessary. A broad inventory of endovascular supplies as well as surgical supplies and instruments are also required.

Personnel requirements. Scrub and circulating personnel must have expertise in both open and endovascular techniques and a familiarity with

Table 3 Components of the Ideal Vascular Workshop

Facility	Space
	Lighting
	Lead-lined walls
	Anesthetic gases
	Air flow
	Limit foot traffic
Equipment	High-resolution imaging
	Pressure injector
	Radiographic table
	Inventory
	Other
	Ultrasound
	Intravascular ultrasound
Personnel	X-ray technologist
	Scrub (both open and endovascular technique)
	Circulator
	Anesthesia

the inventory of supplies, devices, and instruments. X-ray technologists with an understanding of endovascular surgery are needed for help with positioning the image intensifier, enhancing imaging technique, and performing arteriographic sequences. Anesthetic personnel should be able monitor the patient, perform conscious sedation, and perform other types of anesthesia when required.

Converting an OR to a Vascular Workshop

Given the need for high-quality imaging in the OR and the challenges in performing open surgery in most special procedures suites, for many it makes the most sense to modify the operating room to provide the tools required to perform endovascular interventions. If modern vascular therapy is to be performed in an OR, it will need better imaging, a reasonable inventory, and trained personnel. Endovascular inventory and appropriate personnel are mobile and can be brought in. Better imaging capability, with a stationary unit, is expensive but is an important investment. Vascular therapy is not going to regress to the era of blind revascularizations.

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12

Delivering the Goods

Access for Endovascular Therapy

Make Access as Simple as Possible
Sizing Considerations
What Fits Into What?
About Access Sheaths
How Do You Place a Sheath?
Technique: Handling Access Sheaths
When Do You Use a Guiding Sheath or a Guiding Catheter
Technique: How to Place an Up-and-Over Sheath
Selected Readings

Make Access as Simple as Possible

Endovascular therapy is performed using some type of delivery system: an access sheath, a guiding sheath, or a guiding catheter. Whichever one is used represents a ''system'' in the sense that the selected guidewire, balloon catheter, stent, therapeutic catheter, etc. must fit through the sheath and be able to travel over the chosen guidewire. Access for endovascular therapy has several goals: to secure the puncture site, maintain guidewire placement, deliver the therapeutic catheters, and maintain access for interval arteriography of the treatment site and its outflow bed. Selecting the best means of access is about anticipating the scope of the procedure and the sizing required. Choose the right access and you set yourself up for success. Problems with access are a common reason for a procedure to be prolonged, unnecessarily challenging, or complicated. Patience and planning are required to achieve safe and straightforward access.

There are some simple rules to follow in obtaining access for endovascular therapy (Table 1). Don't upsize to a larger sheath or use a specially designed guiding sheath or guiding catheter until it is certain that therapy will be performed. Otherwise, the arteriotomy has been enlarged without cause and the sheath wasted. Make sure you have the puncture site location you want before enlarging the arterial puncture. This rule comes into play when an arteriogram is converted to a therapeutic procedure. Occasionally it is better to puncture at an alternative site, such as the contralateral femoral artery or an upper-extremity artery, rather than use the initial puncture site for therapy. This is sometimes the case with iliac, infrainguinal, or subclavian occlusive disease. When the artery chosen for entry is itself significantly diseased (e.g., a common femoral artery stenosis or aneurysm), it is usually best to pick another site and avoid the increased risk of puncture site thrombosis or hemorrhage. Use arterial dilators at the puncture site to gently and gradually enlarge the arteriotomy prior to placing the access sheath. A sheath is sized by its inside diameter (by what will fit through it). A dilator, like a catheter, is sized by the outside diameter. A 6 Fr dilator has the same outside diameter as a 5 Fr sheath and would therefore be used if full

Table 1 Simple Rules of Access for Endovascular Therapy

Upsize the sheath when therapy is certain.
Confirm that initial puncture site is the best one for therapy.
Use dilators.
Check availability of catheters and guidewires to go with sheath.
Cross-check the size of the sheath with the therapeutic catheters.
Anticipate the extent of the procedure and place the correct sheath initially.
Determine whether a guiding sheath or guiding catheter is required.

dilatation of the arteriotomy was desired before sheath placement. There is more about this in the next section. Check to see that the required guidewires and catheters are available for the procedure you plan before you place the access sheath. Always cross-check the size of the sheath with the size of the balloon catheters and stent delivery catheters. The best way is to look for the inside diameter (ID) of the sheath, which is in inches or millimeters or both, and compare it with the outside diameter of the catheter intended for placement through it. These measured features are usually listed on the package. Anticipate the full extent of the procedure so that the best-sized sheath can be placed initially. This avoids stopping in the middle and placing a larger or differently shaped sheath. Midprocedure sheath exchanges always seem to come at the wrong time, usually after it is clear that something important will not fit through it. Often the most useful stiffer guidewire for access placement has already been removed and a softer, more selective guidewire has been placed. Sometimes the lidocaine has started to wear off and the patient is not comfortable during the sheath exchange. If the table and image intensifier position must be maintained, tamponading the arteriotomy and advancing a new sheath can be challenging and cumbersome. In some instances, sheath exchange may cause loss of guidewire position, which must be later regained after the correct sheath is in place. Part of planning the procedure is anticipating whether an access conduit other than a standard access sheath is required. This could be a longer straight sheath, a guiding sheath, or a guiding catheter. These devices are discussed in more detail below. Most access is accomplished with simple hemostatic access sheaths.

Table 2 Sizing Considerations

	Size measurement for endovascular accessories	
Accessory	Measured feature	Units
Needles	Gauge	Inches[a]
Guidewires	Diameter	Inches[a]
Catheters	Outside diameter	French[b]
Dilator	Outside diameter	French
Access sheath	Inside diameter	French
Guide sheath	Inside diameter	French
Guiding catheter	Outside diameter	French
Balloon catheter	Outside diameter of shaft	French
	Diameter of balloon	Millimeters when inflated
	Length of balloon	Centimeters
Stent	Diameter	Millimeters
	Length	Millimeters

[a] Maximum guidewire diameter for 18-gauge needle is 0.038 in.; maximum guidewire diameter for 21-gauge needle is 0.018 in.
[b] French size ÷ 3.14 = diameter, mm.

Sizing Considerations

Each endovascular device is measured and described in a different way (Table 2). Although the nomenclature can be confusing, mastering the language of endovascular intervention is essential to a successful practice.

Guidewires. Guidewires are described by diameter, which is measured in inches. An "035" is a guidewire that is 0.035 in. in diameter. Guidewires are described in detail in Chapter 3. The most common guidewire thickness or diameter for general usage in noncoronary interventions is 0.035 in. Other common guidewire sizes used are 0.014, 0.018, 0.025, and 0.038 in. in diameter. Each guidewire diameter has a catheter system sized appropriately for it.

Dilators, flush and selective catheters. Catheter sizes are described using the French system to signify the outside diameter (OD) of the catheter. This is true for dilators, diagnostic catheters, and selective catheters. Take the French size, divide by 3, and this provides the actual diameter. For

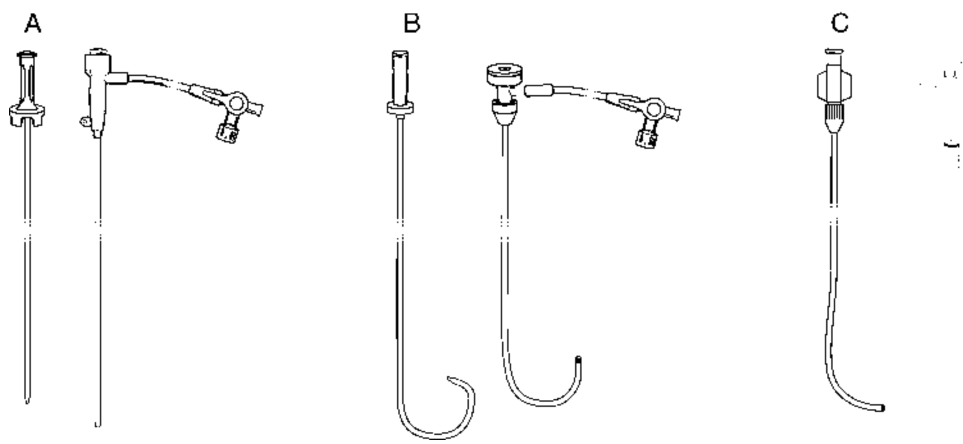


Fig. 1 Access for endovascular therapy. A, A standard access sheath is 12 to 15 cm in length and has a hemostatic valve and a sidearm for administration of contrast and medication. The dilator is used during sheath placement to provide a smooth transition to the tip of the sheath and to provide shaft stiffness. **B,** A guiding sheath has a dilator, hemostatic valve, and sidearm. It may be longer and it usually has a radiopaque band at the tip. Its tip also has a special shape that is functional for certain tasks. The guiding sheath in the example is used for passage over the aortic bifurcation. There are many different sizes and shapes available among guiding sheaths. **C,** A guiding catheter is a large-bore catheter (larger than an arteriographic catheter) with a specially shaped tip. There is no dilator, sidearm, or hemostatic valve. The addition of a Tuohy-Borst adapter permits hemostasis since it has a hemostatic valve and an extra port for contrast administration.

example, a 5 Fr catheter has approximately a 1.6-mm outside diameter. A 6 Fr catheter has about a 2-mm OD, and so on. When a catheter is placed percutaneously, it must always be exchanged for a catheter that is the same Fr size or larger so that the artery does not bleed around it. The most common flush and selective catheter sizes in practice are 4 and 5 Fr. Catheters are discussed in Chapter 3.

Access sheaths and guiding sheaths (Fig. 1). Access sheaths are also described using the French system, but the feature described is inside diameter (ID), not the OD. This explains how a standard 5 Fr diagnostic or selective catheter can fit through a 5 Fr access sheath. A sheath is purposely sized based upon what will be able to fit through it. However, the operator must be aware that a 5 Fr sheath makes a 6 Fr hole in the artery: it has a 5 Fr ID to accept the 5 Fr catheter but its OD is 6 Fr. Guiding sheaths are sized the same way as access sheaths. The main difference between an access sheath and a guiding sheath is that the former is short (usually 10 to 12 cm) and straight and the latter may be long (25 to 100 cm) and have a specially shaped tip for delivery of devices to a side branch.

Guiding catheters (Fig. 1). Guiding catheters are described by their OD using the French system, the same way that other catheters are described. A guiding catheter functions as access to side branches for delivery of endovascular therapy devices. Guiding catheters are usually introduced through standard hemostatic access sheaths. A 7 Fr guiding catheter requires a 7 Fr sheath.

Balloon catheters. Balloon catheters are discussed in detail in Chapter 14. The shaft of the balloon catheter is described as any other catheter would be, by the French size of the OD. The balloon itself is described in terms of its diameter when inflated in millimeters and its length in centimeters with the diameter described first, followed by the length. A "5 by 4" balloon has a 5-mm diameter when inflated and a 4-cm length. An "8 by 2" has an 8-mm diameter and a 2-cm length, and so on. The balloon is tightly wrapped around the catheter when it comes out of the package. After angioplasty, the balloon material never quite folds down to the same profile, so the size of the device has increased slightly. This must be anticipated when choosing a sheath for angioplasty. A 6-mm diameter balloon and an 8-mm diameter balloon may be obtained on a 5 Fr shaft. The 6-mm balloon may be used through a 5 Fr sheath, but the 8-mm balloon should be used with a 6 Fr sheath. This is done to accommodate the balloon material during removal of the balloon catheter.

Stents. Stents are described by width and length when expanded, usually in millimeters, with the diameter stated first. A "10 by 40" would be a 10-mm diameter and a 40-mm length. Stents generally come packaged with a description of the size of the access that is needed to deploy them. Stents are described in Chapter 16. Balloon-expandable stents require a sheath large enough to accommodate the profile of the balloon, with about 1 to 2 French sizes added for the stent. Self-expanding stents are enclosed within a delivery catheter with a set sheath size described on the package. The usual minimum sheath size for both balloon and self-expanding stents using an 0.035-in. guidewire system is 7 Fr.

What Fits Into What?

Taking this array of devices with varying size requirement and putting them together in a workable fashion permits endovascular interventions to proceed. Table 3 shows some examples of "what fits into what?" to make certain procedures possible. For example, a 6 Fr sheath can be used for a standard iliac artery balloon angioplasty up to about 8 mm. If an iliac artery stent is required, a 7 Fr sheath is usually needed. There are some new self-expanding stents in the 0.035 system that are compatible with a 6 Fr sheath.

About Access Sheaths

A hemostatic sheath provides protection of the arteriotomy from the irregular edges of endovascular devices. Multiple guidewire or catheter exchanges are made simpler and safer with a sheath in place. A sheath reduces the friction encountered at the access site when manipulating a selective catheter into a branch. A sheath is usually required for endovascular intervention but not for arteriography. An access sheath has a one way hemostatic valve, a dilator to stiffen it during placement, and a sidearm port that is used for the administration of medication or contrast. The sheath is advanced only with the accompanying dilator in place to avoid uncontrolled endarterectomy by the hollow sheath tip. The operator must be cognizant of the location of the tip of the sheath. Any angiographic or balloon catheter must clear the tip of the sheath to function properly. Sheaths are sized according to the largest-diameter catheter the sheath will accept (see the preceding section on sizing considerations). After the sheath is placed, the seal of the hemostatic valve can be opened for guidewire insertion by placing the tip of the dilator through the valve.

How Do You Place a Sheath?

After the sheath is selected, the dilator and the sheath are each flushed and wiped with heparinized saline. The stopcock on the sidearm is turned to the "off" position. Before placing the sheath, double-check that you have

Table 3 Access for Endovascular Therapy: What Fits Into What?[a]

Sheath size (Fr)	Diameter of balloon (mm)	Balloon shaft (Fr)	Procedure	Stent
4	2–4	3.8	Small-vessel balloon angioplasty (0.018-in. guidewire system)	None
5	3–6	5	Infrainguinal balloon angioplasty	None
6	6–8	5	Balloon angioplasty—aortoiliac, renal, subclavian	None
	5–7	5	Medium Palmaz stent placement—aortoiliac, renal, subclavian with low-profile balloon	Balloon-expandable
7	8–10	5	Balloon angioplasty—aortoiliac	None
	7–9	5	Medium Palmaz stent placement—aortoiliac	Balloon-expandable
	5–10		Self-expanding stent placement (for 10-mm vessel, stent is 12-mm, oversized 2 mm to the artery)	Self-expanding
8	12	5.8	Balloon angioplasty—aorta	None
9	18	5.8	Balloon angioplasty—aorta	None
	8–12	5–5.8	Large Palmaz stent placement—aortoiliac	Balloon-expandable
	12–14		Self-expanding stent placement—aorta	Self-expanding

[a] Modified from Schneider, 2001, p. 59.

the desired size in hand. Lock the dilator hub in place so that the dilator does not back out while the sheath is being advanced. Check the skin insertion site to see if the skin incision needs to be enlarged slightly. Confirm that the guidewire in place is one that is stiff enough to facilitate sheath placement. Sheaths can usually be placed using starting guidewires. If the sheath is large or long or passing through a scarred groin, consider a stiffer guidewire. Make sure that whichever guidewire is in place has been advanced far enough so that the floppy tip is well inside the patient and that the artery entry site is crossed with the stiffer portion of the shaft of the guidewire.

Gradual, stepwise enlargement of the tract and artery entry site with dilators is not always required but is the cleanest way to place a sheath (Fig. 2). If the sheath is upsized by two French sizes or more, dilators should

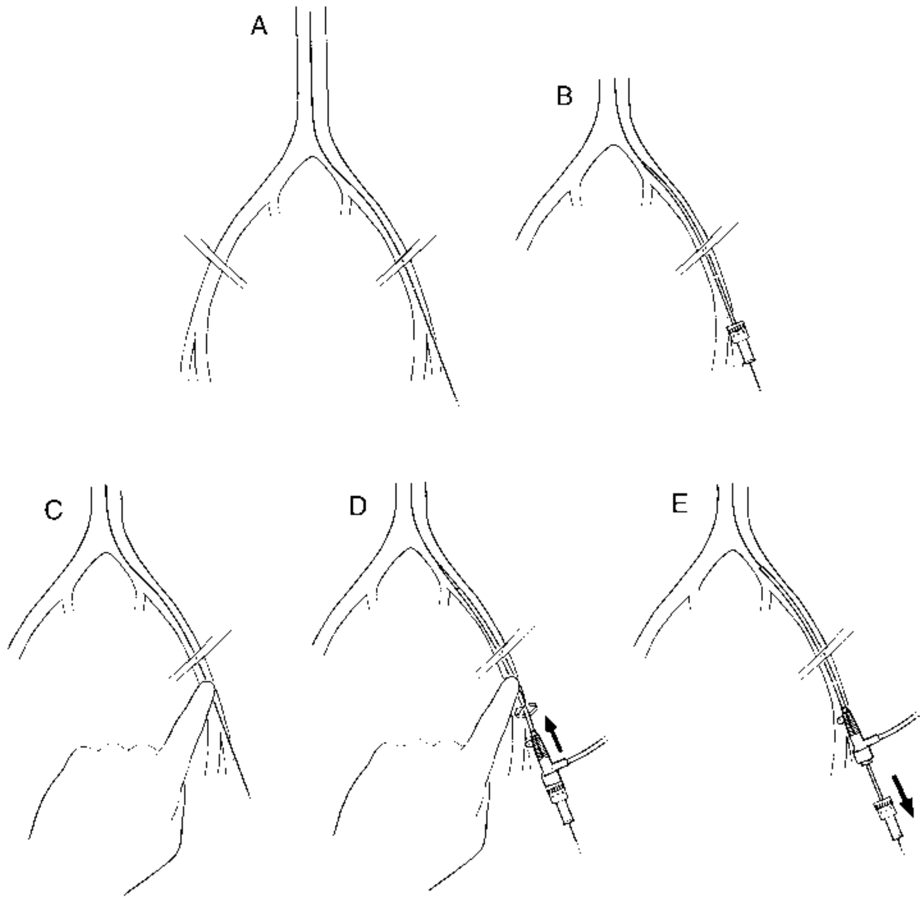


Fig. 2 Sheath placement. When multiple guidewire or catheter exchanges are anticipated, sheath placement permits safer, simpler, and more hemostatic access. **A,** A guidewire is placed in the infrarenal aorta. **B,** The femoral arteriotomy is dilated using the dilator appropriate to the sheath intended for placement. **C,** Digital pressure is maintained over the arteriotomy to prevent hemorrhage after the dilator is removed. **D,** The dilator is placed within its sheath and the dilator–sheath combination is advanced over the guidewire. Slight pressure at the puncture site prevents buckling of the sheath. The sheath–dilator apparatus can be rotated as it is advanced. **E,** After sheath placement, the dilator is removed.

be used. When planning sheath placement through a difficult entry site (e.g., a scarred groin or a previously placed bypass graft), a series of vascular dilators should be used to predilate the entry site to one French size larger than the label on the sheath. This eases placement and helps prevent a buckle at the tip of the sheath that can damage the arteriotomy site and unnecessarily enlarge it. In between passing each dilator and eventually the passage of the sheath, pressure should always be held at the puncture site to prevent bleeding.

The sheath is loaded onto the guidewire by an assistant and advanced all the way to the entry site. The guidewire is pinned by the assistant. The sheath is advanced by holding it along its shaft near its tip so that it does not buckle going through the skin. Sometimes it is helpful to rotate the sheath back and forth to get through the subcutaneous tissue. Place the sidearm port in a convenient orientation, usually toward the operator. Occasionally, when the sheath is advanced, the dilator loosens at the hub and begins to back out. The sheath should be monitored visually during placement to pick this up if it occurs. Pressure is maintained on the arteriotomy with the free hand until the sheath can be felt going into the artery. This helps to avoid subcutaneous blood accumulation. After the tip of the sheath clears the arteriotomy, there is usually minimal resistance. If there is resistance, something may be wrong. Use fluoroscopy to evaluate. Advance the sheath to its hub.

After the sheath is placed, take out the dilator, aspirate through the sidearm port, and flush with heparinized saline. After you administer contrast through the sheath, it should always be flushed. The sheath should also be flushed intermittently throughout any case. Occasionally, a continuous slow infusion of heparinized saline using a pressure bag is required to keep the sheath clear. If there is bleeding around a sheath during the case, apply gentle pressure. If that does not work, upsize the sheath to tamponade the tract. If the sheath is withdrawn at all, to advance it any further, its dilator should be replaced before it is advanced. If the soft edges of the sheath tip have become frayed during a placement attempt, place a different one to avoid irregular tears at the arteriotomy site. When a sheath is placed in a patient with large and tortuous arteries, it tends to slide in and out. It is often worthwhile to secure the sheath with a stitch in the skin and around the hub to avoid spontaneous sliding. If a catheter is placed through the sheath that is labeled the same as the sheath size (i.e., a 5 Fr catheter in a 5 Fr sheath), it will not be possible to administer contrast or heparinized saline through the sidearm since the catheter completely fills the sheath. When performing interventions, you must know where the sheath tip is located to avoid performing balloon angioplasty or deploying a stent within the sheath. There is more information about this in Chapter 15.

TECHNIQUE: Handling Access Sheaths

1. Flush and wipe the sheath and its dilator with heparinized saline.
2. Turn stopcock on sidearm to "off" position.
3. Double-check sheath size.
4. Lock or snug-fit the dilator into the hub of the sheath.
5. Enlarge the skin entry site.
6. Check guidewire type and position.
7. Use arterial dilators to prepare the tract.
8. Hold pressure at entry site during exchanges.

9. Assistant advances sheath–dilator combination to the skin entry site.
10. Assistant pins the guidewire.
11. Insert sheath by holding along its shaft.
12. Rotate sheath slightly to pass through the subcutaneous tissue.
13. Hold pressure at arteriotomy until tip of sheath is in the artery.
14. Orient the sidearm toward the operator.
15. Monitor sheath's dilator to make certain it does not back out.
16. If there is significant resistance in the artery, stop and evaluate.
17. Advance sheath to its hub.
18. After placement, remove dilator, aspirate, and flush.
19. Upsize the sheath if there is bleeding around it.
20. Don't advance sheath without dilator in place.
21. Replace sheath if tip is damaged or irregular.
22. Secure the sheath with a stitch if it tends to slide out.
23. Do not inject through sidearm if sheath is filled with equally sized catheter.
24. Know where the tip of the sheath is located prior to an intervention.

When Do You Use a Guiding Sheath or a Guiding Catheter?

Whenever endovascular therapy is required to treat a side branch lesion, a guiding sheath or guiding catheter helps deliver the devices, maintain access, and permit interval arteriography. Most endovascular therapy is performed through standard access sheaths. As more treatment is being rendered to major side branches, such as the subclavian, carotid, and renal arteries, guiding sheaths have advanced significantly and have become an important adjunct in treatment. A guiding sheath is designed for placement in a major branch vessel origin (Fig. 3). Like other sheaths, there is a dilator for use during placement, a sidearm port, and a hemostatic valve. The shape of the tip reflects its intended function. In Fig. 3, a long (90 cm), straight sheath with a flexible tip may be used for brachiocephalic arteries. The 40-cm up-and-over sheath with the nearly semicircular curve of the tip is used to go up the iliac artery, over the aortic bifurcation, and down the contralateral iliac artery. The 45-cm sheath with various curved-tip configurations is used for renal artery balloon angioplasty and stent placement. The tip of the sheath has a radiopaque marker. The length of dilator that extends beyond the sheath is usually short to reflect its intended passage into a side branch that may contain a lesion.

The guiding catheter has a specially designed tip shape so that it can be used to enter a renal artery or a carotid artery like a guiding sheath. Guiding catheters offer many more shapes and sizes than are available with guiding sheaths, but there are some significant disadvantages. Guiding catheters do

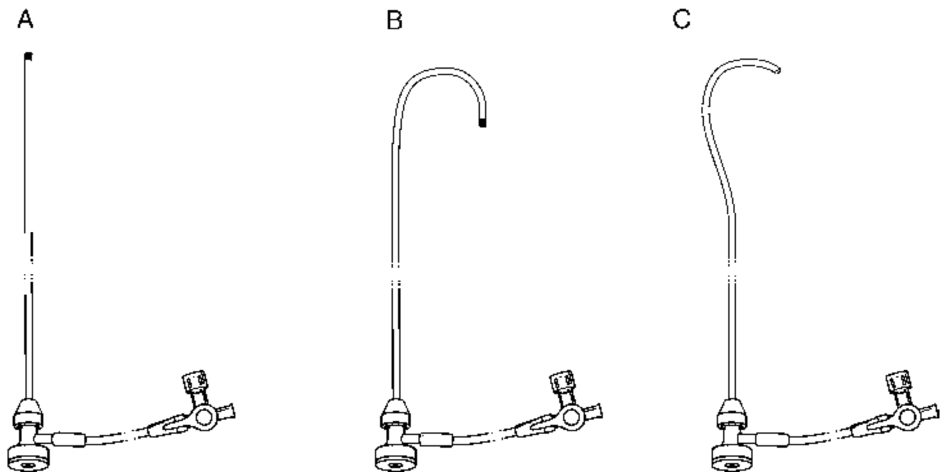


Fig. 3 Guiding sheaths. Guiding sheaths are the future of access for endovascular therapy. The special shapes and sizes have simplified access and provide more reliability. **A,** A long straight sheath with a flexible shaft and a radiopaque tip can be used for brachiocephalic balloon angioplasty and stenting, such as the Shuttle or the Raabe sheaths (Cook, Inc., Bloomington, Ind.). **B,** The up-and-over guiding sheath has a long curve for passage over the aortic bifurcation. **C,** The Ansel guiding sheath is used for renal artery interventions.

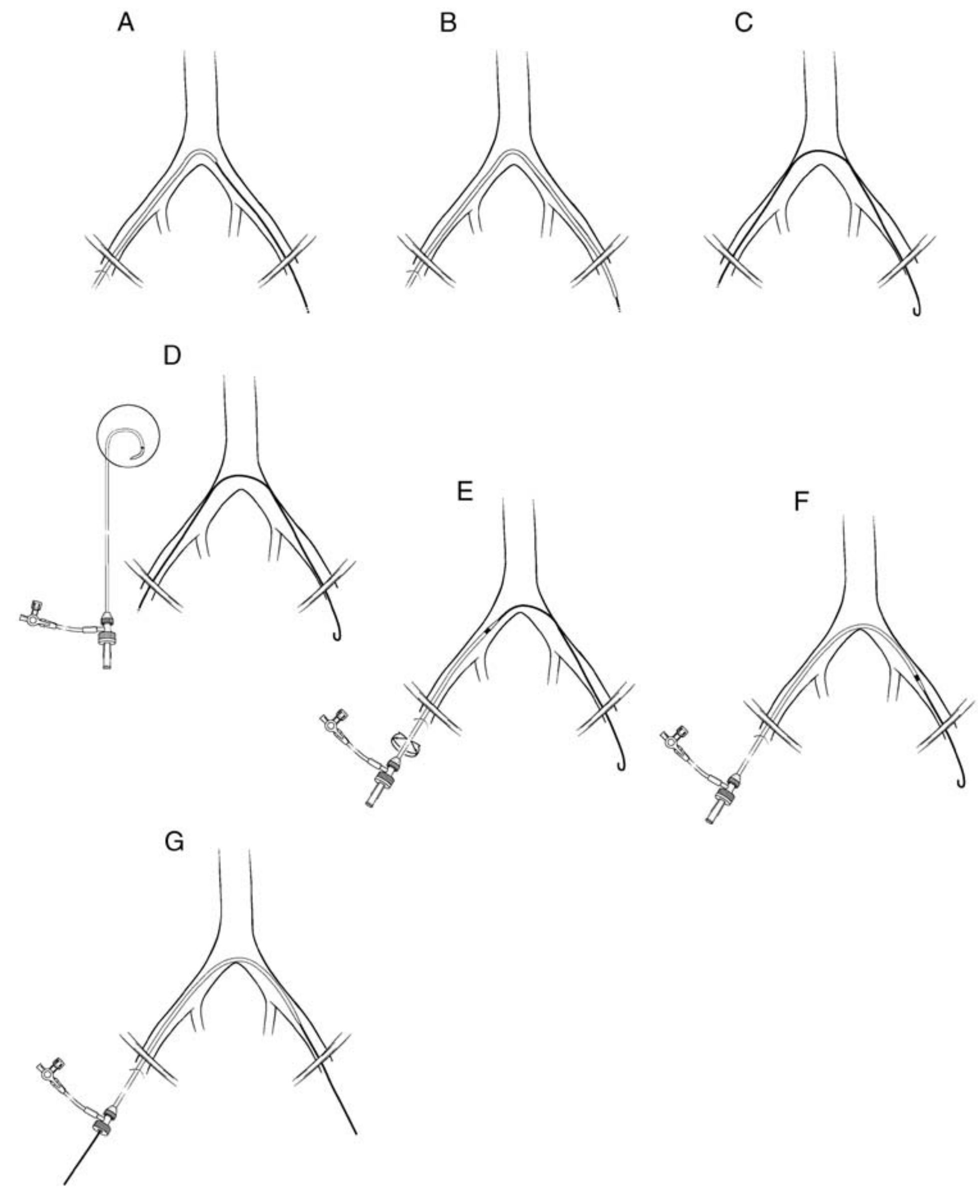
not have a dilator or obturator to facilitate smooth passage. To compensate for this, they are usually introduced through the soft tissue and into the artery through a standard, hemostatic access sheath. This generally means that the arteriotomy is slightly larger than would otherwise be necessary. After passage into the artery, they often require another device, such as a selective catheter, to act as an obturator for passage into the desired side-branch location. There is no end valve for hemostasis. A Tuohy-Borst adaptor must be used to make a guiding catheter hemostatic and to allow it to be flushed. It is likely that when a broad array of guiding sheaths becomes available, guiding catheters will be used only rarely. Nevertheless, if a certain shape is required to guide passage and it is not available with a guiding sheath, a guiding catheter should be used.

In later chapters on balloon angioplasty and stent placement in various vascular beds, the placement of guiding sheaths is described when indicated. In general, placement of guiding sheaths is performed as follows. Flush aortography is performed. A selective catheter and steerable guidewire are used to cannulate the side branch of interest. The selective guidewire is removed and exchanged for an exchange guidewire. The arterial entry site is dilated and the selective sheath is advanced over the exchange guidewire. After the tip of the sheath is in the side branch, the dilator is removed, arteriography is performed, and therapy is initiated. An up-and-over sheath (Cook, Inc., Bloomington, Ind.) is a good example of a frequently used guiding sheath. It is useful for contralateral iliac or infrainguinal intervention. It maintains hemostatic access at the femoral artery, promotes and maintains guidewire access across the lesion, permits interval arteriography, and enhances the ability to evaluate the runoff bed. The technique of placement of an up-and-over sheath is described in Fig. 4.

TECHNIQUE: How to Place an Up-and-Over Sheath

1. A starting guidewire is placed in the aorta through a retrograde femoral puncture. A hook-shaped catheter, such as an Omni-flush, is placed just above the aortic bifurcation, and a Glidewire is advanced antegrade into the contralateral iliac system. Selective catheterization of the aortic bifurcation is described in detail in Chapter 6.
2. After the guidewire is advanced into the femoral artery, the hook-shaped catheter is advanced to the distal external iliac or proximal femoral artery.
3. A stiffer guidewire for exchange is placed, such as a Rosen (180-cm, 0.035-in., atraumatic J tip). Occasionally, an Amplatz guidewire is required.
4. The catheter is removed and the entry site is enlarged with arterial dilators. The up-and-over sheath is advanced over the exchange guidewire. The radiopaque tip of the sheath can be followed with fluoroscopy to evaluate progress over the bifurcation. The sidearm of the sheath is oriented opposite the curvature in the sheath tip.
5. The sheath is advanced to its hub if it will go but if significant resistance occurs, the sheath tip can be parked anywhere in the contralateral iliac system.
6. The dilator is removed, and the sheath is aspirated and flushed.

Fig. 4 Placement of up-and-over sheath. A, A guidewire and catheter are passed over the aortic bifurcation (see Fig. 10 of Chapter 6). **B,** The catheter is advanced into the contralateral femoral level. **C,** An exchange guidewire, such as a J-tipped Rosen, is placed and the catheter is removed. **D,** The arteriotomy is dilated, if this has not already been done. The up-and-over sheath is oriented with the tip directed toward the contralateral side and the sidearm of the sheath is directed toward the ipsilateral side. **E,** The sheath is advanced over the guidewire. The dilator and the tip of the sheath are observed as they pass over the aortic bifurcation. A slight back-and-forth rotating motion along the shaft of the sheath is sometimes helpful during passage. **F,** The sheath is advanced to its hub if it will go without significant resistance. If resistance is met, check to see that the guidewire is advanced far enough so that there is plenty of stiff guidewire to support the advancing sheath. The tip of the sheath may be placed anywhere from the mid-iliac to the proximal femoral level to be functional. If the sheath is not advanced to its hub and some length of it is left outside the access site, the extra length must be taken into account when guidewire and catheter length is considered. **G,** The dilator is removed and the sheath is ready for use.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13

Medications for Endovascular Therapy

Sedation and Analgesia
Local Anesthetic
Prophylaxis with Antibiotics
Anticoagulants
Vasodilators
Treatment of Contrast Reactions

Sedation and Analgesia

Using low-osmolality contrast and thorough local anesthesia and performing an expeditious procedure help to limit the depth of sedation and pain relief required. Conscious sedation is required because the patients' cooperation is necessary to control ventilatory and other types of motion. Conscious sedation is usually performed using a combination of a narcotic and a sedative.

Opiate narcotics cause drowsiness and decrease the perception of pain. Fentanyl lasts 30 to 60 min and can be titrated with small, incremental intravenous doses. It is more potent than morphine and can be reversed with naloxone.

Midazolam (Versed) relieves anxiety and causes amnesia. Intravenous midazolam is titrated in small doses of 1 or 2 mg and can be reversed with Romazicon.

Local Anesthetic

Plain lidocaine 1% is an excellent local anesthetic. It lasts up to 2 hours, which will cover most percutaneous procedures. The maximum dose of lidocaine is 5 to 7 mg/kg. Since 1% lidocaine contains 10 mg/ml, a 70-kg patient can be treated with 35 to 50 ml.

Prophylaxis with Antibiotics

Most strategic arteriography and simple interventions do not require antibiotic administration. However, patients with vascular prostheses in place or who will undergo placement of a stent or other foreign body should be treated with antibiotics. A first-generation cephalosporin such as cephazolin 1 g is administered prior to the procedure. If a patient has ongoing evidence of bacteremia or localized infection, appropriate antibiotic coverage should be initiated prior to entry into the arterial system.

Anticoagulants

Heparin is routinely used in the saline flush solution during all arteriographic and endovascular therapy cases. Systemic heparinization is not usually required for strategic arteriography but is administered during carotid arteriography or when an arteriographic catheter is passed across a critical lesion. Intravenous boluses of heparin, ranging from 50 to 100 U/kg, are often used in conjunction with percutaneous interventions (Table 4 in Chapter 14). The half-life of heparin is 1 to 1 1/2 hours and is prolonged in patients with renal or hepatic dysfunction. An activated clotting time (normal is 150 to 170 secs) can be used to assess residual heparinization prior to sheath removal.

Vasodilators

Papavarine is a smooth-muscle relaxant and can be administered as a bolus (15 to 30 mg) or as an infusion at 1 to 3 mg/min. Papavarine is most commonly used to produce extremity vasodilatation in an effort to elicit evidence of the hemodynamic significance of a lesion. Nitroglycerine (20 to 100 μgs) is administered to prevent or treat vasospasm that may occur during endovascular therapy. Vasodilators may cause hypotension.

Treatment of Contrast Reactions

Reactions to contrast media vary in severity and include a broad spectrum of potential symptoms. Nausea, vomiting, urticaria, pruritis, bronchospasm, upper respiratory congestion, facial edema, laryngospasm, glottic edema, respiratory distress, hypotension, and cardiac collapse represent some of these.

Four doses of prednisone (20 mg) are prescribed for the 18 hours leading up to the procedure in patients with a previous history of contrast reaction. When a contrast reaction occurs, administer Benadryl (25 to 50 mg IV, IM, or PO), which blocks histamine receptors and treats contrast-induced urticaria. Provide oxygen, give inhaled albuterol treatment, infuse epinephrine (1 to 3 ml of 1:10,000 IV). Administer fluid and elevate the legs for hypotension due to a vasovagal episode. Lasix is given to patients in pulmonary edema.

14

Balloon Angioplasty

Minimally Invasive Autologous Revascularization

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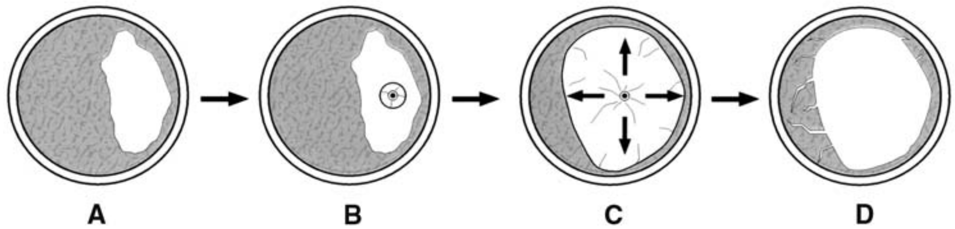

Fig. 1 Balloon dilatation causes plaque fracture. A, A cross-sectional view of an atherosclerotic lesion. **B,** A balloon catheter is placed in the lesion. **C,** The radial force generated by dilatation is applied to the lesion. **D,** Plaque fracture causes dissection, which is often observed during completion studies.

Balloon Dilatation Is (Un)Controlled Dissection!

The radial force of the angioplasty balloon causes plaque fracture at an area of fixed stenosis (Fig. 1). There is often evidence of dissection on completion images immediately following the angioplasty. Contrast fills cracks in the plaque, most of which are longitudinal. Experience with balloon angioplasty before the development of stents indicates that nearly all of these dissections heal without treatment, so the availability of stents has prompted the current dilemma. How aggressively should mild to moderate post-angioplasty dissections be stented?

About Balloon Catheters

The coaxial balloon angioplasty catheter has two lumens. One lumen fills the balloon and the other lumen is used for placement over a guidewire (Fig. 2). The balloon is not preinflated because after inflation it assumes a higher profile and may be difficult to advance into the lesion. The catheter is irrigated and wiped with heparin–saline solution. Balloon catheters with inflated diameters of 3 to 12 mm may be obtained on 5 Fr shafts and can be placed over 0.035-in. guidewires. Balloon lengths of 2 and 4 cm are most commonly used, but lengths of up to 10 cm are available. Bursting pressure specifications usually range from 8 to 12 atm, but thicker polymer balloons have a bursting pressure of 17 atm. Radiopaque markers on the catheter at each end of the balloon are observed by using fluoroscopy to place the balloon in the correct location.

Desirable features for angioplasty balloon material are strength (rupture-resistant), low compliance (maintains correct shape at high pressure), and low profile (enhances trackability and crossability). Most angioplasty is

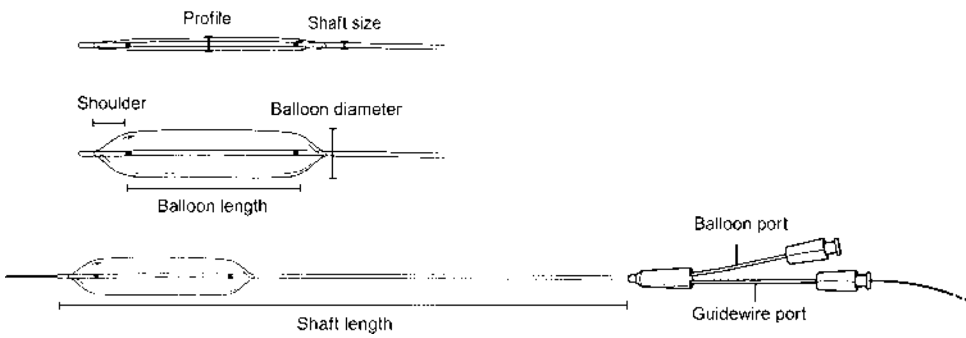

Fig. 2 Balloon angioplasty catheter. The width of the folded balloon over the catheter is the profile. The shaft size depends on the size and type of the balloon. A wide range of balloon diameters are available on a 5 Fr shaft. The shoulder is the distance from the radiopaque marker, where the balloon is filled out to its specified diameter, to the actual end of the balloon. The balloon diameter is the fully inflated diameter of the balloon. The length is the distance between the radiopaque markers. The shaft length provides working distance between the operator and the angioplasty site. The balloon port is used to inflate the balloon, and the guidewire or distal port extends the length of the catheter and is used for passage over the guidewire.

currently performed with balloons constructed of polyethylene terephthalate or a similar, low-compliance plastic polymer.

Reinforced high-pressure polymer balloons exert pressures in excess of 17 atm (e.g., Blue Max, Boston Scientific Corp., Medi-Tech Division, Natick, Mass.) and are useful for residual, recurrent, calcified, or intimal hyperplastic lesions. These are mounted on slightly larger shafts of 5.8 Fr and assume a higher profile due to thicker balloon material. Larger balloons (from 14 to 28 mm inflated diameter) are available for use in endovascular aortic graft placement, large-vessel work, and cardiac valvuloplasty. These are on shafts that range from 5.8 to 7 Fr, and the redundancy of the balloon material requires that substantially larger sheaths be used. Smaller-diameter balloons (2 to 4 mm) for tibial angioplasty are available on a 3.8 Fr shaft that travels over a 0.018-in. guidewire.

The Angioplasty Procedure

Percutaneous balloon angioplasty is similar to other surgical procedures. After patient selection and preparation, the next most important factor in success is a stepwise game plan that proceeds methodically, with contingencies available for managing any untoward events that may occur. The general steps include: (1) identifying the lesion and confirming that it is a reasonable lesion for endovascular treatment (arteriography), (2) gaining control of the lesion (by passing a guidewire across the lesion, (3) securing percutaneous access (sheath placement), (4) selecting and preparing the balloon catheter, (5) placing the balloon, (6) dilating the lesion, and (7) confirming an acceptable result (completion arteriography). Steps 1 through 3 were covered in previous chapters. Steps 4 through 7 are detailed in this chapter.

Balloon Selection

Choosing the balloon diameter is more art than science. It is unlikely that immediate trouble will be caused by selecting a balloon with a diameter that is a little too small. Underdilatation in the short term is an extra step, since the smaller-diameter balloon must be exchanged for a larger size to finish the procedure. If underdilatation is not recognized, it may result is a residual lesion that requires treatment at some later date. Conversely, significant overdilatation can cause immediate problems such as rupture or dissection.

Balloon selection was much simpler when cut film arteriography was the standard. If anyone is still using cut film, they will know that the appropriate balloon diameter is selected by measuring the diameter of the "normal" artery on the cut film just proximal or distal to the lesion and using that size balloon. Cut film usually results in about a 10% magnification, and balloon angioplasty should be performed with a slight overdilatation. Measuring a segment of poststenotic dilatation will result in choosing a balloon diameter that is too large.

In many angiographic suites and operating rooms, digital subtraction arteriography is the only method available for evaluating arteries. In this case, there are two choices for balloon diameter sizing:

(1) After performing arteriography, choose a static image and transfer it to the inactive television monitor. (See Table 1.) Choose a slightly smaller than anticipated balloon diameter and dilate the artery without moving the image intensifier. When the balloon diameter is selected conservatively, the likelihood of significant overdilatation is low. The real-time image of the inflated balloon is juxtaposed to the image of the artery. The operator will have a sense for whether the balloon appears appropriate for that artery (the "eyeball" method). If it appears that the balloon is too small, it may be exchanged for a larger one. If it appears to be appropriate in size, the operator proceeds to evaluate the treated artery for evidence of residual stenosis. Steps for assessing the adequacy of angioplasty are detailed later in this chapter.

(2) Another option is to perform arteriography with a catheter that has graduated radiopaque centimeter markers and to use this known length to calculate vessel diameter. This method is not without the potential for error. If the catheter is traveling in the anteroposterior

plane, the marked centimeter may appear shorter than it really is and cause an overestimation of vessel size. This method is also cumbersome since it requires the use of an extra catheter and the performance of real math. A variation of this method is available in some angio suite cockpits that have the software to estimate vessel diameter using a known standard for comparison, such as a 5 Fr catheter. This also takes enough time that it interrupts the procedure and there are major potential sources of error based upon where the cursor is placed to measure the walls of the catheter.

Most operators who have been doing angioplasty for a while just use the "eyeball" method described above. Dissection or rupture can result if the balloon is too large so, when in doubt, start small.

The balloon should be long enough to dilate the lesion and allow a short overhang on either end. Balloon length choices are usually limited to 2 or 4 cm. If the balloon used is too short to cover the whole diseased segment, additional inflations are required. There are some 6- and 8-cm length balloons available, mostly for use in the superficial femoral artery. Low-profile, thin-walled balloons are generally preferable for ease of placement. The profile of the unexpanded balloon is important to ease passage through the sheath and across the lesion and should be minimized as much as possible. Other

Table 1 Balloon Sizing for Angioplasty[a]

Angioplasty site	Balloon diameter (mm)
Abdominal aorta	8–18
Aortic bifurcation[b]	6–10
Common iliac artery	6–10
External iliac artery	6–8
Superficial femoral artery	4–7
Popliteal artery	3–6
Tibial artery	2–4
Renal artery	4–7
Subclavian artery	5–8
Dialysis graft	4–6
Infrainguinal graft	2–5

[a] Each arterial segment has a general range of appropriate balloon sizes from which to choose.
[b] When kissing balloons are used at the aortic bifurcation, the diameters of the two balloons are additive. Kissing 10-mm balloons should be used only if the distal aorta can tolerate dilatation to 20 mm.

Table 2 Angioplasty Balloon Catheter Length

Location of balloon angioplasty	Entry site	Length (cm)
Carotid	Femoral	110–130
Subclavian	Femoral	110–120
	Brachial	75
Visceral	Femoral	75–90
Renal	Femoral	75–90
	Brachial	90–110
Aorta	Femoral	65–75
Iliac	Ipsilateral femoral	40–75
	Contralateral femoral	75
Femoropopliteal	Ipsilateral femoral	75
	Contralateral femoral	75–110
Infrapopliteal	Ipsilateral femoral	75–90
	Contraleral femoral	90–120

balloon types may be chosen for certain lesions. Reinforced polymer (high-pressure) balloons are used for recalcitrant lesions. Puncture-resistant balloons are used for stent placement. The shaft length must be adequate to reach the lesion from the entry site. Shaft size should be as small as possible. Most angioplasty can be performed with 5 Fr balloon catheters (range 3.8 to 7 Fr). The hemostatic access sheath should be selected in anticipation of the balloon to be used. If a stent is likely to be required to treat the lesion, the operator will choose the sheath with the balloon–stent combination in mind. There is more information about sheaths in Chapter 12.

The length of the balloon catheter itself must also be considered. There is more information about this in the individual chapters about intervention in specific vascular beds. Table 2 provides some guidelines. Balloon catheter lengths vary from 40 to 150 cm. A full complement of medium-length balloon catheters (75 or 80 cm) should be maintained in active inventory since these can be used for a wide range of balloon angioplasty procedures. Longer catheters, ranging from 90 to 120 cm, are also useful for angioplasty using remote access.

ANGIO CONSULT: How Do I Choose the Right Balloon for the Job?

1. **Balloon diameter.** Start small. Use guidelines based upon which artery is being dilated. If cut film is available, measure the diameter directly from the hard-copy x-ray film (Table 1).
2. **Balloon length.** Aim to cover the lesion and a little beyond (usually 2 or 4 cm, occasionally 6 or 8 cm).

3. **Balloon type.** Choose material based on the type of lesion.
4. **Shaft length.** Must reach the lesion from the entry site (range from 75 to 130 cm). Table 2 provides guidelines for choosing balloon catheter lengths. Additional information is available in the sections on angioplasty at specific sites.
5. **Shaft size.** Use as small as possible (usually 5 Fr or smaller).
6. **Shoulder length.** The length of the shoulder is important if the lesion is near an area that should not be dilated. The shoulder of the balloon is the end that extends beyond the radiopaque marker. If the shoulder extends into an adjacent branch vessel that is not intended for treatment, overdilatation may result.
7. **Balloon profile.** Lower is better but the profile varies with balloon type and somewhat from one manufacturer to another.

Supplies for Percutaneous Balloon Angioplasty

Table 3 includes a list of items that should be available to initiate a balloon angioplasty procedure. The "arteriography pack" of basic supplies is included in Table 1 of Chapter 8. An inventory of disposable endovascular supplies, such as guidewires, catheters, sheaths, angioplasty balloons, and stents, must be maintained and continuously updated. There is more information about inventory in Chapter 24. In Chapters 17 through 21, which cover intervention in different vascular beds, there is more specific information about which supplies should be available for balloon angioplasty.

Sheath Selection and Placement

Sheaths have been introduced and discussed in Chapter 12. Sheaths are not usually required for strategic arteriography, but sheath access to the arterial system is part of the standard approach to percutaneous balloon angioplasty.

Table 3 Supplies for Balloon Angioplasty

Starting guidewire	Balloon angioplasty catheter
Selective guidewire	Inflation device
Exchange guidewire	Balloon-expandable stent
Dilator	Self-expanding stent
Flush catheter	Arteriography pack (see Table 1 of Chapter 8)
Selective catheter	Heparinized saline
Exchange catheter	Contrast
Access sheath	Protective gear (e.g., leaded apron)
Guide sheath	

The access sheath maintains control of the access site, provides hemostasis, and functions as a conduit for simple placement of balloon catheters and angiographic catheters. In general, the sheath is selected on the basis of the Fr sizing of its caliber and its length. General-access sheaths are straight and are available with radiopaque tips if desired. Special sheath configurations may be required for some types of angioplasty where a high degree of selectivity is required. These guiding sheaths are discussed in Chapter 12.

The size of the sheath is selected to fit the endovascular device. In the case of balloon angioplasty, the sheath must accommodate the balloon after it has been inflated and aspirated and it is time to withdraw it from the patient. See the section in Chapter 12, 'What Fits Into What?' (Table 3 of Chapter 12). As a general rule, a 5 Fr sheath will accommodate balloons up to 6 mm. A 6 Fr sheath will permit balloons up to 8 mm to pass, especially if low-profile balloons are used. A 7 Fr sheath will accommodate a balloon up to 10 mm, as long as it is mounted on a 5 Fr shaft. Larger balloons may come on 5 Fr shafts or larger and generally require 8 to 10 Fr sheaths.

If stent placement is anticipated, the sheath size must be increased accordingly. Palmaz stents are placed through 7 or 9 Fr sheaths. Premounted Palmaz or Palmaz Corinthian stents of 7 mm or less may be placed through 6 Fr sheaths. Wallstents and Smart stents likewise require 7 or 9 Fr sheaths. There is more information about sheath sizing requirements for stent placement in Chapter 16. Newer self-expanding sheaths require 6 Fr sheaths.

The standard sheath length of 12 to 15 cm is adequate for most angioplasty. If the catheter must be guided over a bifurcation or into a specific branch vessel, such as the carotid or renal arteries, a longer sheath from 40 to 90 cm may be selected, often with a special curve to help smooth out the turns that must be negotiated.

The sheath is placed over the guidewire, usually in exchange for whichever angiographic catheter has been used to evaluate the lesion. The guidewire is maintained across the lesion and the entry site. Pressure is held at the arterial puncture site as the angiographic catheter is removed. Preparation and management of the sheath are detailed in Chapter 12. The sheath is advanced into the artery and the dilator is removed. Turn the sheath appropriately so that the sidearm is oriented toward the operator for ease of use. The sheath may be turned back and forth slightly to help make the advancement easier. As the tip of the sheath enters the skin entry site, the sheath is gripped along its shaft, close to its leading edge. Be sure to watch it so that the dilator does not pop backward. If the lesion is in proximity to the arterial entry site, care should be taken to avoid advancing the sheath across the lesion and unintentionally dottering the intended balloon angioplasty site. The sheath is generally advanced to its hub, unless it is too close to the lesion. The dilator is removed. The sheath is flushed with heparinized saline.

If any additional arteriographic projections are required prior to endovascular treatment, they are obtained. Placement of an external marker, such as radiopaque marking tape, is performed at this point if desired and a contrast run is performed with the marker in place.

Balloon Preparation and Placement

The balloon catheter is taken from its sterile package. The protective plastic cover that is placed over the balloon for shipping is removed. This is saved on the field so that it can be used to help refold the balloon wings later if the catheter is going to be used again during the same procedure. Balloons of widely varying diameters appear similar in the nondilated state. The operator must ensure that the correct size of balloon is being placed by checking the size inscription on the balloon catheter prior to insertion. The catheter and balloon are wiped with a heparin–saline soaked gauze sponge. The distal or guidewire port is irrigated with heparin–saline. The balloon should not be preinflated; this raises the profile of the balloon and makes the operator look silly. The companies are responsible for quality control and do a remarkable job, in general. The balloon catheter is placed on the guidewire and advanced toward the entry site until guidewire is available to be grasped on the other end of the catheter. Do not insert the balloon catheter unless manual guidewire control has been achieved.

Heparin is administered if indicated by the type of procedure being performed (Table 4). When heparin administration is required, this should occur at least 3 minutes prior to balloon inflation. In general, the more distally the lesion is located or the more complex the planned reconstruction, the more likely the patient will be to benefit from heparin administration. As with open vascular surgery, there is a high degree of variability

Table 4 Heparin Administration During Percutaneous Balloon Angioplasty

Procedure	Systemic heparin administration (u/kg)	Other considerations
Brachiocephalic	75–100	IIb/IIIa inhibitors
Renal	50–75	Nitroglycerin for spasm
Aortoiliac		
Simple	25–50	
Complex	50–75	
Femoropopliteal		
Simple	25–50	
Complex	50–75	
Tibial	50–75	

between different vascular specialists as to appropriate heparin indications and dosages. Table 4 is one operator's method and is intended for use as a general guideline. Before placing the balloon catheter, confirm appropriate heparin administration and prepare the inflation device so that angioplasty is permitted to proceed as soon as the balloon is in place. The balloon catheter is advanced through the sheath (Fig. 3). The location of the lesion is marked after arteriography using bony landmarks or an external radiopaque marker or road mapping. The catheter is advanced using fluoroscopic guidance, and the radiopaque markers on the balloon are placed across the location of the lesion. The shoulder of the balloon must not extend into an area where

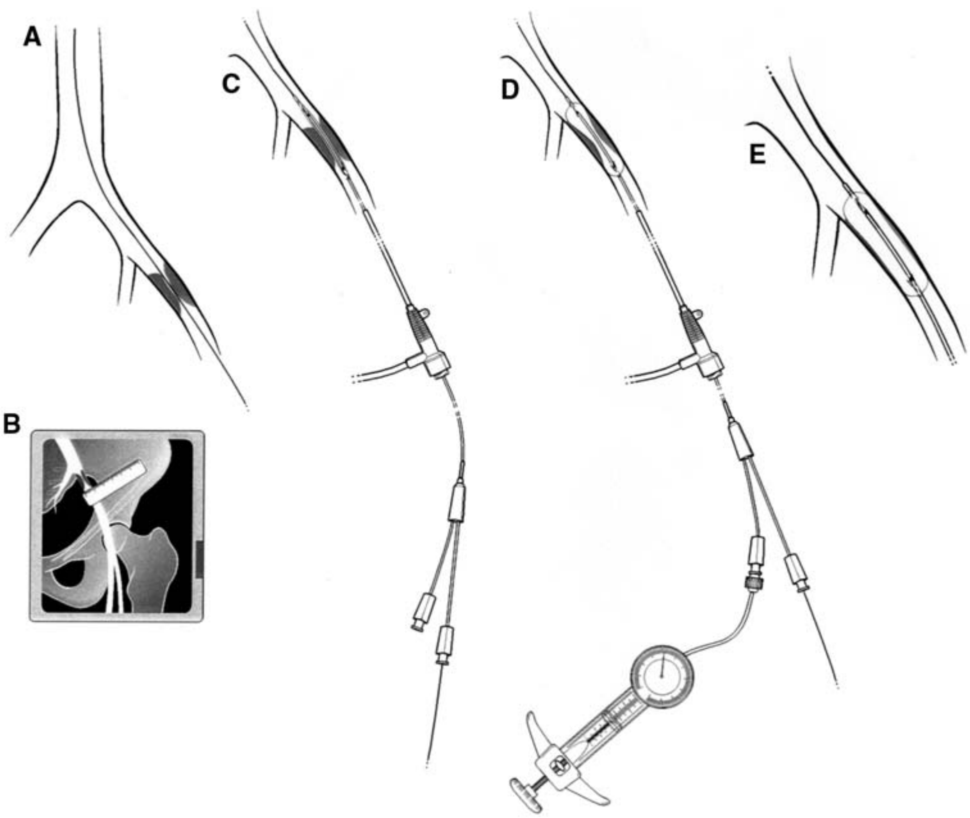

Fig. 3 Balloon angioplasty. A, The guidewire is placed across an iliac artery stenosis. **B,** The diameter of the balloon is selected based on the diameter of the uninvolved, juxtaposed iliac artery as measured on the cut film arteriogram. **C,** The balloon catheter is passed over the guidewire, through the hemostatic sheath, and into position across the stenosis. **D,** The balloon is inflated using an inflation device. Pressure within the angioplasty balloon can be monitored as the waist of atherosclerotic material resolves. **E,** The lesion is fully dilated and the cylindric shape of the balloon is confirmed using fluoroscopy.

angioplasty is not desired. The balloon is centered in the lesion so that the most stenotic segment is dilated by the central portion of the balloon.

Balloon Inflation

Balloons can be inflated with anywhere from 2 to 12 ml of contrast and saline solution, depending upon the diameter and length of the balloon. The inflation devices usually hold 10 to 15 ml. A 30 to 50% contrast solution allows the outline of the balloon to be visualized fluoroscopically. Full-strength contrast is more viscous and therefore prolongs inflation and deflation. Air should be removed from the inflation device. Sizable air bubbles inside the balloon may make it difficult to tell whether or not the balloon is fully expanded. If the balloon breaks, the patient will receive an intra-arterial bolus of air. Balloon inflation is usually but not always performed with an inflation device. The plunger on the inflation device is compressed until a few atmospheres of pressure register on the pressure gauge. The plunger is locked in compression mode. At this point, the outline of the partially inflated balloon is visible on the fluoroscopic monitor. The inflation is completed by turning the screw handle to gradually increase pressure in the balloon while the fluoroscopic image is monitored for complete balloon dilatation. An inflation device permits pressure within the balloon to be measured during inflation to avoid exceeding the balloon's bursting pressure. Observation of balloon expansion can be compared with the pressure data to gain a better understanding of the lesion. Higher pressures required to dilate recalcitrant lesions can be sustained and monitored with an inflation device. When kissing balloons are required, as with aortic bifurcation lesions, pressure in the two balloons can be equalized.

The balloon may also be inflated by hand. A 10-ml syringe is filled to the 8-ml level and used to expand the balloon directly by hand-generated pressure. This is most effective with smaller balloons. Use a luer lock syringe when dilating by hand. In practice, this is simple, fast, and inexpensive, and it works well for most garden-variety atherosclerotic lesions.

Angioplasty is performed without delay after the balloon is placed, since the presence of the catheter alone in the remaining patent lumen can decrease flow and enhance thrombus formation. Angioplasty is always performed using fluoroscopic guidance. Atherosclerotic narrowing makes itself apparent on the outline of the balloon as it is being inflated under fluoroscopy (i.e., by the atherosclerotic waist). The atherosclerotic waist, which is present at the most stenotic part of the lesion, usually resolves when adequate pressure is applied by the balloon (Fig. 4).

There are many recommendations to guide inflation parameters but almost no data to support them—the amount of pressure to apply, the

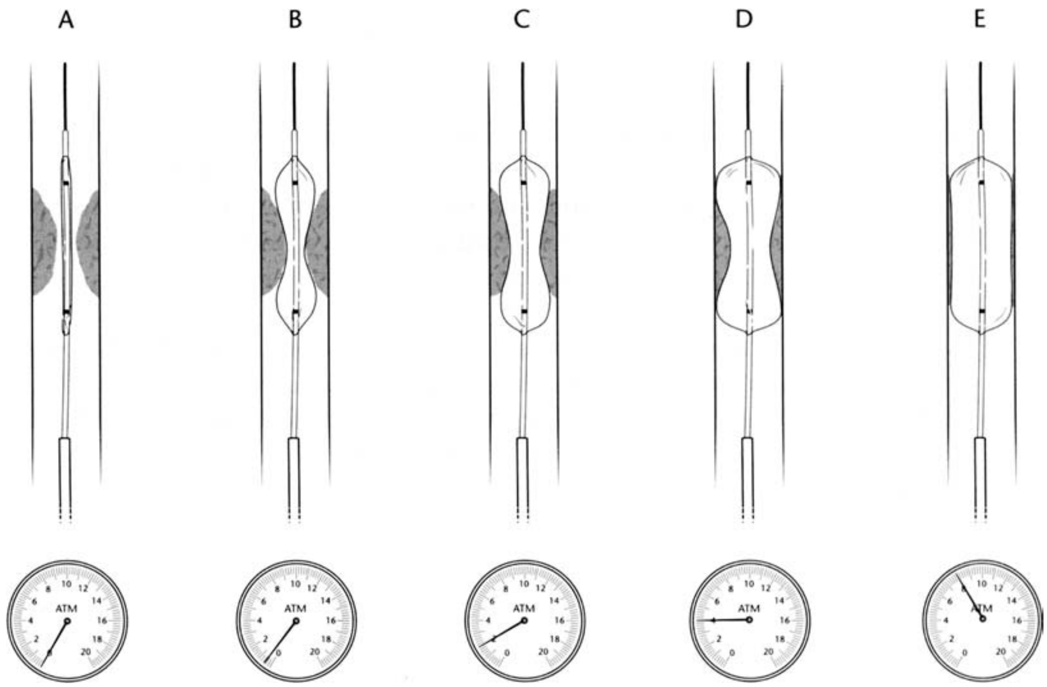

Fig. 4 Dilating the atherosclerotic waist. A, The balloon catheter is placed within the lesion. The radiopaque markers straddle the stenosis. **B,** The balloon begins to take shape at low pressure. **C,** At 2 atm of pressure, the waist begins to become evident. A waist of atherosclerotic material represents the area of heaviest plaque formation and is usually the last area to be fully dilated. **D,** At 4 atm of pressure exerted by the balloon, a substantial residual, unresolved stenosis is apparent. **E,** When the pressure is doubled to 8 atm, the waist of atherosclerosis has been completely dilated.

length of time balloon inflation is maintained, the number of times the balloon is expanded at the same location, and the length of time between inflations. A common approach is to dilate a lesion to a slightly higher pressure than that required for full balloon expansion as observed under fluouroscopy. Inflation is maintained for 30 to 60 seconds. The balloon is deflated so that flow resumes, and then reinflated for another 30 to 60 seconds. A third inflation to higher pressure is recommended if a waist is still present at the lesion. Additional dilatations may be performed as needed. In practice, however, it is usually acceptable to dilate the lesion with a single balloon inflation until the waist expands. Longer inflation times at higher pressures are required for intimal hyperplasia, recurrent lesions, residual lesions, and occasionally heavily calcified lesions. Most lesions are fully dilated with less than 8 to 10 atm of pressure. Intimal hyperplasia is a notable exception and may require 20 atm. Resolution of the waist is an important factor in assessing the adequacy of dilatation. If the balloon will not maintain pressure, this may be due to rupture of the balloon. Sometimes contrast can be seen leaking from the balloon on the fluoroscopic image. Aspiration of the balloon may reveal blood in the inflation mixture. Usually, the balloon must be exchanged in this case. Deflate the balloon as well as possible. Remove the balloon under fluoroscopic guidance to be certain that the irregular, torn balloon wings are not caught on the lesion.

A common finding in the awake patient is a complaint of pain at the angioplasty site during balloon inflation. This generally is a sign that balloon pressure has reached its reasonable maximum. The pain should resolve when the balloon is deflated. Continued pain may be a sign of dissection or rupture and should be evaluated with immediate repeat angiography.

After angioplasty, the balloon is completely deflated. The balloon port is aspirated vigorously using an empty 20-ml syringe. The balloon is not moved until it is visualized using fluoroscopy to ensure complete deflation.

Balloon Removal and Completion Arteriography

Withdraw the balloon but keep the guidewire in place. Occasionally, the balloon material catches on some irregular or sharp part of the dilated lesion, usually when there is significant calcification. If the balloon is caught, deflate the balloon again with constant negative pressure. Rotate the balloon on the guidewire. Advance the catheter a centimeter and then withdraw. Remember to hold the sheath so that it does not pull out when the balloon catheter is removed. When the balloon wings reach the tip of the sheath, there is some resistance as the redundant material is forced into the sheath.

There are several methods of assessing the results of balloon angioplasty (Table 5). Some combination of these are usually performed. Completion arteriography is the most widely applicable method. The quality of completion arteriography may be improved by magnified views of the angioplasty site, oblique views, and a qualitative assessment of contrast flow through the angioplasty site during digital subtraction arteriography. In general, a residual stenosis of less than 30% is acceptable, even if the angioplasty site has a somewhat irregular surface. Although completion arteriography is the most widely used and readily accessible method of assessing the results of balloon angioplasty, after the dissection planes are raised by angioplasty the degree of stenosis may be very difficult to assess. Pressure may be measured proximally and distally to the lesion. This is relatively simple to do by measuring pressure through an angiographic catheter placed over the guidewire that crosses the angioplasty site and measuring through the sidearm of the sheath that is on the other side of the angioplastry site. Any gradient following angioplasty is

Table 5 How Do You Assess the Results of a Balloon Angioplasty?[a]

Method	Comment
Completion arteriogram	Performed in all cases; usually the only method required.
Magnified view	Enhanced detail at angioplasty site.
Oblique projection	Assesses residual stenosis or dissection flap.
Measure pressure	Quantitative hemodynamic assessment.
Intravascular ultrasound	Useful for evaluating residual stenosis. Adds cost to the case.
Clinical evaluation	Helpful in identifying complications.
Hemodynamic stability	
Pulse/color of extremity	
Flank pain	

[a] Modified from Schneider, 2001, p. 61.

probably significant since it takes more than a 30% stenosis to cause a gradient. Remember that when outflow occlusion is present, the pressure will tend to equalize proximally and distally to the lesion or the angioplasty site. Intravascular ultrasound may also be used in this setting and is probably most accurate for assessing the precise degree of stenosis after angioplasty.

Figure 5 gives methods for performing completion arteriography after aortoiliac angioplasty. Completion arteriography is most commonly performed using a catheter placed through the sheath and over the access guidewire after the balloon catheter is removed. If a previous contralateral puncture has been performed, a separate catheter may be placed through this access site to obtain a completion study. Sometimes completion arteriography is performed simply by injecting contrast through the sidearm of the sheath with the tip either proximal or slightly distal to the angioplasty site. High-pressure contrast injection should not be performed directly into the fresh angioplasty site because it may extend a local dissection plane caused by the balloon injury. General options and techniques for completion arteriography at various sites are presented in Table 6. Further examples of completion arteriography are provided in the chapters on angioplasty in different vascular beds.

The guidewire is maintained in its position across the lesion until the completion arteriogram has been deemed satisfactory. If for some reason the guidewire is no longer across the lesion and more endovascular intervention is required, the lesion is recrossed with a J-tip guidewire to avoid entering a newly created dissection plane.

A balloon can be reused during the same angioplasty procedure. The balloon arrives in the package with a funnel-shaped plastic cover that protects the balloon during shipping. With a firm negative-pressure aspiration on the balloon port, the balloon material can be folded and reshaped by hand and advanced into the funnel to lower its profile for repeat use.

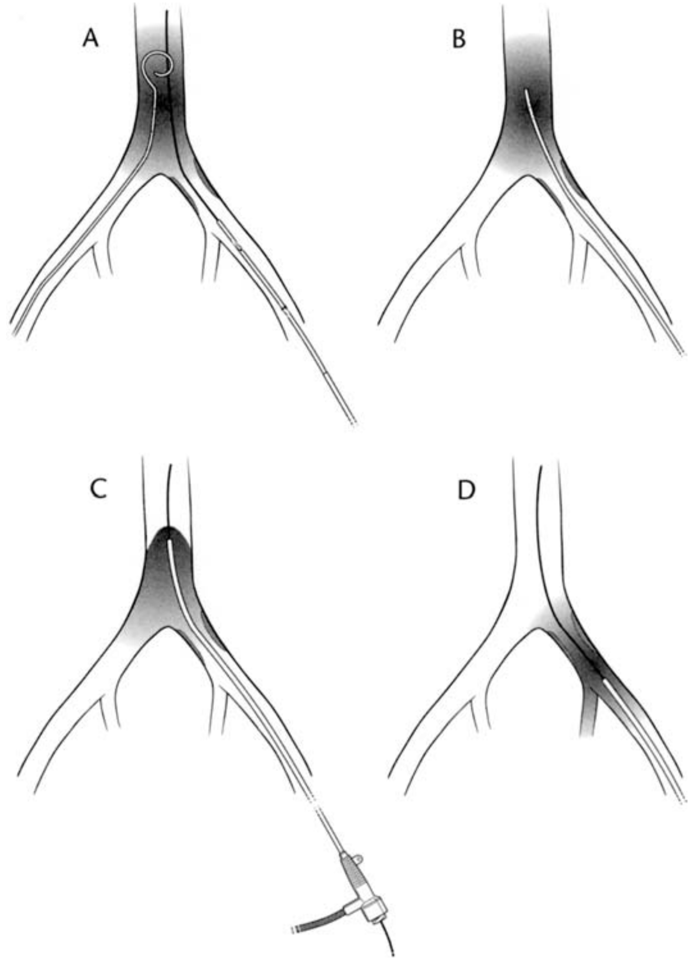

Fig. 5 Completion arteriography. A, After iliac angioplasty, the balloon catheter is withdrawn from the angioplasty site. Completion arteriography can be performed through a proximal catheter placed in the aorta through the contralateral femoral artery. This is a reasonable approach if an arteriographic catheter had been originally placed to perform strategic aortography prior to the angioplasty procedure. **B,** The balloon catheter can be removed completely and exchanged for an arteriographic catheter. Intraluminal position across the angioplasty site is maintained by the catheter itself. **C,** If a long sheath has been used for the procedure, it may be most expedient to insert the dilator and advance the sheath through the lesion. Contrast administration through the sidearm of the sheath permits completion arteriography. **D,** Retrograde arteriography can also be performed if the contrast can be delivered through a large-bore device such as a sheath. Power injection into a fresh angioplasty site should be avoided.

Table 6 Options for Completion Arteriography After Endovascular Intervention

General options	Technique
Proximal flush catheter	Place flush catheter over guidewire used for balloon angioplasty. Place catheter head proximal to balloon angioplasty site and administer contrast. Use flush catheter to maintain control at intervention site. This technique most common in aortoiliac intervention.
Access sheath	Maintain guidewire control with original guidewire. Administer contrast through sidearm of access sheath. Tip of sheath must be proximal to lesion (e.g., in SFA balloon angioplasty) or just distal to the lesion (e.g., retrograde femoral approach to iliac lesion).
Straight catheter	Place multi-side-hole straight catheter through the lesion and remove the guidewire. The straight cathether may extend slightly beyond the lesion and is used to maintain control of the lesion. Contrast fills the angioplasty site by passing through the side holes on the catheter. This technique is useful for side branch balloon angioplasty, which is done without a guiding sheath (e.g., renal, subclavian).
Separate catheter	Administer contrast through a separately placed catheter. When arteriography is performed through one puncture site and intervention performed through an alternate site, the original access site can be used for the completion arteriogram. An example of this is a transfemoral arch aortogram, followed by transbrachial, retrograde subclavian intervention. The completion arteriogram is performed through a transfemoral catheter.
Guiding sheath	Long access sheaths with shaped tips are used for branch vessel balloon angioplasty (e.g., carotid, renal). After angioplasty, contrast is administered through the sheath and directly into the vessel origin.

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15

More About Balloon Angioplasty

Keeping Out of Trouble

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Keeping Out of Trouble Is Simpler Than Getting Out of Trouble

There are numerous ways to get into trouble during the course of a balloon angioplasty procedure. Appropriate patient selection and lesion selection remain the two most important factors in preventing problems. However, premature loss of guidewire access, overdilatation of a lesion, and thrombus generation caused by inadequate flushing or lengthy catheter times, and many other avoidable problems may occur. The best way to ensure success is to treat endovascular operations with the same selectivity, preparation, and methodical approach that is required for open operations.

What's the Strategy for Managing Multiple Lesions?

When contemplating angioplasty for multiple sequential lesions, it is important to remember that the long-term success rate of the procedure decreases with each additional angioplasty site. This is especially true when there are several lesions in a series in the same conduit, such as a single iliac artery or superficial femoral artery. Surgical revascularization may be a better solution, even if each lesion is eligible for treatment with endovascular technique.

When multiple sequential lesions require dilatation, angioplasty usually proceeds from proximal to distal, even if the proximal lesion is less stenotic (Fig. 1). Dilatation of a distal critical lesion is most likely to remain uncomplicated if there is adequate inflow to the area when the balloon is deflated. It is usually safest to dilate each lesion separately and to avoid angioplasty where it is not required between lesions.

Sequential ipsilateral lesions that occur in different arteries (e.g., the ipsilateral iliac artery and superficial femoral artery) are managed with angioplasty of the inflow artery first. Success rates after dilatation of the proximal (larger) artery are superior to that of the distal artery in most settings. The best approach is to assess the results of iliac angioplasty first and proceed with further angioplasty after the proximal lesion has been adequately treated.

When multiple sequential significant stenoses occur in the same conduit artery (e.g., the superficial femoral artery) without any significant branches between the stenoses, all the lesions should undergo angioplasty if any dilatation is performed. Angioplasty of only some of the lesions changes the anatomy but yields no hemodynamic improvement, and the lone angioplasty site(s) may thrombose because of continued low flow after dilatation. One possible exception to this is when a critical lesion is located in the middle of

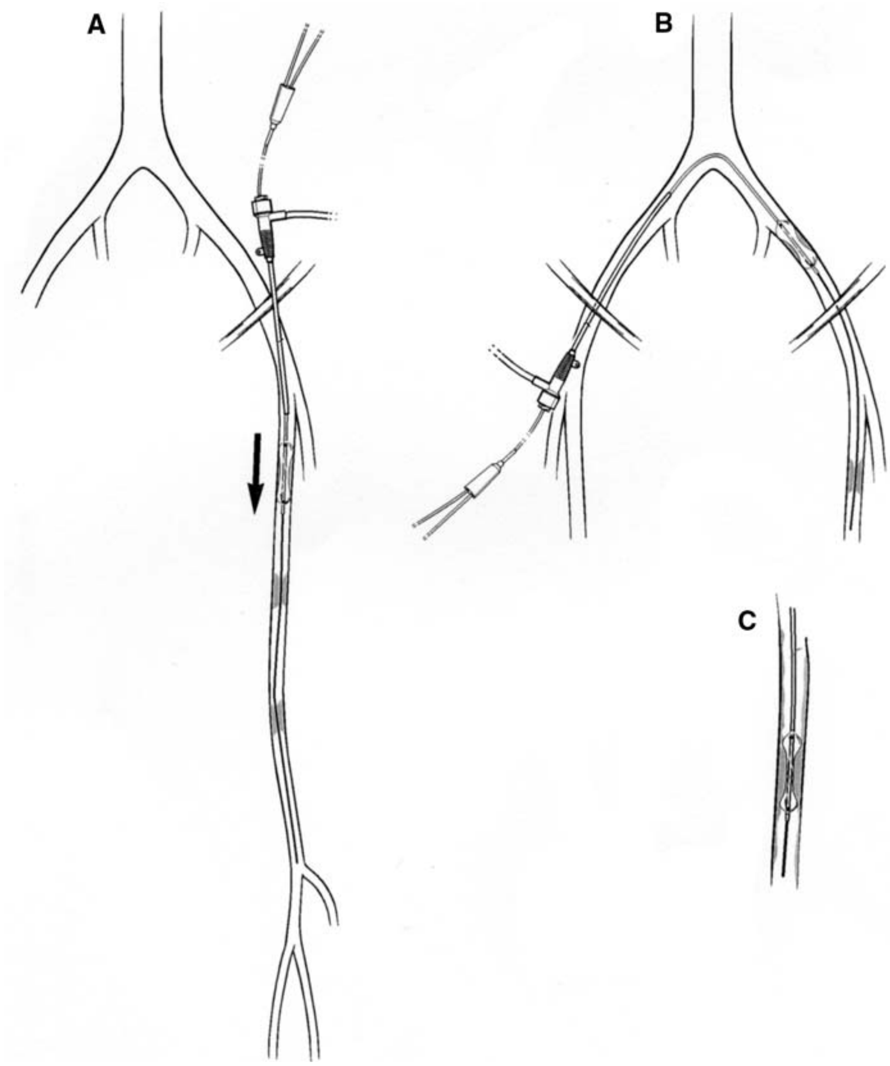


Fig. 1 Strategy for angioplasty of multiple lesions. The approach to angioplasty of multiple lesions is from proximal to distal, regardless of which lesion is most stenotic. **A,** When multiple lesions are in the same conduit artery, and any requires dilatation, all the lesions are treated. **B,** When sequential lesions are in different arteries, the proximal lesion is dilated first. **C,** When a diffusely diseased artery requires treatment, consider dilating only the critical areas of stenosis.

an arterial segment that is diffusely diseased but that is comprised of only mild stenoses (Fig. 1). In this case, it may be better to dilate the single critical area only and then assess the results. The guidewire should be placed across the entire arterial segment in case extensive dissection occurs.

Complications are avoided if lesions are dilated on the basis of clinical problem solving rather than the appearance of the lesions.

TECHNIQUE: Keeping Track of the Tip of the Sheath

During the angioplasty procedure, a common concern is keeping track of the location of the tip of the sheath (Fig. 2). Placement of the sheath too far within the artery may unintentionally dotter the lesion. Balloon inflation within the sheath tip may damage the sheath tip causing it to require exchange and risking damage to the artery when it is removed. The location of the sheath tip should be confirmed prior to inflation.

1. When working room between the sheath tip and the lesion is minimal, the sheath must occasionally be withdrawn partially to make way for the inflated balloon.
2. Many different types of sheaths are currently available with a radiopaque marker in the tip. This adds a little cost, but also simplifies the procedure and makes it more efficient. Some operators use these routinely.
3. A magnified view of the area of the sheath may also detect the end of the sheath along the guidewire where the profile of the guidewire changes.
4. Filling the sheath with contrast through its sidearm may also be helpful.
5. If the balloon catheter fits snugly within the sheath, the operator can usually sense when the balloon portion of the catheter is passing through the tip of the sheath because of the change in the friction applied to the catheter at this point. This location can be identified using fluoroscopy.

Which Lesions Should Be Predilated?

When balloon angioplasty was performed in the past using cut film as a guide without the availability of stents, predilatation was only rarely required. There was not much benefit to this extra step: film development between steps took longer and balloon sizing based upon cut film was a little more life-sized. The conversion of imaging to digital angiography has provided nearly immediate feedback on the results of angioplasty but has also introduced some additional uncertainty as to the optimal diameter of angioplasty at a given site. In addition, the ready availability but high cost of stents has created a situation where dilating first, assessing the results, then placing a stent or

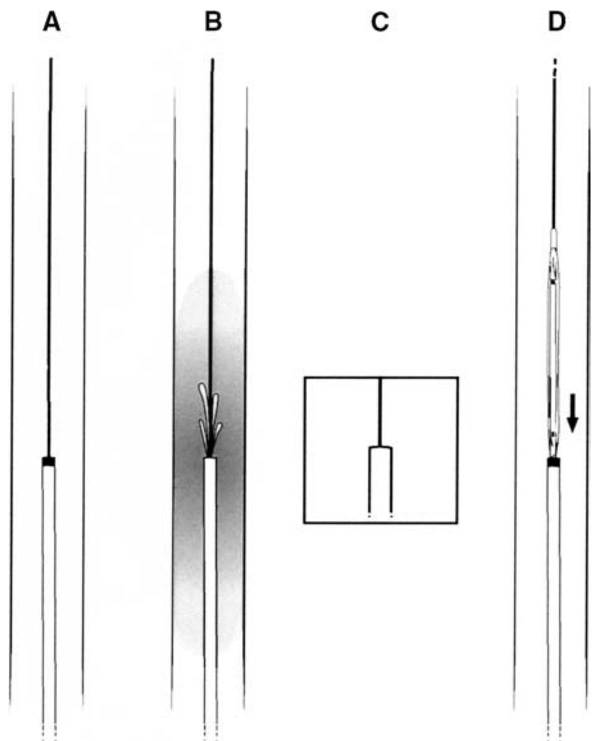


Fig. 2 How do you know where the tip of the sheath is located? Losing track of the sheath tip is a common mistake that leads to problems. **A,** Use of a radiopaque sheath tip is the best way to keep track of the sheath location. **B,** Contast can be placed within the sheath to make it easier to see. Contrast puffed from the tip of the sheath is also useful. **C,** A magnified view often helps identify the outline of the sheath. **D,** After balloon angioplasty, the balloon on the end of the angioplasty catheter usually is met with some resistance as it is pulled into the sheath. The balloon location as observed fluoroscopically identifies the location of the sheath tip.

performing further dilatation is common practice. If a preocclusive stenosis cannot be crossed with an appropriately sized balloon because of the high profile of the catheter, a lower-profile balloon is required to create a space within the lumen. The balloon catheter should not be kept in the lumen for longer than necessary since the potential for thrombosis at the angioplasty site is high. If a stent is required, but the minimal remaining lumen prevents passage of the appropriate sheath or stent delivery catheter, predilatation is required. It is sometimes useful to perform predilatation of heavily calcified but critically stenotic arteries to assess how the lesion will respond to angioplasty. When the correct balloon size is not clear based on arteriography, predilatation with a smaller balloon is reasonable to assess more accurately the correct sizing of the artery diameter.

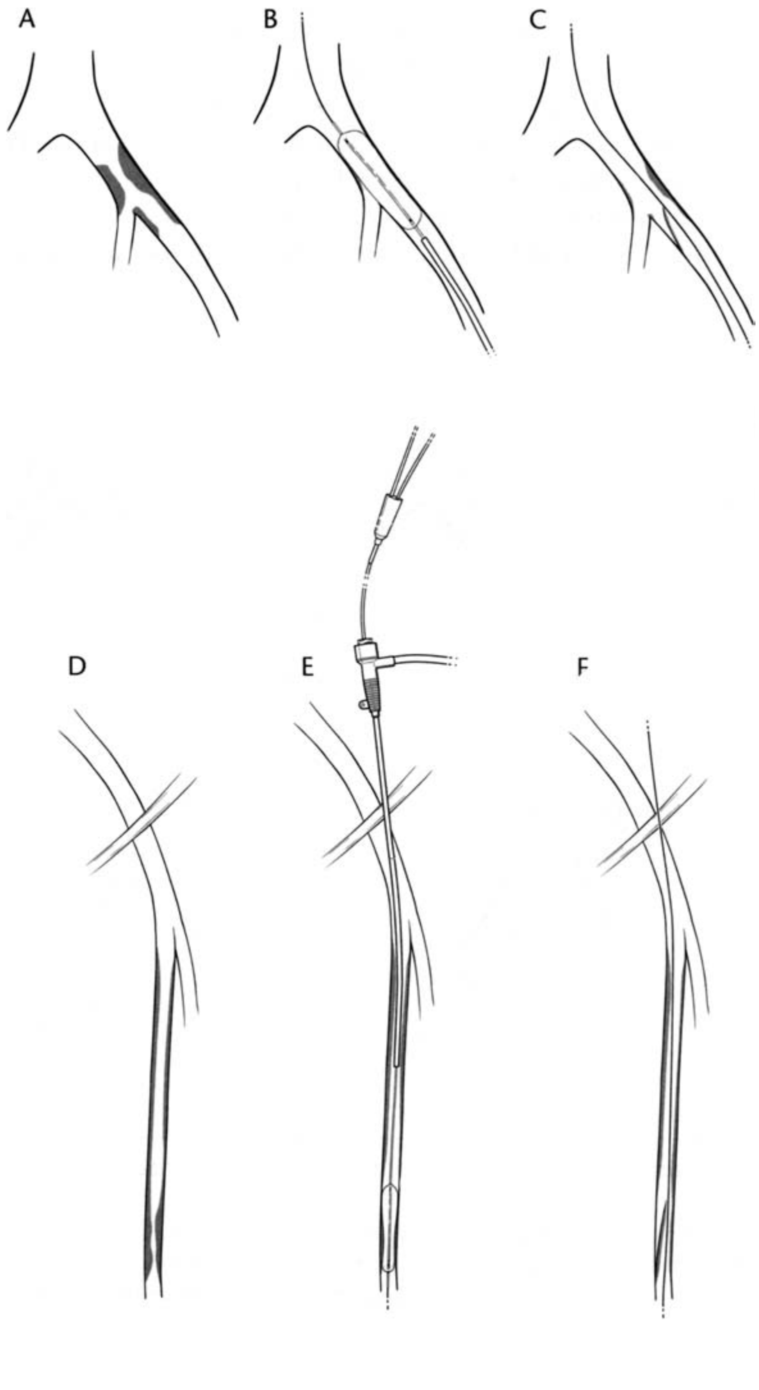
Which Lesions Are Most Likely to Embolize?

Embolization of clinical importance is not common after angioplasty but can be devastating. The incidence of embolization is minimized with appropriate anticoagulation, cautious passage of endovascular devices, and minimal manipulation of the lesion prior to definitive therapy. Some lesions pose a higher risk of embolization, including those that present with embolization, occlusions, lesions that are highly irregular or ulcerated, lesions that have fresh thrombus associated with them, lesions that are aneurysmal, and complex lesions located in the infrarenal abdominal aorta or the innominate artery. If the risk of embolization is high and endovascular treatment of the lesion is most appropriate, open arterial access and distal control of the outflow vessels should be considered. Primary stent placement or even placement of a covered stent may also be considered. If one of these lesions is being treated percutaneously, without outflow control, consider extra anticoagulation. Also, the outflow bed may be evaluated angiographically prior to removing the guidewire and sheath. If the lower extremities are the outflow bed, simple clinical evaluation may be useful.

Which Lesions Are Most Likely to Dissect?

Balloon angioplasty causes dissection. Thorough arteriographic inspection of a balloon angioplasty site usually reveals some evidence of dissection. Intravascular ultrasound will identify it more readily. Significant dissections may occur after balloon angioplasty of any artery. However, dissections tend to occur at branch points, in juxtaposition to very bulky or circumferential plaques, and in arteries with diffuse longitudinal plaque formation without natural cleavage planes, especially if the plaque is heavily calcified. The external iliac artery, especially near its origin, and the superficial femoral artery, especially at its origin and in the adductor canal, tend to dissect (Fig. 3). The aortic bifurcation, the common carotid artery, and the subclavian artery also share this propensity for dissection, although primary stent

Fig. 3 Arterial dissection after balloon angioplasty. A, A common iliac artery lesion extends into the proximal external iliac artery. **B,** Balloon dilatation is performed across the iliac bifurcation. The balloon may be oversized for the proximal external iliac artery, especially if the location of the bifurcation is not completely clear or if the size differential between the common and external iliac arteries is not appreciated. A contralateral anterior oblique projection should be used for angioplasty of this segment. **C,** A proximal external iliac artery flap is raised and it dissects distally. **D,** A superficial femoral artery stenosis is identified in the adductor canal. **E,** Balloon angioplasty is performed through an ipsilateral antegrade femoral artery approach. **F,** A significant dissection occurs at the angioplasty site.


A
B
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E
F

placement during treatment of these arteries is more common. Dissection may also occur as a result of inadvertent overdilatation of any artery.

Although dissection has been one of the feared complications of angioplasty in the past, the development of intravascular stents has made it possible to successfully treat postangioplasty dissection when it is recognized on the angiographic table. Nevertheless, it adds cost and needless excitement and, if dissection is not recognized or occurs at a later interval, it may cause acute failure of the procedure. Another benefit of stent availability is that a broader array of complex lesions may be considered for angioplasty, since a treatment option is available if the lesion is not adequately treated or is even worse after balloon angioplasty alone. This is discussed in greater detail in the next chapter.

Pain During Balloon Angioplasty

Discomfort is common at the angioplasty site during balloon inflation. This usually indicates stretching of the adventitia. When pain occurs, do not push the pressure in the balloon higher. Deflation of the balloon should be followed by an immediate resolution of discomfort. If pain continues, it could represent rupture or dissection. These possibilities should be immediately ruled out with a completion arteriogram. The management of arterial rupture is discussed later in this chapter.

What About Spasm?

Spasm is not a frequent clinical problem. However, a small minority of patients seem to be prone to spasm. Patients with atherosclerosis are less likely to develop spasm since arterial wall thickening and plaque formation tend to prevent it. Younger patients with nonatherosclerotic conditions are more likely to develop spasm. When one considers how often and aggressively endoluminal arterial manipulation is performed, it is amazing that spasm does not occur more often.

Spasm is not a clinical issue at the balloon angioplasty site. More commonly, it may be considered as a possibility in the outflow bed for an angioplasty site. If the operator is unable to visualize the end artery or outflow vessels, it may be poor technique, low flow, thrombosis, embolization, dissection, or spasm. Be sure that an adequate bolus of contrast was delivered and that the concentration was appropriate. Check to see if there are reasons for a low flow state. The usual setting where this comes up is in the course of an endovascular intervention when an area of the outflow can no longer be visualized or appears substantially different than the preintervention arteriogram. When this occurs immediately after balloon angioplasty and it involves the angioplasty site, it is probably dissection. Usually there is some evidence of trapped contrast in the few centimeters distal to the angioplasty site. If this occurs immediately after balloon angioplasty and involves a distant outflow bed, it is probably embolization and/or thrombus, especially if the angioplasty site looks technically well treated but flow remains slow. Spasm may be initiated by endovascular manipulation, even by just a guidewire, ischemia, or contrast administration. The arteries most prone to spasm include the distal internal carotid, axillary, renal and tibial arteries. Balloon angioplasty in these vascular beds often includes administration of a vasodilator, such as nitroglycerine. If spasm occurs, leave a guidewire across, but take off everything else you can, such as sheaths and catheters. Administer additional heparin intravenously and nitroglycerine into the treated artery.

PLAN OF ATTACK: Options for Treating Residual Stenosis After Balloon Angioplasty

Some residual stenoses do not require treatment. The degree of residual stenosis that may be acceptable is dictated by the clinical situation (Fig. 4). For example, a mild to moderate residual iliac artery stenosis may be acceptable after angioplasty of a critical lesion in a patient with rest pain and high surgical risk but not in a patient who also needs a femoral–tibial bypass for extensive pedal gangrene.

1. If the significance of a mild to moderate residual stenosis is not clear, measure pressure across the lesion. Proceed with other steps listed in Table 14 in Chapter 5 on assessing the results of balloon angioplasty.
2. If the atherosclerotic waist fails to resolve, repeat dilatation (up to several times) with the same-diameter balloon but to a higher pressure and with a longer expansion time.
3. If the initial balloon choice is unable to withstand higher pressures and it ruptures, use a high-pressure polymer balloon (up to 17 atm by label, which can be pushed above 20 atm).
4. Place a stent and perform poststent balloon angioplasty, especially if the residual stenosis exceeds 30%. Stent placement is now fast, reliable, and durable and it may be more efficacious to proceed to stent placement early, rather than struggle with a difficult residual stenosis and risk arterial rupture from overdilatation.

Preventing Puncture Site Thrombosis

Thrombosis at the access site is rare after arteriography since catheters are small in caliber and the indwelling times are short. However, this problem

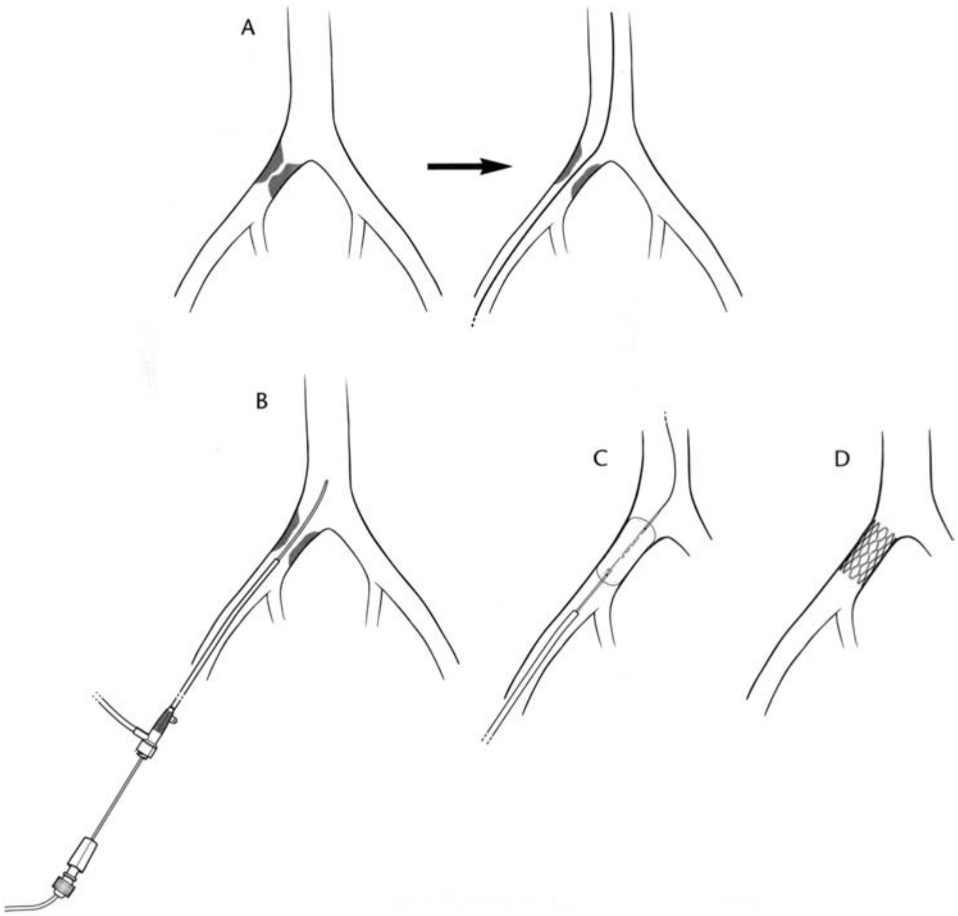

Fig. 4 Management of residual stenosis after angioplasty. A, A residual common iliac artery stenosis remains after balloon angioplasty. **B,** If the significance of the lesion is not clear, arterial pressure is measured proximally and distally to the lesion. The distal pressure is measured either through the straight catheter pulled down through the lesion or through the sidearm of the hemostatic sheath. **C,** Repeat dilatation is performed to a higher pressure using longer expansion times. **D,** A stent is placed at the site to treat the residual lesion.

is a little more common after endovascular therapy. When endovascular manipulation proceeds from strategic to therapeutic, the devices become larger, the length of time they are in the artery is longer, blood flow through the artery at the puncture site area may be altered by upstream endovascular intervention, and postprocedure hemostasis is more difficult after use of larger caliber sheaths. Avoiding puncture site thrombosis of the access artery during the angioplasty procedure relies upon skills learned in planning arterial access and in strategy for performing interventions (Table 1).

Table 1 Preventing Puncture Site Thrombosis After Endovascular Intervention

Palpate anatomy prior to puncture.
Duplex-scan the artery if uncertain.
Do not puncture an aneurysm.
Do not puncture a heavily calcified or critically stenotic artery.
Do not puncture the femoral bifurcation.
Use small-caliber catheters and sheaths.
Do not upsize the catheter or sheath if there is a critical lesion very near the puncture.
When pressure is held, do not stop flow through the artery.

Feel the artery. If it feels calcified or aneurysmal, perform a duplex evaluation. Access through a heavily calcified or critically stenotic common femoral artery is not advised. Do not puncture an aneurysm. Careful attention to anatomy and landmarks will assist the operator in avoiding a low puncture at the femoral bifurcation.

Access that is adequate for arteriography may not be satisfactory for endovascular therapy. If arteriography shows a critical lesion just distal to the location where the catheter goes into the artery, do not enlarge the arteriotomy with a sheath. Obtaining hemostasis later will be difficult without stopping flow altogether and risking thrombosis. Consider performing balloon angioplasty through an alternate access site.

After obtaining access, use the smallest-caliber catheters and sheaths that are adequate for the job. Arteriography can often be accomplished with 4 Fr catheters. Balloon angioplasty may be performed up to a diameter of 8 mm with a sheath of 6 Fr or smaller. Angioplasty of larger arteries or placement of stents usually require 7 to 9 Fr sheaths. Upsizing of sheaths is done after consideration since it also increases the risk of puncture site problems.

After sheath removal, when manual pressure is held to achieve hemostasis, flow through the access artery should be permitted to continue so that platelets deposit at the puncture site. If pressure is held too aggressively and flow is stopped, a puncture site thrombosis is more likely to occur.

Balloon Angioplasty Troubleshooting

Assessment of working room or distance between the arterial access site and the balloon angioplasty site is performed on every case. Long distances require that appropriate length guidewires and catheters are available (Tables 2 and 3 in Chapter 3). This is also discussed in greater detail in later chapters about angioplasty in specific arterial beds. Occasionally, working room is inadequate. Adequate working room requires that a standard 12-cm access sheath be able to fit between the puncture site and the lesion. If the tip of the sheath extends to the lesion, working room will not be satisfactory to pass catheters and perform interventions. Options include a percutaneous approach at an alternative location, an arterial cutdown at another location if percutaneous access is not possible, or proceeding with the same access site with the sheath partially withdrawn and well secured (Fig. 5).

Balloon rupture within the specified inflation pressure is possible when an attempt is made to dilate a sharp or heavily calcified lesion (Fig. 6). Occasionally, even after balloon rupture, a partial or complete dilatation of the lesion can be accomplished by exerting high pressure on the balloon. This allows the balloon to fill to the extent possible by overwhelming the leak. Usually, however, it is necessary to switch to a thicker and more puncture-resistant polymer balloon. The shoulder portion of the balloon often successfully dilates this type of lesion without rupture. The balloon is advanced in small increments and several inflations are required to dilate the entire lesion with the shoulder of the balloon. If the balloon ruptures again, placing a stent and dilating the lesion through the stent should be considered.

Occasionally, the nearly fully expanded balloon herniates past the resistant lesion, either proximally or distally, during an attempt to dilate (Fig. 7). This occurs more commonly during dilatation of intimal hyperplasia. Balloon herniation is observed using fluoroscopy. The balloon seems to pop out of the lesion just before it reaches its full, rounded profile. To minimize the likelihood of herniation, place the center of the balloon just beyond the center of the lesion, partially inflate the balloon to secure it, and then hold traction on the catheter shaft as inflation is completed. The balloon is held in place even though it tries to pop forward. Another option to prevent herniation is to use a longer balloon.

Dilating a lesion that is located adjacent to a large ulcer or an aneurysmal segment may be contraindicated by the increase in risk of embolization or rupture. If angioplasty is required in this setting, consider covering the entire segment with a stent or a covered stent. Open access for outflow control may also be a reasonable adjunct to prevent distal embolization.

Dilatation with a large (more than 10 mm) or compliant balloon is sometimes followed by an inability to empty contrast from the balloon in a timely manner because of an airlock. The balloon port should be aspirated with a large empty syringe (20 ml or larger) for a few seconds and the catheter and hub flicked with the finger to disrupt and mobilize any air bubbles. If the airlock remains, constant, high negative pressure is applied by withdrawing the plunger on the syringe and locking it in place with the plunger fully withdrawn and the syringe forming a vacuum. If negative pressure must be maintained during balloon catheter removal, a two-way stopcock may be placed on the syringe and closed with the syringe on full

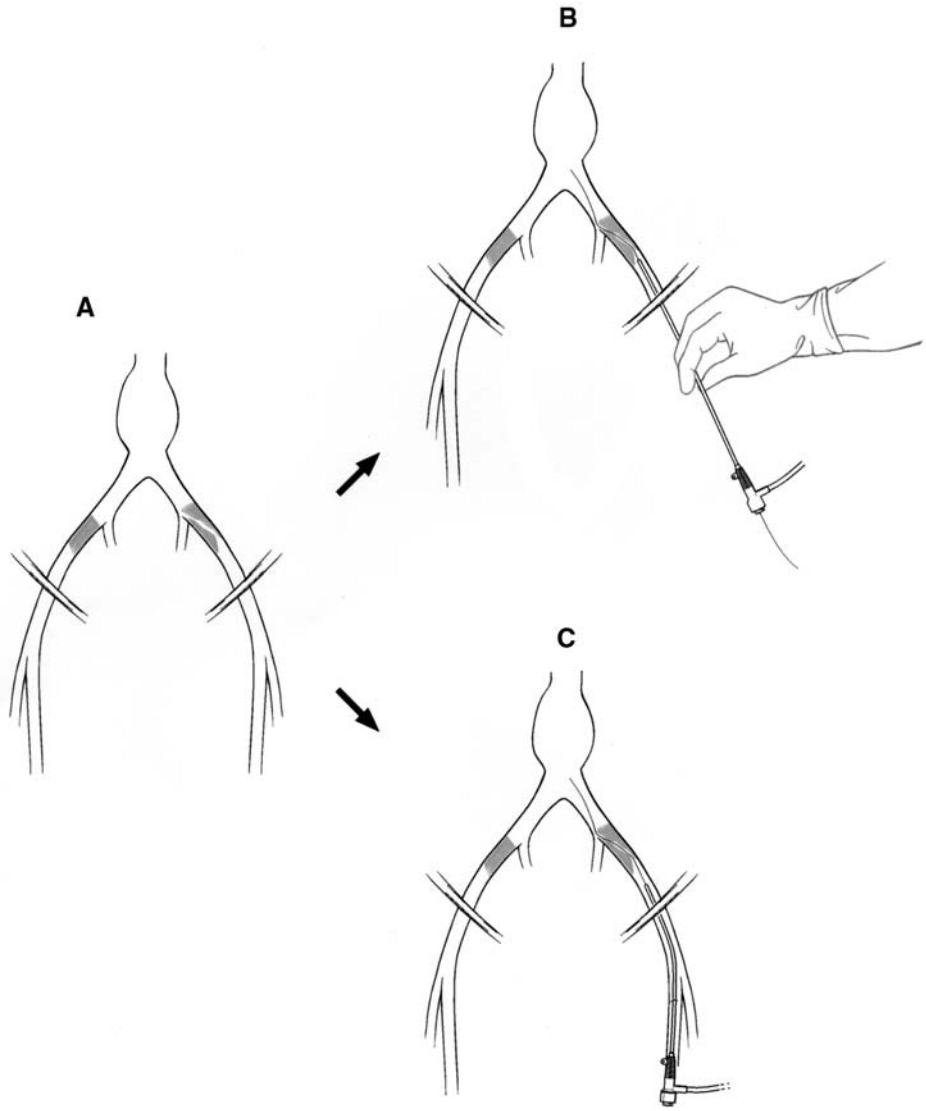

Fig. 5 Options for when working room is inadequate. A, In this example, working room between femoral access sites and the iliac lesions is inadequate. A proximal, transbrachial approach is an option but is suboptimal because it must be performed across an aortic aneurysm. **B,** Another option is to proceed with femoral access but to have the sheath only a few centimeters into the artery. If that option is chosen, the sheath must be secured so that it does not pop out at an inopportune time. One way to do this is to have an assistant secure the sheath. **C,** Another option is to create more working room by placing the sheath in the proximal superficial femoral artery, either percutaneously or through a cutdown.

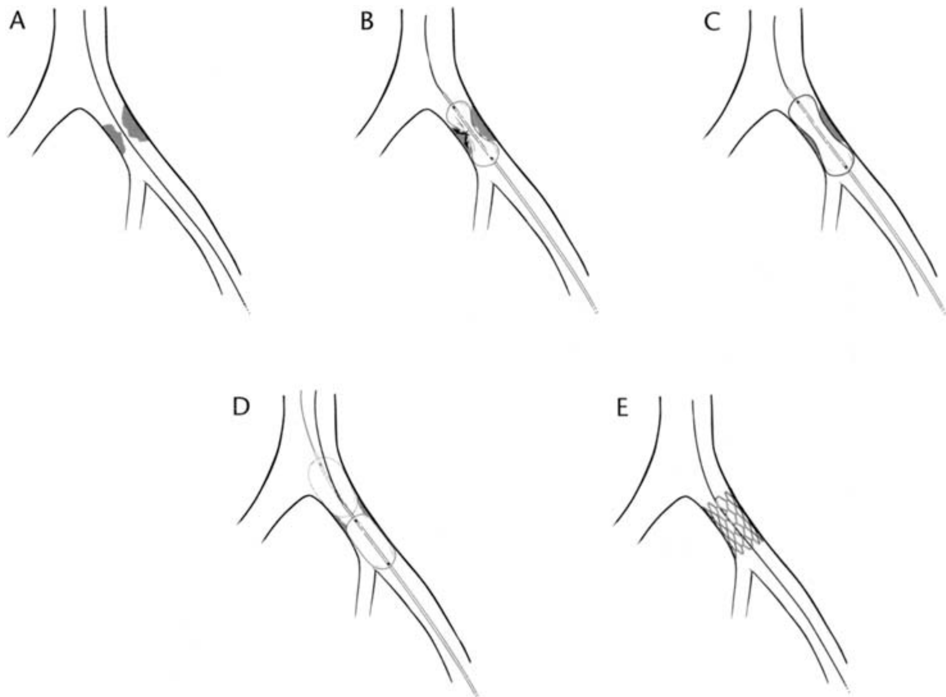

Fig. 6 Management when balloon ruptures on a calcified plaque. A, A guidewire is placed across a common iliac artery stenosis. **B,** The appropriately sized balloon is advanced into position but ruptures during inflation. Using fluoroscopy, contrast is seen extravasating from the balloon. Aspiration of the balloon port of the angioplasty catheter reveals bloody return fluid. **C,** A more puncture-resistant, polymer balloon is used to dilate the lesion, which may require a larger sheath to accommodate the shaft size. **D,** The lesion can also be dilated incrementally using the shoulder of the balloon, avoiding the sharpest part of the lesion until last. **E,** A stent can also be placed to dilate the calcified lesion. Occasionally, a sharp lesion perforates the balloon through the struts during placement of a balloon-expandable stent.

aspiration so that there is constant negative pressure. (Fig. 8). These maneuvers maintain a vacuum by preventing the plunger from sliding back into the body of the syringe.

TECHNIQUE: Solving Angioplasty Problems

1. Balloon catheter won't track along the guidewire. Exchange for a stiffer guidewire and/or insert a long sheath (see Fig. 4 in Chapter 4).
2. Balloon won't advance through lesion. Determine that the guidewire is intraluminal, predilate with a van Andel–tapered catheter or a low-profile (smaller-diameter) balloon. Do not force.

3. Balloon is unable to dilate residual atherosclerotic waist. Follow plan of attack outlined for residual stenosis after angioplasty (Fig. 4).
4. Balloon ruptures on calcified lesion. Use a thicker polymer balloon, dilate calcified portion with the shoulder of the balloon, or place stent and dilate (Fig. 6).
5. Balloon herniates past lesion during inflation. Apply traction to the catheter during inflation or use a longer balloon (Fig. 7).
6. Balloon won't empty after inflation (airlock). Apply continuous negative pressure with a large (20 ml or larger) syringe (Fig. 8).
7. Balloon can't be withdrawn into sheath. Rotate to fold wings and aspirate while applying steady traction.

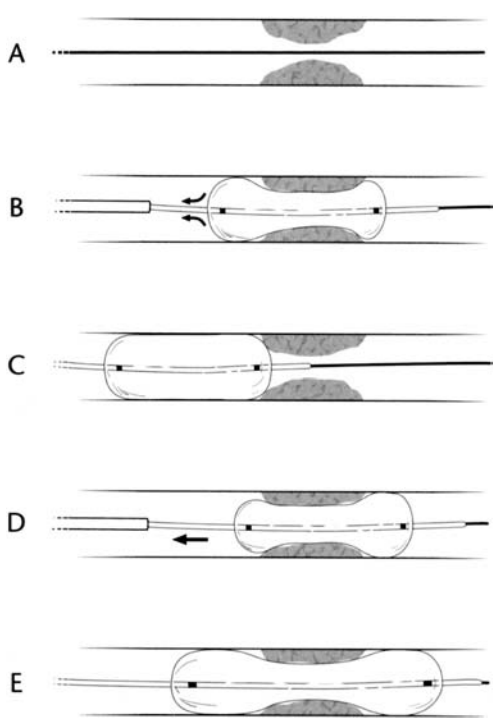

Fig. 7 Management when balloon herniates past the lesion during inflation. A, A guidewire is passed through a stenosis. **B,** As the balloon takes its shape, it begins to migrate out of the lesion. **C,** The expanded balloon pops out of the angioplasty site. **D,** The balloon catheter is deflated and advanced so that one radiopaque marker is well beyond the lesion. The balloon is reinflated while traction is applied to the catheter. As the balloon attempts to pop out of the lesion, it is held in place with manual traction. **E,** The catheter can also be exchanged for a catheter with a longer balloon.

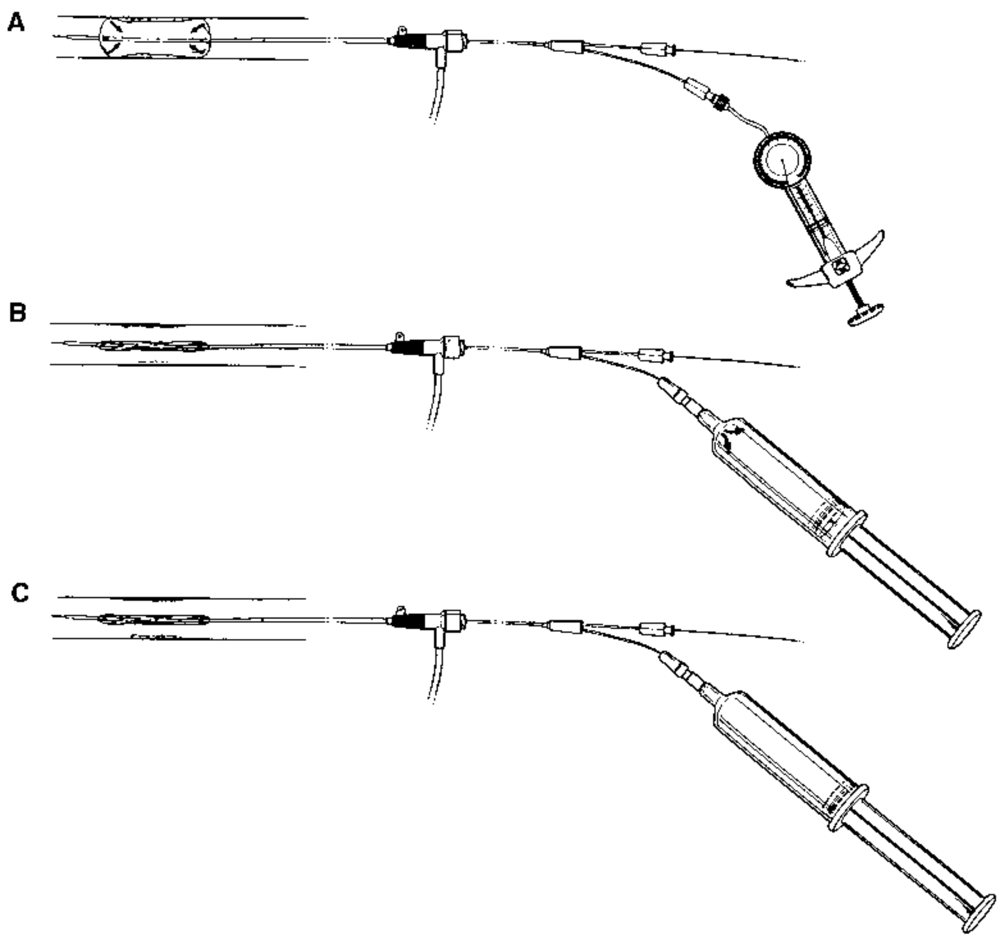

Fig. 8 Management when balloon will not empty or empties slowly. A, Aspiration of a large balloon may produce minimal emptying. **B,** A big, empty syringe generates more negative pressure. It is used to aspirate the balloon. **C,** Continuous aspiration can be achieved by drawing the plunger back to the rubber seal of the syringe and locking it in place.

Management of Arterial Rupture

Acute, sharp, or unremitting pain may indicate arterial rupture, and an immediate arteriogram should be performed. If arterial rupture has occurred, the best maneuver is to advance the balloon back into the location of the rupture site and inflate it completely (Fig. 9). This tamponades bleeding until emergency repair can be performed with either open surgery or a covered stent.

If the patient is heavily sedated, however, or if the procedure is being performed concomitantly with another operation and the patient is under

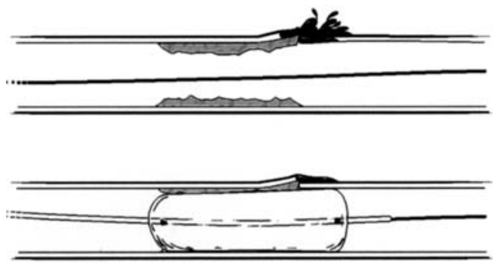

Fig. 9 Management of arterial rupture at the angioplasty site. A, A rupture occurs at the interface between hard, calcified plaque and the adjacent soft artery after angioplasty. **B,** The angioplasty balloon is reinserted and reinflated to tamponade the bleeding site.

anesthesia, pain may not serve as a warning sign. Following angioplasty, several minutes may pass before completion arteriography is performed. Hemodynamic instability in this setting should be considered a rupture until proved otherwise.

Any extravasation of contrast or vessel wall staining on completion arteriography is significant. Visualization of contrast extravasating through the arterial defect means that a high-flow rupture has occurred and that shock is only moments away. Contrast that has leaked beyond the confines of the vessel wall but appears to be stable may represent a contained rupture. A rupture after balloon angioplasty should not be stented because the stent is likely to reopen the incidental arteriotomy. This situation must be carefully distinguished from an acute local dissection, which is much more common and for which a stent is often indicated.

Rupture of the superficial femoral artery, popliteal artery, or tibial artery is much less likely to cause life-threatening hemorrhage and more often results in acute occlusion. Some localized ruptures heal or form chronic pseudoaneurysms. If a rupture occurs in the infrainguinal arteries, wait several minutes and repeat an arteriogram. If the artery remains patent and the extramural hematoma is not expanding, surgery may not be required.

The most common cause of postangioplasty arterial rupture is overdilatation. Rupture is rare if simple guidelines are followed:

Carefully consider the diameter of the chosen balloon prior to usage.
Double-check that the correct balloon is being advanced, especially if multiple different-sized catheters have been opened for the case.
Accept a decent result; don't be greedy about obtaining a cosmetically perfect completion image.
Know when to quit (or when to convert to surgery) if the limit of endovascular capability has been reached.

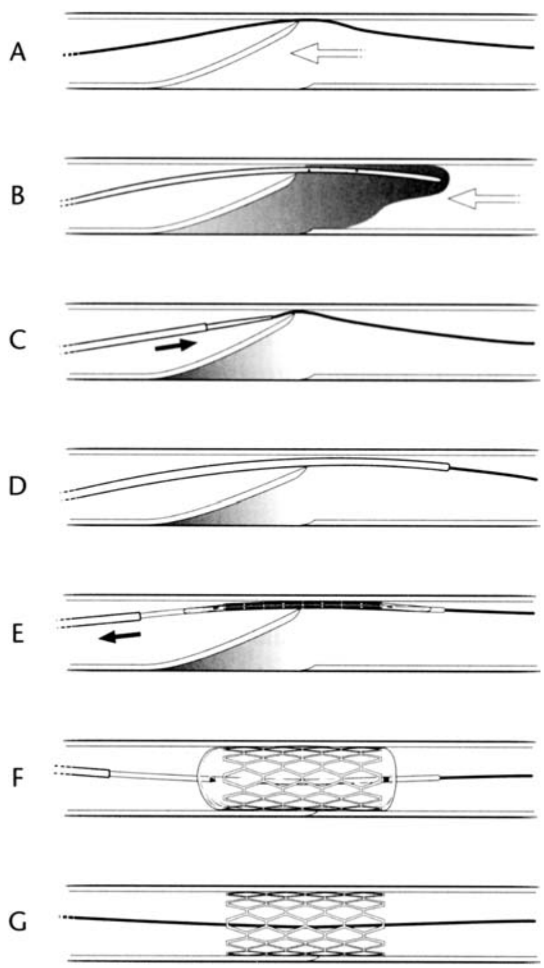

Fig. 10 Management of acute occlusion at the angioplasty site. The most common cause of acute occlusion after angioplasty is dissection. **A,** A dissection flap is raised at the angioplasty site that occludes flow. **B,** A catheter is passed over the guidewire and limited arteriography is performed. **C,** A sheath and dilator are passed over the guidewire. **D,** The dilator is removed. **E,** An angioplasty balloon with a Palmaz stent is passed through the sheath and the sheath is withdrawn. **F,** The balloon is inflated to deploy the stent at the site of the dissection. **G,** The dissection flap is tacked down by the stent.

Conditions treated with balloon angioplasty are rarely, if ever, life threatening but arterial rupture is one complication that may result in death. Ruptured arterial segments should not be treated with stents, but covered stents may obviate the need for emergency surgery in some cases.

Management of Embolization

Clinically significant postangioplasty embolization is unusual but may result in organ or limb loss. In some angioplasty cases, the patient starts off with one problem (the lesion) and ends up with two problems (a partially treated, possibly unstable, upstream lesion and an ischemic or occluded outflow bed). Embolization may present as filling defects at some location distal to the angioplasty site or as pain experienced by the patient in the outflow vascular bed. If this occurs, the following steps should be taken.

Administer a fully anticoagulating dose of heparin.
Maintain any guidewire that is in the distal affected vascular bed.
Inspect sheaths that are already in place. Aspirate and flush.
Initiate intra-arterial heparin drip through the sheath.
Administer vasodilators.
Consider the cause. Is the embolus from the angioplasty site or the access site or is it due to thrombus formation from low flow?
Stabilize the angioplasty site as soon as possible. This usually means stent placement.

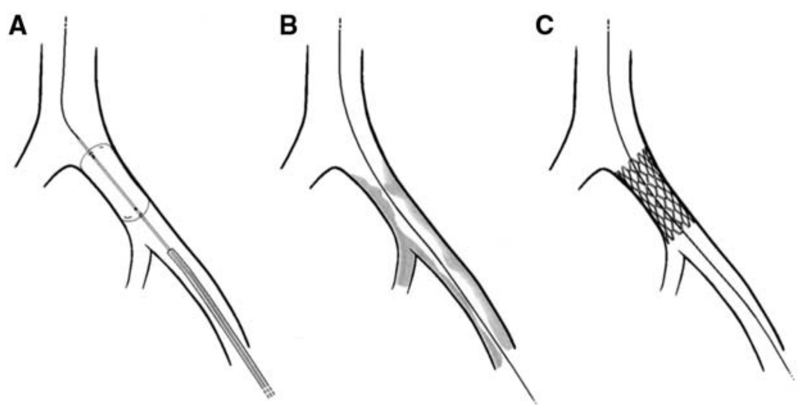

Fig. 11 Stent placement after dissection. A, Balloon angioplasty of a focal, mid–common iliac artery lesion causes a dissection. **B,** The dissection is identified by the appearance of contrast retained in the arterial wall, flow streaming effects through the lumen, and extension of abnormality well beyond the original lesion. Guidewire access is carefully maintained. **C,** Stent placement at the original angioplasty site usually closes the false channels.

Place a multi-side-hole catheter distally into the affected outflow bed and perform a local arteriogram. Administer tissue plasminogen activator, 1 mg as a pulse spray over 10 min.
Repeat arteriogram.
If continued filling defects, continue tissue plasminogen activator at 1 mg per hour.

Management of Acute Occlusion

An acute occlusion at the angioplpasty site that occurs immediately after balloon angioplasty and is apparent on the completion arteriogram is usually caused by dissection (Figs. 10 and 11). The guidewire, left in place during completion arteriography, is exchanged for a stiff guidewire. A stent is placed at the same site where the balloon angioplasty was performed to tack down the dissection flap that has been elevated and propagated from the angioplasty site. After the placement of a single stent, arteriography usually demonstrates patency. If necessary, additional stents are placed distally and proximally to the first stent until patency is achieved.

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Stents

Endovascular Repaving

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Impact of Stents

Vascular stents have made it possible to repave the inner lining of a diseased artery. Stents have had a major impact on the development of endovascular surgery that is manifested in four ways.

1. The complications of balloon angioplasty, such as dissection and residual stenosis, may be immediately treated.
2. Lesions that otherwise would have required open surgery, such as occlusions or long lesions or recurrent stenoses, may be treated with endovascular surgery. This is particularly appropriate when it provides an additional option for the treatment of patients who are at high risk for open surgery.
3. The overall spectrum of arterial lesions that can be approached with endovascular techniques has broadened dramatically. Whether or not a particular lesion ultimately requires stent placement, the availability of stents has permanently altered the general approach and the consideration of options.
4. Combining stents with graft material to create stent–grafts has permitted the endovascular treatment of aneurysm disease.

Each stent application has its own cost and complication risks. The sheath must usually be upsized, a foreign body is implanted, the procedure time is often extended somewhat, and stents have their own unique complications. In addition, the cost of a single stent substantially increases the cost of an endovascular intervention. The placing of stents may be motivated by the wish to extend the short- or long-term success of balloon angioplasty, to avoid surgery, or to avoid repeat balloon angioplasty, but should be considered in each case. Future applications of stents may include further miniaturization and the ability to release antithrombotic agents, emit irradiation, or prevent intimal hyperplasia through bioengineering design changes.

Stent Choices

Stents are either balloon-expandable or self-expanding. The main characteristics of these two types of stents are listed in Table 1. These two categories are best exemplified by the stents currently being used in the United States that have been approved by the FDA for some peripheral endovascular indications: the Palmaz stent and the Wallstent (Fig. 1). (Federal Food and Drug Administration [FDA] approval has been granted for limited peripheral vascular uses of the Palmaz stent and the Wallstent. Current approved uses of stents should be confirmed by specialists performing these procedures.)

Table 1 Stent Characteristics

Balloon-expandable stent	Self-expanding stent
Slotted-tube design	Wire mesh or slotted tube
High radial force	Low radial force (oversize for vessel)
Rigid	Flexible
Most functional at short lengths	Longer lengths very functional
Premounted, or mount onto balloon of choice	Delivery catheter with covering sheath
Some shortening with expansion	Variable shortening; some do not shorten
Steel or stainless steel	Nitinol or light metal alloy
Moderate radiopacity	Poor radiopacity (some have markers)

The Palmaz stent (Cordis, a Johnson & Johnson Co., Miami, Fla.) is a straight, metal, rigid, balloon-expandable cylinder. The stent is crimped onto a standard angioplasty balloon and is deployed when the balloon is inflated. The rigid Palmaz stent has excellent hoop strength but can be crimped by external forces. These stents perform best when placed in locations that have no mobility, such as the renal artery orifice. Balloon-expanding stents perform best when they are relatively short in length since they are rigid. These stents also shorten somewhat as they expand in diameter. Most renal artery stents are between 1 and 2 cm, and most iliac stents are 3 to 4 cm. These are the places where Palmaz stents are most useful. The medium Palmaz stent can be expanded from a diameter of 4.0 mm to 9.0 mm and the large stent can be expanded from 8.0 mm to 12.0 mm. An aortic stent is also available that can be expanded to more than 2 cm in diameter.

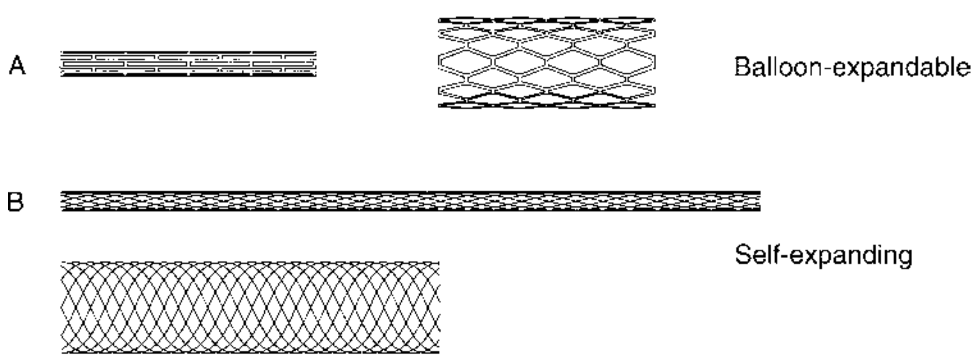

Fig. 1 Stent choices. A, The rigid, stainless steel, balloon-expandable Palmaz stent is crimped onto an angioplasty balloon and deployed by balloon inflation. **B,** The self-expanding, wire mesh Wallstent is deployed by passing the delivery catheter over a guidewire and withdrawing a covering sheath.

The Wallstent (Medi-Tech, Natick, Mass.) is a flexible, self-expanding, wire mesh tube that is deployed by retracting a covering sheath. Self-expanding stents are packaged on their own delivery catheters. Wallstents are intentionally oversized at the time of deployment in the artery, usually by 2 to 3 mm, and they maintain continual outward radial force after deployment. They are not as susceptible to damage from external forces since they are more flexible, but they have much less hoop strength. The Wallstent may be moved after deployment begins or even reconstrained and removed if not yet fully deployed. Wallstents cover more distance but they are more difficult to place with great accuracy since they foreshorten significantly based upon the final resting diameter achieved. Several other self-expanding stents are now available, mostly of Nitinol construction, that do not shorten significantly at the time of placement.

Self-expanding and balloon-expandable stents tend to play complementary roles. Deciding which type of stent to use may be somewhat subjective from one practice to another, but endovascular specialists must become facile with the use of each of these two general stent types. In addition, there are numerous other stents, both balloon- and self-expanding, that are available but are not approved for vascular usage (Table 2). Some of these add further options of interest. The Smart stent (Medi-Tech) is a self-expanding Nitinol stent. It does not foreshorten when deployed, the way the Wallstent does. Its radiopacity is poor but markers have been added to the ends to help visualize the stent during positioning. Because it is Nitinol, a larger stent (up to 12 mm diameter) may be placed through a 7 Fr sheath. The Corinthian (Cordis) and AVE (Medtronic) stents are balloon-expandable stents. However, they contain less metal than the original Palmaz stents.

Table 2 Some Stents on the Market[a]

Type	Stent	Manufacturer
Balloon-expandable	Bridge Stent, extra support	Medtronic AVE
	Bridge stent, flexible	Medtronic AVE
	Herculink	Guidant
	Megalink	Guidant
	Palmaz[b]	Cordis
	Palmaz-Corinthian	Cordis
	Perflex	Cordis
Self-expanding	Luminex	Bard
	Memotherm	Bard
	SMART	Cordis
	Symphony	Boston Scientific
	Wallstent[b]	Boston Scientific
	Zilver	Cook

[a] Many other stents are available that are not included here.
[b] Approved by the FDA for limited use in the noncoronary vasculature.

They have more articulations and excellent hoop strength once they are deployed and they are simpler to place.

Indications for Stents: Primary or Selective Stent Placement

The key difference between primary and selective stent placement is that with primary placement the operator knows ahead of time that a stent will be placed versus the selective approach where the operator must decide during the procedure. The concept of primary stent placement presupposes that the patient is better off with a stent, regardless of the results of treatment of the lesion with balloon angioplasty alone. The operator places a stent at each site of intervention, without first performing a balloon angioplasty to see if this would be adequate treatment. This approach appears to work best for some lesions that were treated with balloon angioplasty alone in the past with marginal to mediocre results, including recurrent lesions, occlusions, orifice lesions, and others. Primary stent placement has made endovascular intervention a very reasonable option in some areas of treatment, such as for renal artery origin lesions. This approach has also been advocated for carotid bifurcation and aortoiliac occlusive disease. The idea behind primary stent placement is that the short and/or long-term results are generally improved with stent placement to the point where it justifies the up-front increase in risk and cost. Taken to its fullest extent, however, every lesion in every patient would receive a stent, and this would be expensive and unnecessary.

Selective stent placement assumes that the cost and risk of stent placement are not justified in every case and that not every patient requires a stent to have acceptable treatment results. Balloon angioplasty was widely practiced for more than 15 years before stents became available. This experience yielded reasonable long-term results with balloon angioplasty for many aortoiliac, infrainguinal, nonorifice renal lesions and some upper-extremity lesions. Balloon angioplasty is performed. The results are assessed. If the results are not acceptable, stent placement is performed. Indications for selective stent placement after balloon angioplasty include residual stenosis, a persistent pressure gradient, and significant dissection.

The indications for stents have expanded steadily since they became available. Endovascular specialists have become more adept at placing stents, and the development of new stents and simpler ways of placing them have assisted in this process. Each stent added to the mix in a given case brings the entire process closer to a point of diminishing returns. The temptation with stents is to continue to lay them in place until the entire arterial tree appears to be perfect. The "stack o' stents" phenomenon should be avoided.

Which Lesions Should Be Stented?

Although each specialist must decide what the appropriate level of stent placement aggressiveness is, there are specific situations where stents are useful.

Postangioplasty dissection. Stent placement should be considered for any significant dissection after angioplasty, even if there is no gradient. Because plaque fracture is the mechanism of angioplasty, some degree of dissection is common. Unfortunately, there is no good method of assessing the severity of dissection or predicting its behavior (Fig. 2). As a result, many postangioplasty dissections that would have healed spontaneously in the past are currently not being given that opportunity and are stented immediately after balloon angioplasty. Stents should be placed for any false channel or for any intimal flaps that impede flow, increase in size during the procedure, or extend into a previously uninvolved segment of artery.

Residual stenosis after angioplasty. Residual stenosis can usually be resolved with stent placement. The concept of preventing recurrence by eliminating residual stenosis makes empiric sense. A 30% postangioplasty stenosis is used as a general threshold for continued intervention, although there is no convincing justification for using this particular degree of stenosis.

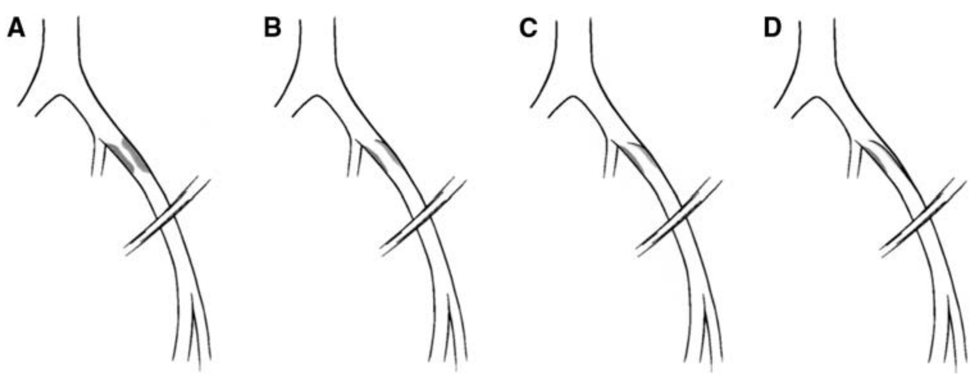

Fig. 2 Degrees of dissection after angioplasty. A, An external iliac artery stenosis is treated with balloon angioplasty. **B,** Angioplasty creates separations between the intima and media that are demonstrated by completion arteriography as small dissection flaps. **C,** A more prominent dissection flap may not impede flow but does protrude into the lumen. Stent placement should be considered. **D,** Dissections that impede flow, lengthen during the procedure, or extend into an adjacent nondiseased segment of artery should be stented.

Pressure gradient. A pressure gradient (more than 10 mm Hg systolic) after angioplasty usually indicates a residual stenosis or dissection that requires treatment. Again the threshold for treatment is somewhat arbitrary.

Recurrent stenosis after angioplasty. Treating recurrence with stent placement after previous angioplasty is an empiric approach with reasonable results.

Occlusion. Balloon angioplasty alone for occlusions has only fair results and these may be improved with stent placement. Stent placement may make the procedure safer by stabilizing residual thrombus that could embolize from the lesion site.

Embolizing lesion. Stent placement at the site of an embolizing lesion is thought to trap the embologenic plaque and prevent further embolization

Table 3 Which Lesions Should Be Stented?

Indication	Rationale	Reality
Postangioplasty dissection	Prevents acute occlusion	Makes angioplasty safer because dissection can be managed without emergency open surgery. More complex lesions can be treated with angioplasty. Which dissections need stents is unknown. Most dissections healed without stents in the past.
Residual stenosis after angioplasty (> 30%)	Causes early failures and late recurrence	Makes empiric sense but there is little proof. Mild residual stenosis may not cause harm. Moderate residual stenosis (>50%) can almost always be resolved with stent placement.
Occlusion	Poor results with angioplasty alone	Better short- and long-term results with stents. Avoids open surgery in most patients with iliac occlusion.
Recurrence	Limited success of primary angioplasty	Repeat angioplasty alone has reasonable results in iliac artery. Makes empiric sense but there is no proof.
Long lesion	Not sure	More likely to dissect after angioplasty. Looks better with stents.
Embolizing lesion	Cages and compacts the embolic material	Makes sense and there are reports of success. Be certain it is not an aneurysm. Control outflow during procedure.
All lesions (primary stent placement)	Extends long-term results	Looks great. Provides excellent opportunity to practice stent placement. Unclear if long-term results justify the upfront cost and complications.

during intervention. Because embolizing lesions are often soft, care must be taken during guidewire and catheter crossing. The lesion must also be evaluated to be certain it is not an aneurysm.

As experience is gained with stents, indications for their placement have been continuously modified (Table 3). Other relative indications include a significant ulceration, a long lesion, or a highly irregular, calcified plaque.

The location of the intended angioplasty site affects the likelihood of stent placement. Since most atherosclerotic renal artery lesions are aortic plaque that has spilled over into the renal artery, stent placement is usually necessary to resolve these stenoses. It is not yet clear whether carotid bifurcation balloon angioplasty will be durable but stent placement appears to be safer than angioplasty alone in that location, possibly because these are primarily embolizing lesions. Aortoiliac angioplasty is fairly durable without stents, and stents can be used selectively with reasonable results. Infrainguinal angioplasty is not as durable and stent placement offers no improvement in long-term results.

Placement Technique for Balloon-Expandable Stent (Palmaz)

The selection of diameter is an important decision in the placement of balloon-expandable stents. The stent size is selected based on the anticipated diameter of the reconstructed artery. If the selected stent is too small in diameter, it may not adhere to the vessel wall after deployment and could migrate. The balloon must be rapidly exchanged for a larger one, which will upsize the stent. If the stent is too large, it will overstretch the artery and may cause rupture, and it is not retrievable once it is deployed. If selective stent placement is performed, the inflated balloon profile from the initial angioplasty may be used to size the artery. When primary stent placement is performed, sometimes it is necessary to dilate the lesion with the balloon alone to size the lesion. Medium stents can be dilated up to 9 mm and large stents up to 12 mm. Either type can be dilated 2 mm further, but as the diameter increases, the length decreases. The shortest stent that covers the lesion (usually 1 to 4 cm) is crimped onto an angioplasty balloon between the radiopaque markers. Longer balloon-expandable stents are available (up to almost 8 cm) but there are disadvantages to the rigidity of these stents over longer distances. They do not conform to any tortuosity or any change in vessel diameter along the length of the stent.

The balloon chosen for deployment must be the same length or longer than the stent. If it is the same length, mount the stent directly between the radiopaque markers. If the balloon is longer than the stent, it should not be more than a centimeter longer. The stent should be mounted so that the end of the stent is on either the proximal or distal radiopaque marker on the balloon, so that its location is known when it is time for deployment. Vigorous crimping with the thumb and forefinger secures the stent without bending it. The stent should not be able to slide on the balloon unless firm traction is applied. Test the adherence of the stent to the balloon, but do not slide the stent back and forth on the balloon because the sharp end of the stent can pierce the balloon. Mounting of the stent on the balloon is best performed prior to advancing the sheath across the lesion so that the stent is ready for deployment. Each of the major endovascular companies make a puncture-resistant balloon that is designed for stent delivery. A medium Palmaz stent requires a 7 Fr sheath and a large stent is placed through a 9 Fr sheath.

The appropriate sheath and dilator combination is passed through the lesion (Fig. 3). If the lesion has a residual lumen of less than the diameter of the sheath (for a 7 Fr sheath it is about 2.3 mm), the lesion should be predilated or the sheath and dilator will dotter the lesion. The sheath must be of adequate length to pass from the skin entry site through the lesion. A radiopaque tip on the sheath is useful so that it is always clear where the sheath tip is located relative to the lesion. The dilator is removed and the sheath is flushed. The sheath will stop or impede blood flow, since it occupies the remaining lumen at the site of the lesion. If there is any question about the exact location for stent placement, a repeat arteriogram should be performed prior to sheath placement. The balloon catheter, with the stent crimped into place, is passed over the guidewire and into the sheath. A customized metal cannula may be used to temporarily open the hemostatic valve on the sheath. This cannula comes in the package with the stent. However, the stent may also be passed through the hemostatic valve by hand. Grab the balloon–stent with a pincer grasp at the end of the stent that is farthest from the valve and push the balloon and stent through the valve. Using fluoroscopy, the balloon and stent are passed into the appropriate location. Check the balloon while it is still in the sheath using a magnified field of view to visualize the stent on the balloon and ensure it is still located where it was crimped on the balloon. The sheath is withdrawn, exposing the balloon and stent. A sheath with a marker at the tip is very useful in this circumstance. Before deployment, it is important to make sure that the stent is still in the correct place on the balloon and that it is well positioned to cover the lesion. The balloon is then inflated to expand the stent. The stent should be slightly overdilated to embed its metal struts into the plaque.

Palmaz stents expand to an hourglass shape with the proximal and distal ends flaring initially and the middle portion of the stent filling out at the completion of the balloon inflation. The proximal or distal end of the stent is

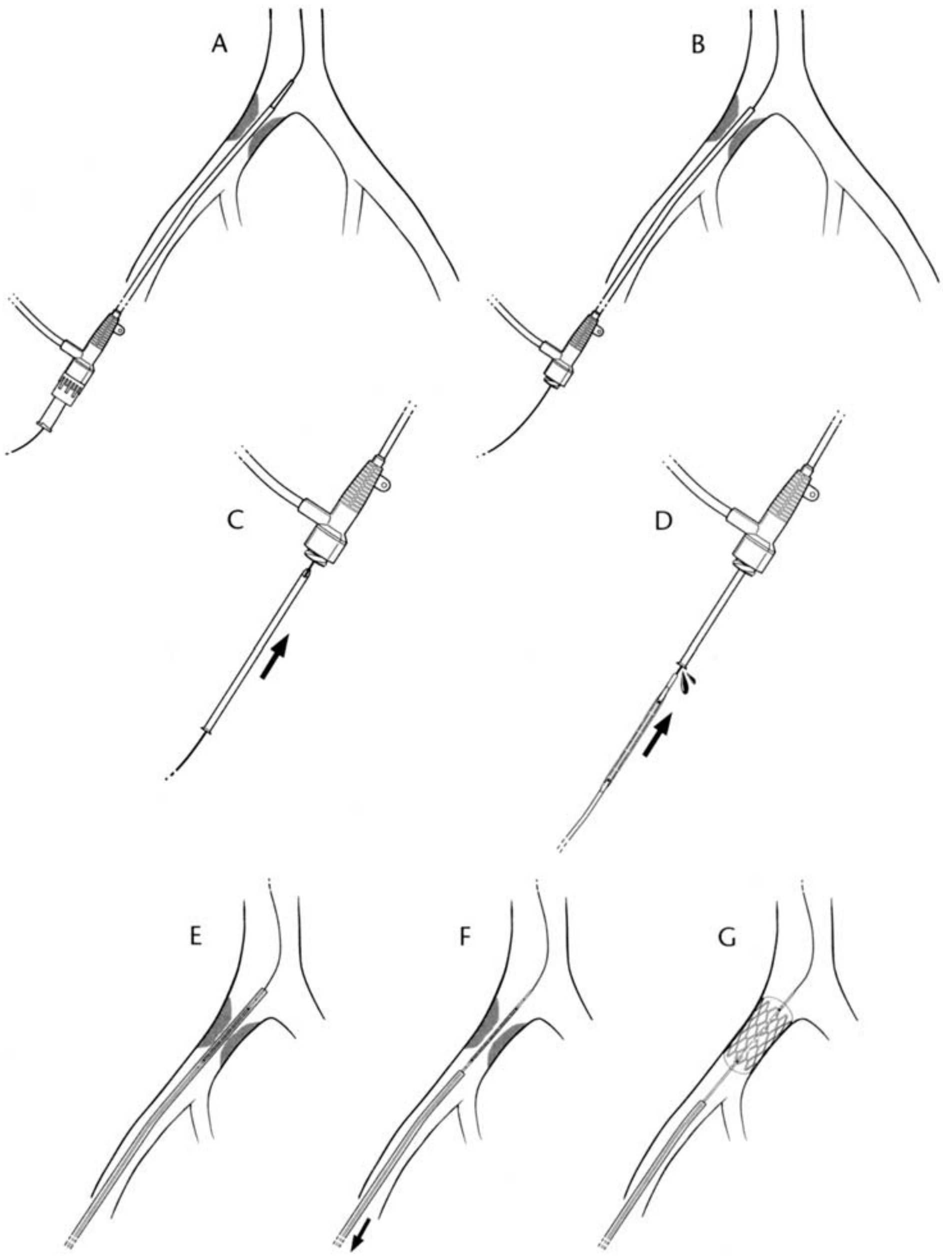

Fig. 3 Placement technique for palmaz stent. A, The dilator and sheath are advanced through the lesion. **B,** The dilator is removed, leaving the sheath across the stenosis. **C,** A metal introducer with a beveled end opens the hemostatic valve on the head of the sheath. **D,** The stent is mounted on the balloon and crimped into place between the radiopaque markers. The balloon and stent are advanced through the metal introducer and into the sheath. **E,** Using fluoroscopy, the stent is placed at the desired location within the lesion. **F,** The sheath is withdrawn to expose the stent. **G,** The balloon is inflated to deploy the stent.

often only partially dilated into an oval shape, which is not always apparent on completion arteriography. The balloon is deflated after the stent has been fully deployed. The balloon is advanced slightly and reinflated so that the proximal end of the stent is fully dilated. This maneuver is repeated on the distal end of the stent.

Precise stent deployment is challenging. The stent may be difficult to visualize in larger individuals, especially if it is in a location with a lot of ventilatory motion. A difference in location of a few millimeters may be the difference between perfect placement and a misplaced stent. Bony landmarks may be useful, especially the vertebral bodies or some identifiable vascular calcification. If there are no suitable landmarks, use an external marker, such as a stent guide. This is an adherent, radiopaque measuring tape that can be placed on the patient parallel to the guidewire. These are particularly useful when treating longer lesions. Be cautioned that external markers are susceptible to parallax error if the field of view is modified. They are also in error if there is any change in angle of view, any catching of the tape on the image intensifier, or any significant ventilatory motion. When you use external markers, recheck the lesion before you deploy the stent. Road mapping may also be used for deploy stents but the image degrades with time and motion.

A method for precise placement of balloon-expandable stents is as follows. Position the image intensifier and set the field of view in a manner that provides the best view of the lesion. A smaller field of view, such as a 6-in. field, is often best since it provides magnification. Choose bony landmarks or place external markers. Perform an arteriogram. Once the image intensifier is positioned, do not move it until after the stent is deployed. Transfer the best image onto the save monitor and use it as a guide during live fluoroscopy. After the stent is in place across the lesion, but before it is deployed, if there is any doubt about correct placement, puff contrast through the sheath to reconfirm the position.

Guidewire control must be maintained across the stent until the reconstruction is complete. If additional stents are required, the dilator is placed back through the sheath and the dilator and sheath combination is advanced into the appropriate position. If numerous overlapping stents are required, the distal stent is placed first and built proximally to create a "telescope" effect (Fig. 4). If dilation to a larger diameter is required, the deployment balloon is exchanged. A Palmaz stent can be dilated to a slightly larger size on one end if necessary to match vessel size and taper.

A completion arteriogram is performed by placing the tip of the sheath at the distal end of the stent and injecting contrast so that it refluxes through the area of stent placement. Another option is to place a 5 Fr straight catheter through the sheath, over the guidewire, and position the tip of the catheter

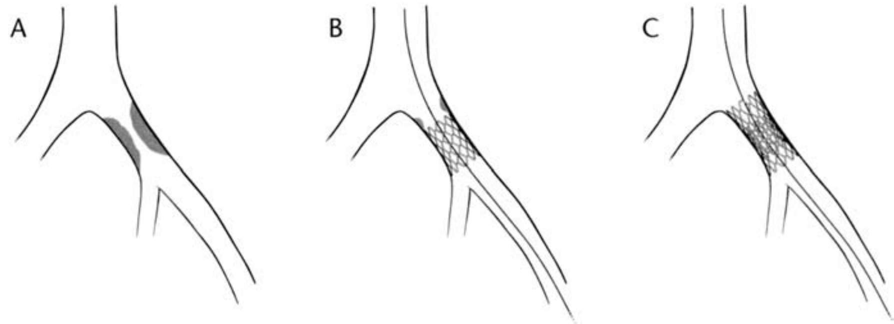

Fig. 4 Telescope effect using Palmaz stents. A, A long iliac artery stenosis requires more than one Palmaz stent for coverage. **B,** The distal stent is placed first. **C,** The second stent overlaps the first and fits inside to create a telescope effect. This technique avoids a prominent metal edge protruding into the flow stream.

at the location proximal to the stent. A 4 or 5 Fr flush catheter may also be placed in the same manner and positioned upstream from the stent site.

Placement Technique for Self-Expanding Stent (Wallstent)

Self-expanding stents must be oversized by 1 to 3 mm so that they exert continuous outward radial force at the site of deployment. Placing a stent that is too small in diameter is to be avoided since these stents cannot be dilated beyond their maximum list diameter. If there is doubt about the appropriate diameter stent to use, consider balloon angioplasty first with an evaluation of the inflated balloon profile. Placement of a self-expanding stent is performed by withdrawing a covering sheath that encloses the stent on a prepackaged catheter. The prepackaged stent delivery catheter is placed through a 7 or 9 Fr sheath, as recommended by the manufacturer. Stent length choice varies significantly from one stent type to another. Self-expanding stents are manufactured in multiple lengths, from 20 to 100 mm in fully expanded form. However, Wallstent length changes significantly at deployment depending upon the final resting diameter, whereas many of the other self-expanding stents do not.

The constrained length of the Wallstent (in the package) is longer than the deployed length (partially constrained by the artery), which in turn is longer than the stent would be if it were to be completely expanded (unconstrained). For example, a 10 × 42 Wallstent (10-mm diameter × 42-mm length) placed in a 9-mm iliac artery is 50 to 52 mm long after deployment.

The Wallstent in practice is never completely expanded, since it is oversized for the artery into which it is placed.

The Wallstent catheter is removed from its package, flushed, and wiped with heparin–saline solution. The end stopcock is closed and the catheter is advanced over the guidewire (Fig. 5). Because the apparatus is somewhat flexible, it can be passed over the aortic bifurcation. The stent is marked by radiopaque markers on its proximal and distal ends, which are observed using fluoroscopy. To deploy the stent, the metal pushing rod is held steady and the valve body is withdrawn, which removes the covering membrane. Fluoroscopy is used because it is easy to move the stent with minimal force. As the metal pushing rod is held stationary and the valve body is withdrawn, the proximal end of the stent begins to expand. The position of the stent is continually assessed. Before 50% of the stent has been deployed, it can still be moved (dragged) more distally, if necessary. There is also a reconstrainable Wallstent that can be pulled back under the covering membrane if needed during the deployment process. The valve body is withdrawn completely to fully deploy the stent. Most of the self-expanding stents are deployed in a similar manner: holding a pushing rod in a stationary position while withdrawing the covering membrane and allowing the stent to expand.

It is best to have an assistant hold the access sheath during deployment. Any withdrawal of the catheter for placement accuracy will also tend to pull the sheath out. After stent deployment, the delivery catheter is removed and balloon angioplasty is performed of the length and ends of the stent, especially in sections where there is residual crimping of the stent by the lesion. It is sometimes difficult to assess whether the stent is fully expanded. When balloon angioplasty is to be used within the Wallstent, the central part of the stent is dilated first. The ends of the stent are dilated last because the tines of the stent may rupture the balloon.

The guidewire is maintained across the stented segment until after satisfactory completion studies are performed. Completion arteriography is performed in the same manner as with balloon-expanded stents. If guidewire control of the stent is relinquished prematurely, advance a J-tip or very floppy tip guidewire back through the stent using a small field of view for magnification. This is done to avoid passing the guidewire through the struts of the stent. This is easy to do, especially prior to postdeployment balloon angioplasty.

The precision of deployment is not as good with self-expanding stents as it is with balloon-expandable stents. The end of the self-expandable stent that is deployed first, from the leading end of the delivery catheter, may be placed accurately. However, the following end of the stent is not possible to place with a high degree of accuracy. In the case of the Wallstent, because the overall vessel diameter has an impact on the stent length, the end of the stent

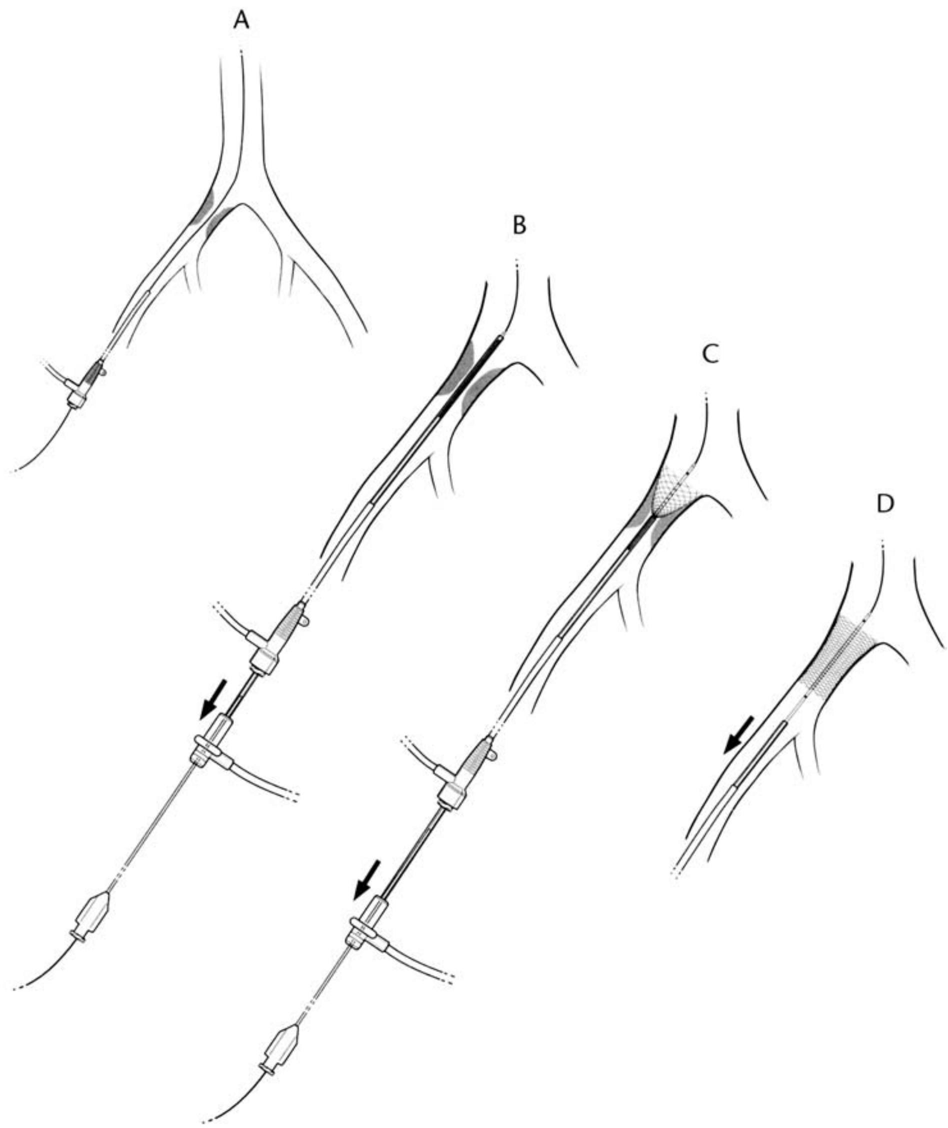

Fig. 5 Placement technique for Wallstent. A, The guidewire is placed across the lesion. **B,** The Wallstent delivery catheter is placed over the guidewire so that the proximal radiopaque marker on the catheter is proximal to the lesion. The metal pushing rod is held stationary while the valve body is slowly withdrawn. **C,** The position of the stent is continuously monitored using fluoroscopy. As the stent opens, it can be "dragged" distally but not advanced. As the valve body is withdrawn along the length of the pushing rod, the covering sheath that constrains the stent is removed and the stent expands. **D,** After stent deployment, the stent delivery catheter is removed.

may vary significantly from its nonconstrained length. Some of the other self-expanding stents, such as the Smart or the Symphony, have a prescribed length that is not dependent upon vessel diameter. These Nitinol self-expanding stents are difficult to visualize on the fluoroscopic image. They can be obtained with radiopaque markers on the ends that enhance visibility. Although it is more readily discernible where the following end of the stent will land with these nonshortening Nitinol stents, the final location of the following end is determined by the location of the leading end of the stent.

QUESTION: What to Consider When Selecting a Stent

1. Can you visualize the stent in this position?
2. What are the length and diameter requirements of the diseased segment?
3. What is the location of the lesion and what type of lesion is it?
4. Are there delivery restrictions posed by diseased access arteries, sheath size, vessel tortuosity, working room, or distance to the lesion?
5. Can the number of required stents be minimized?
6. Is it in your inventory?

Which Stent for Which Lesion?

Table 4 offers a practical comparison of the working properties of a balloon-expandable stent, a foreshortening self-expanding stent, and a nonshortening Nitinol self-expanding stent. In general, orifice lesions and those that are heavily calcified are best treated with balloon-expandable stents. Lesions located in flexible arteries or tortuous arteries or that are more than several centimeters in length are usually treated with self-expanding stents.

Either balloon-expanding or self-expanding stents may be used in the aorta (Table 5). Short focal lesions may be treated with balloon-expanding stents. Placement is precise and the single stent is less expensive. Self-expanding stents are well suited to longer aortic lesions (longer than 2 to 3 cm). Placement of a single longer self-expanding stent is usually simpler, faster, and less expensive than placing multiple balloon-expandable stents.

Lesions in the aortic bifurcation are treated by "raising" the aortic flow divider with balloon-expandable stents. Precise, "kissing," side-to-side placement is possible with self-expanding stents but difficult. Aortic bifurcation plaque usually extends through the common iliac artery orifices. Self-expanding stents usually lack the hoop strength desirable for orifice lesions.

Garden-variety common and external iliac artery lesions may be treated with either type of stent. Focal lesions are treated with balloon-expandable

Table 4 Practical Stent Comparison: Working Qualities of Palmaz, Wallstent, and Smart Stents[a]

Working quality	Palmaz[b]	Wallstent[c]	SMART[a]	Advice
Method of expansion	Balloon-expandable	Self-expanding	Self-expanding	Requirement for balloon expansion to deploy makes Palmaz stent placement a little more complicated but Wallstent and SMART always require postexpansion balloon dilatation.
Maximum length	>5 cm	>9.4 cm	8 cm	Palmaz length limited; lesions more than 2 to 3 cm need more than one; adds complexity, time and cost to the case; Wallstent and SMART provide longer length.
Length changes during placement	Shortens by 5% to 25%, depending upon final diameter	Shortens by more than 30% of constrained length	Less than 8% Does not depend upon final diameter	Final resting Wallstent length can be difficult to predict; SMART stent has minimal shortening.
Hoop strength	High	Low	Low to medium[d]	Palmaz stent is a better choice for orifice lesions.
Flexibility	None	High	High	Wallstent and SMART are better choices for tortuous arteries.
Contourability	None	Moderate	High	
Maximum diameter	12 mm	24 mm	14 mm	Wallstent is a better choice for vessels >12 mm in diameter; current Palmaz stents can be pushed beyond 12 mm (another 3 to 4 mm), but with severe foreshortening.

Precision of placement	Precise	Precise only on one end	Precise	Proximal end (first end to be deployed) of Wallstent can be placed precisely and can be moved prior to full deployment; location of second/distal end of stent is not precise. SMART can also be moved prior to full deployment.
Delivery sheath	7 to 9 Fr	7 to 9 Fr	6 to 9 Fr	Palmaz stent requires that a long sheath be placed through the lesion, which adds risk of instrumenting lesion and creates problems for remote delivery. Wallstent and SMART are on delivery catheters.
Biohazard	Sharp edges. Cannot be clamped; can tear balloon	Loose wire ends are sharp; can be clamped in emergency	No sharp edges; can be clamped in emergency	In an emergency, Wallstent and SMART can be clamped with shodded clamp.

[a] SMART stent not FDA approved for vascular usage.
[b] Cordis.
[c] Boston Scientific, Nattick, Mass.
[d] SMART stent is constructed of Nitinol, which gains in rigidity at body temperature.

Table 5 Which Stent to Use

Angioplasty site	Lesion type	Stent to use	Reason
Aorta	Focal, short	Balloon-expandable	Length match
	Large, bulky plaque	Balloon-expandable	Hoop strength
	Long (>2 to 3 cm)	Self-expanding	Fewer stents required
Aortic bifurcation	Iliac origin	Balloon-expandable	Hoop strength
Iliac	Focal	Balloon-expandable	Length match; simple
	Tortuous	Self-expanding	Flexible
	Long (especially external iliac)	Self-expanding	Fewer stents required; handles tortuosity well
SFA-popliteal	Long	Self-expanding	Fewer stents required
	Across joint	Self-expanding	Flexible
	Focal, short	Either	-
Renal	Orifice	Balloon-expandable	Hoop strength, rigid,
	Body of artery	Either	-
Subclavian	Tortuous	Self-expanding	Flexible
	Orifice	Balloon-expandable	Hoop strength

stents, and self-expandable stents are used for longer lesions and those located in tortuous arteries. Distal iliac artery lesions that are close to the groin should be treated with self-expanding stents.

Self-expanding stents are better for stenting in flexible arteries, such as the popliteal and distal subclavian arteries. Lesions in an aortic branch orifice, such as the proximal subclavian artery or renal artery, are best treated with rigid, balloon-expandable stents.

How Do You Select the Best Stent for the Job?

Although there are multiple considerations when selecting a stent for a given case, there is substantial overlap in the capabilities of the various stents. Most specialists develop a short list of one or two favorites in each stent category, balloon-expandable and self-expandable. What follows is a discussion of some of the issues that drive those preferences in clinical practice.

Most practices have at least some restriction on the variety of stents stocked and the number of different stent sizes available. Specialists with a limited inventory will ask the question sooner, but everyone must face the availability issue at some point in a case. Work with what is available or plan ahead well enough so that specific items are anticipated and ordered.

The single most important thing to do when selecting a stent is to visualize the stent in the intended location. Will it expand to oppose the wall of the artery? Can it handle the tortuosity and/or diameter changes? Does it have the hoop strength to stand up to the amount of calcification present in the lesion? Will the distal end of the stent be floating free in a segment of poststenotic dilatation?

The length and diameter requirements of the lesion must be taken together with the type and location of the lesion to come up with a stent choice. Lesion type and location were discussed in the previous section. It is not always apparent how long a length of artery should be stented if there is mild or even moderate disease juxtaposed to the lesion. The operator must make an arbitrary decision in many cases. The diameter may be sized the same way as for balloon angioplasty, but the consequences of a bad guess are greater. If a balloon-expandable stent is undersized, it may not be securely adherent to the artery. If it is oversized too much, the artery may split. One method of dealing with this dilemma is to undersize the balloon-expandable stent just slightly. Deploy the stent so that it is held in place by the newly dilated lesion. Then redilate to the desired size using a larger balloon if necessary. The diameter choices for self-expanding stents provide more leeway since the stents are oversized from 1 to 3 mm. Nevertheless, if too small a stent is used, it may become free-floating. Wallstent deployed lengths are difficult to anticipate, but several self-expanding stents, such as the SMART stent, Symphony, and Bard, expand without significant change in length.

Finally, delivery restrictions may be posed by diseased access arteries, the sheath size of the selected stent, vessel tortuosity, inadequate working room, long distance to the lesion, or branch points between the access point and the lesion. The risk of puncture site thrombosis increases when a large sheath is passed through a diseased common femoral artery. Sheath size may influence the choice of stent, since relatively larger-diameter self-expanding stents may be placed through 7 Fr sheaths. Vessel tortuosity or a branch point on the way to the lesion can usually be overcome with longer, sometimes guiding access sheaths. Occasionally, a more flexible stent is required to make these turns and a self-expanding stent is used instead of a balloon-expandable stent. The distance to the lesion is an important variable. Balloon-expandable stents must be mounted on a balloon with an adequate shaft length. A balloon catheter that is too short will have to be discarded, and there may be some challenge in getting the undeployed stent out if it has already been passed through the sheath. Self-expanding stents are generally mounted on two different lengths of catheter, either 80 cm or 120 cm. If an 80-cm shaft is opened when the longer shaft is required, it will have to be discarded. These challenges can usually be solved by using the balloon shaft length to estimate distance if the lesion was dilated prior to stent placement. If not, a standard arteriographic catheter with a bright tip may be placed over the guidewire and advanced close to the lesion and used to estimate the length from the access to the lesion.

Tricks of the Trade

RAISING THE FLOW DIVIDER WITH KISSING STENTS

A bifurcation can be reconstructed by modifying the flow divider with kissing stents. Two stents are placed simultaneously with the leading edge of each stent abutting the other at a point proximal to the location of the native flow divider. The need for kissing stents arises most commonly at the aortic bifurcation (see Chapter 19 for a detailed discussion of this technique).

TAPERING A STENT

The various self-expanding stents tend to taper naturally with diminishing distal arterial diameter. The Wallstent may be tapered further by slightly overdilating the proximal end. The upper body of the Wallstent is usually dilated first (Fig. 6). The Wallstent shortens with expansion. The very end of the Wallstent is dilated last since it may lead to rupture of the balloon. The distal end of the stent can be half the proximal diameter and still be functional.

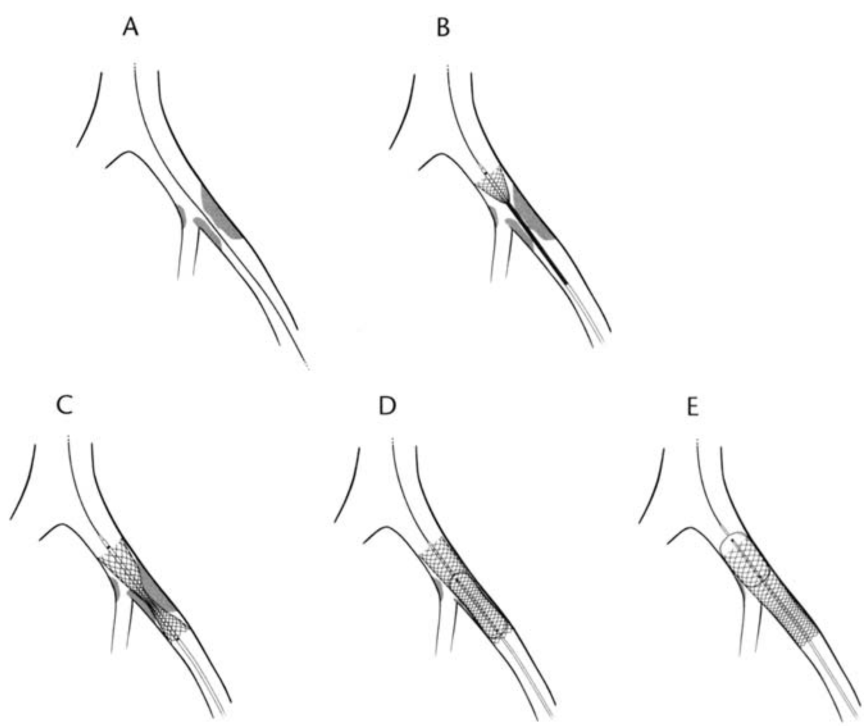

Fig. 6 Tapering a Wallstent. A, The guidewire is passed through an iliac artery stenosis. **B,** The Wallstent is deployed across the lesion. **C,** The Wallstent tends to taper naturally with decreasing distal arterial diameter. **D,** The distal end of the stent is ballooned to the diameter appropriate for the external iliac artery. **E,** Angioplasty is performed in the larger proximal end of the stent that lies in the common iliac artery.

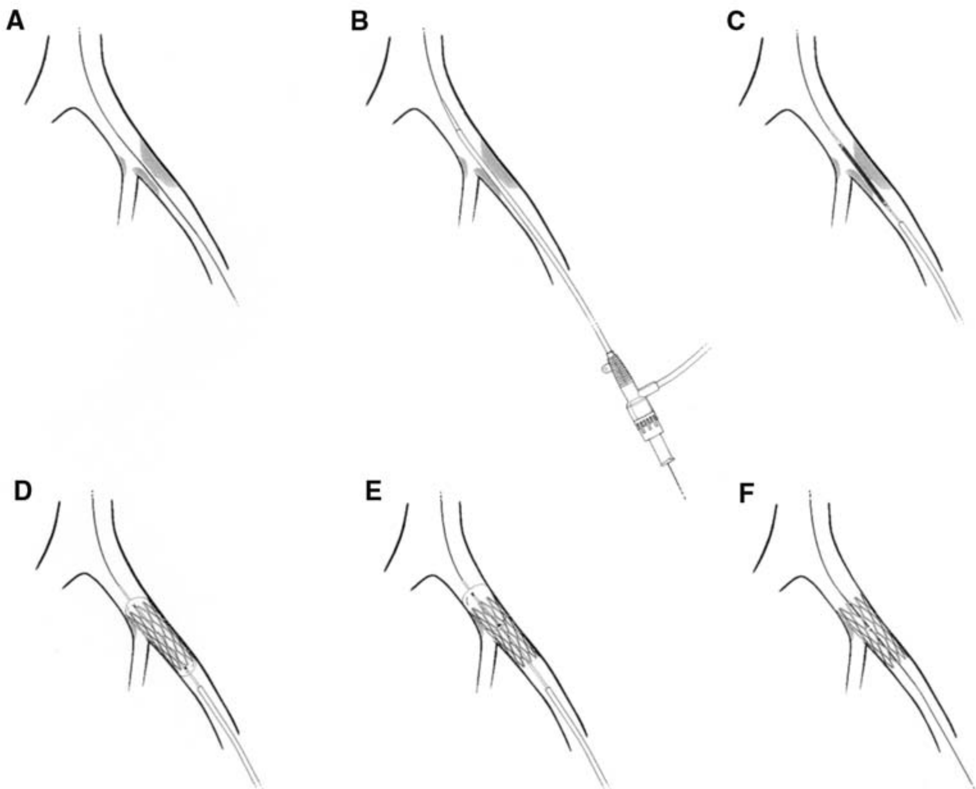

Fig. 7 Tapering a Palmaz stent. **A,** The guidewire is passed through an iliac artery stenosis. **B,** The sheath and dilator are advanced through the lesion. **C,** The balloon and mounted stent are advanced through the lesion and the sheath is withdrawn. **D,** The Palmaz stent is deployed to a size appropriate to the diameter of the external iliac artery. **E,** A larger diameter angioplasty balloon is used to enlarge the proximal end of the stent. **F,** A slight taper of the stent is created across the iliac bifurcation.

The shorter, more rigid balloon-expanding stents can also be tapered, but to a lesser degree (1 to 2 mm maximum). One end of the stent is selectively dilated using only the shoulder of the balloon (Fig. 7).

MOVING A SELF-EXPANDING STENT

Self-expanding stents can be withdrawn or pulled back but not advanced forward after partial deployment. The entire deployment catheter apparatus must be withdrawn in a retracted position to move the stent (Fig. 8). An assistant should hold the access sheath since it will come out if not secured. Moving the stent can be helpful in achieving very precise placement of its proximal end. It is not possible to move a stent after it has been fully deployed. If the stent has not been deployed in the correct location, the best solution is to place another stent at the desired location.

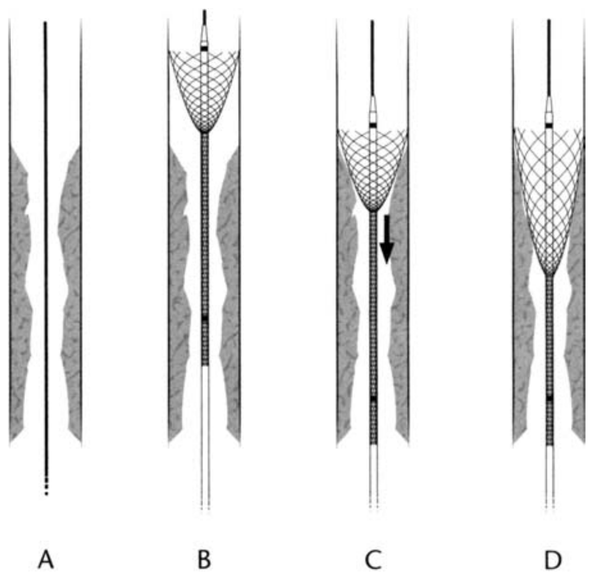

Fig. 8 Moving a Wallstent. A, The guidewire is placed across the lesion. **B,** Stent deployment is initiated more proximally than its final intended location. **C,** The entire delivery apparatus is withdrawn to move the proximal expanded end of the stent into the lesion. **D,** After correct positioning, deployment continues.

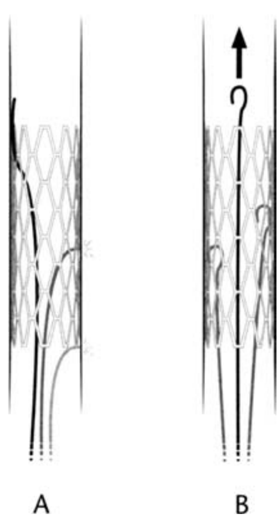

Fig. 9 Crossing a stent. A, After deployment of a stent, there are many potential routes of false passage. **B,** Passage through the struts of a stent is usually avoided with a J-tip guidewire.

RECONSTRAINING A WALLSTENT

The Wallstent has an extra feature that is occasionally useful in cases where the stent has not been deployed beyond a certain point. The usual process of self-expanding stent deployment includes holding the pushing rod steady and withdrawing the valve body toward the head of the pushing rod. If fluoroscopic image shows the stent deployment is not just right, the operator may decide to move the stent. The stent may be reconstrained or recovered by reversing the deployment maneuver: hold the pushing rod steady and advance the valve body back toward the patient. This recovers the stent and reconstrains it. The delivery catheter has a marker on it to identify the point of no return during deployment which can be seen with fluoroscopy.

CROSSING A STENT

Once a stent has been deployed, the guidewire position across the stent is not relinquished until the procedure is completed. If the guidewire position is lost, or if a repeat study is necessary in a patient who has a stent, it is best to

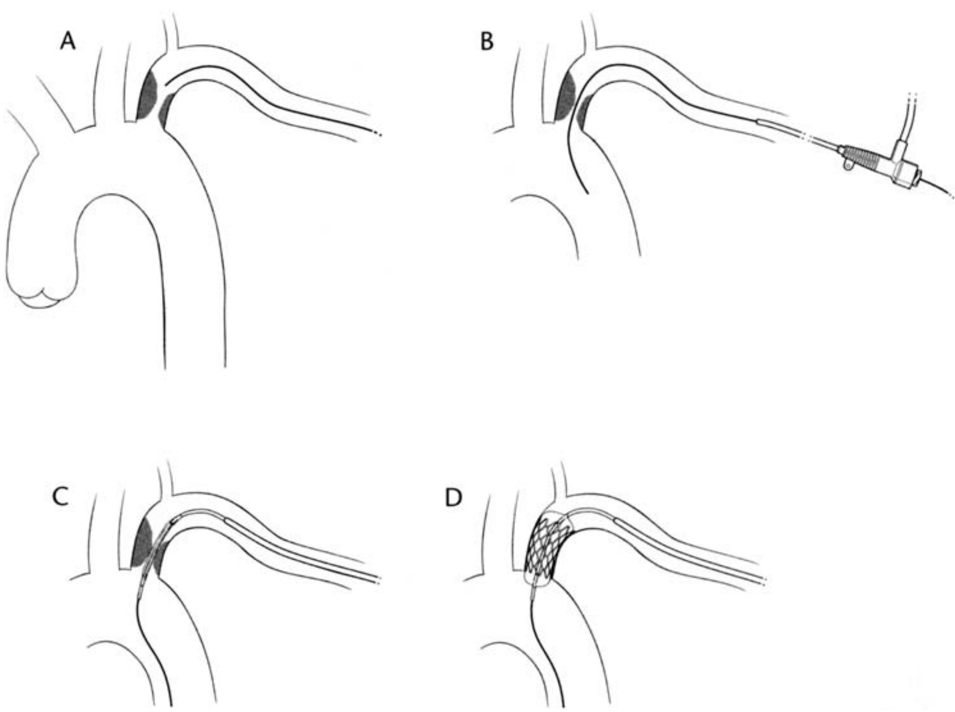

Fig. 10 Placement of a Palmaz stent without a sheath. A, The guidewire is placed across a lesion at the origin of the subclavian artery. **B,** A transbrachial sheath is placed but the artery is too tortuous to permit safe passage of the sheath through the lesion. **C,** The angioplasty balloon with premounted stent is passed beyond the sheath and through the lesion. **D,** The stent is deployed.

cross the stent using a J-tip guidewire (Fig. 9). The elbow of the J-tip guidewire is less likely to pass through the struts of the stent. If there is any doubt about the position of the guidewire, it should be withdrawn and a repeat crossing should be performed. The J-tip guidewire should be able to twirl and bob freely within the lumen of the stent. After the guidewire is across the stent, intraluminal position can be checked using a 5 Fr straight angiographic catheter passed over the guidewire. Any resistance as the

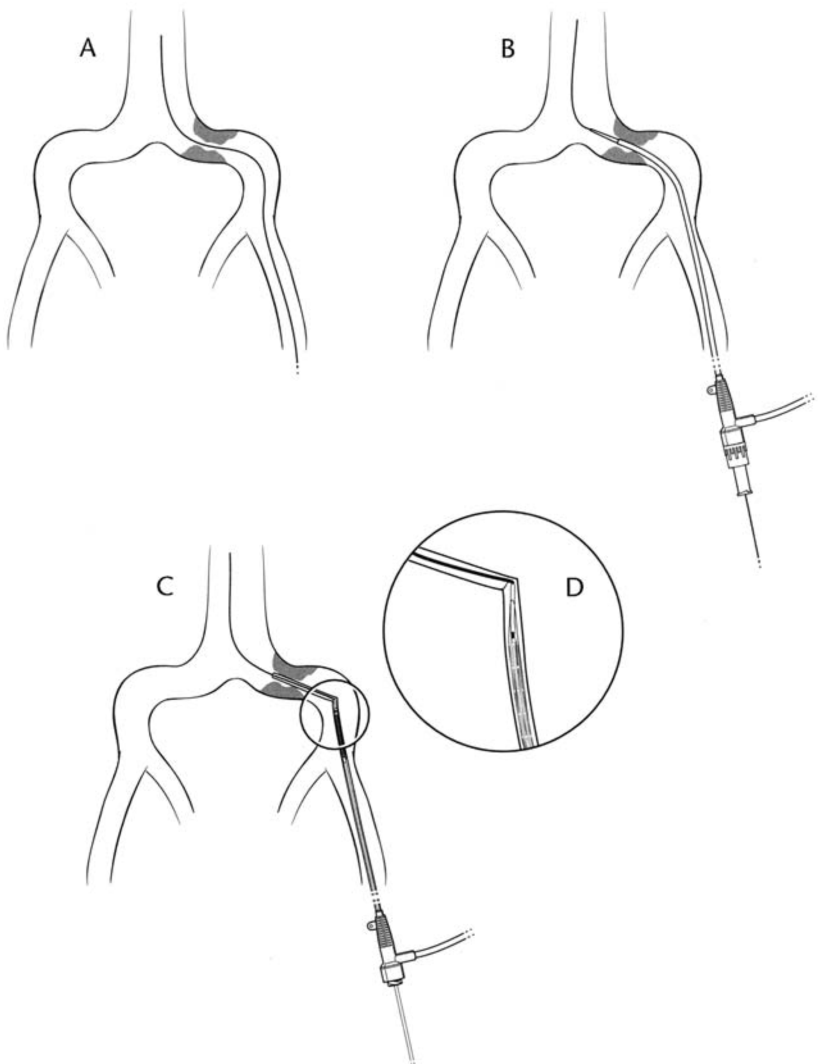

Fig. 11 Kinked sheath prevents passage of a Palmaz stent. A, The guidewire is passed through a lesion in a tortuous iliac artery. **B,** The sheath and dilator are advanced through the lesion in preparation for stent placement. **C,** After the dilator is removed, the sheath becomes kinked. **D,** The balloon with mounted stent cannot pass because the sheath is kinked.

catheter passes through the stent indicates a false passage. Use a small field view for magnification, and oblique views if needed. Passing the guidewire through the interstices of the stent will lead to complications if it is not recognized that this has occurred.

GOING NAKED: PLACEMENT OF A BALLOON-EXPANDING STENT WITHOUT A SHEATH

Placement of balloon-expandable stents was designed to be performed with a sheath. Occasionally, however, placement of the sheath into the desired location across the lesion is difficult, dangerous, or both, especially

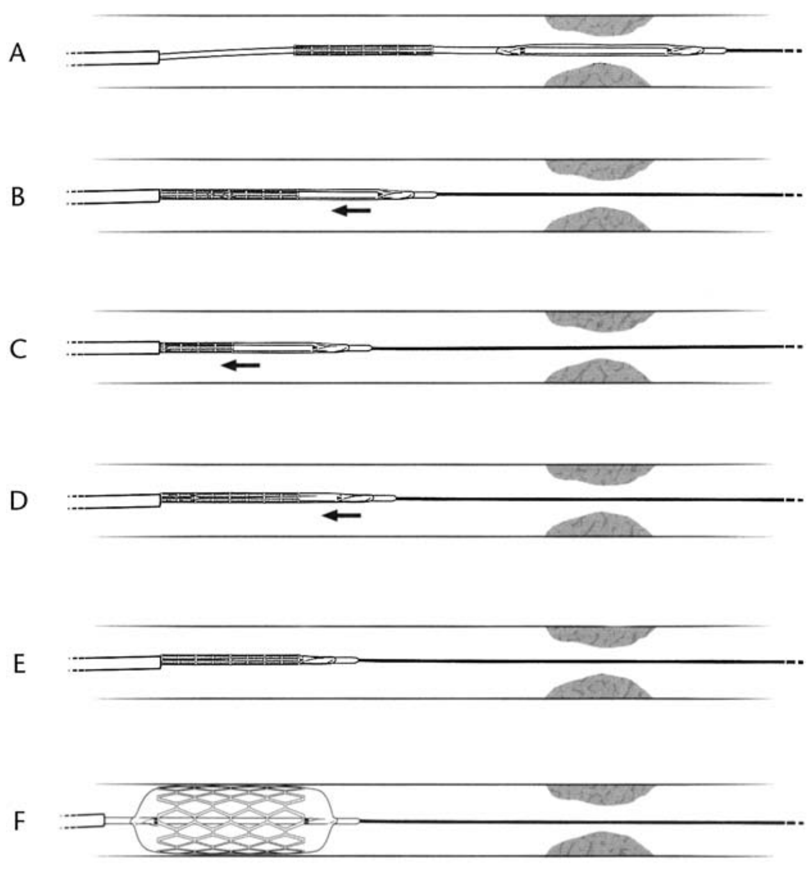

Fig. 12 Palmaz stent is loose on the catheter shaft. A, A stent becomes dislodged from its position on the balloon catheter during passage through the sheath. **B,** An attempt is made to pull the stent back into the sheath. **C,** The entire sheath is removed with the stent inside. **D,** If the stent cannot be dragged back into the sheath, the end of the stent is pinned with the tip of the sheath. **E,** The balloon is pulled back into the stent to reload. **F,** The sheath is withdrawn and the newly remounted stent is deployed in a neutral location.

with highly tortuous approach arteries or when the sizable sheath hangs up on the lesion itself (Fig. 10). One option is to use a short access sheath. Advance the balloon and stent over the guidewire and through the lesion without a sheath to protect them. Use a premounted stent, which comes in a package with the stent already sealed onto the balloon (Cordis, a Johnson & Johnson Co., Miami, Fla.). If treating a critical stenosis, predilate the lesion so that the stent will pass through without being dislodged from the balloon.

TECHNIQUE: Bailout Maneuvers for Balloon-Expandable Stents

1. **Sheath won't advance across the lesion.** Dilate the lesion, then advance again. Consider using a stiffer guidewire.

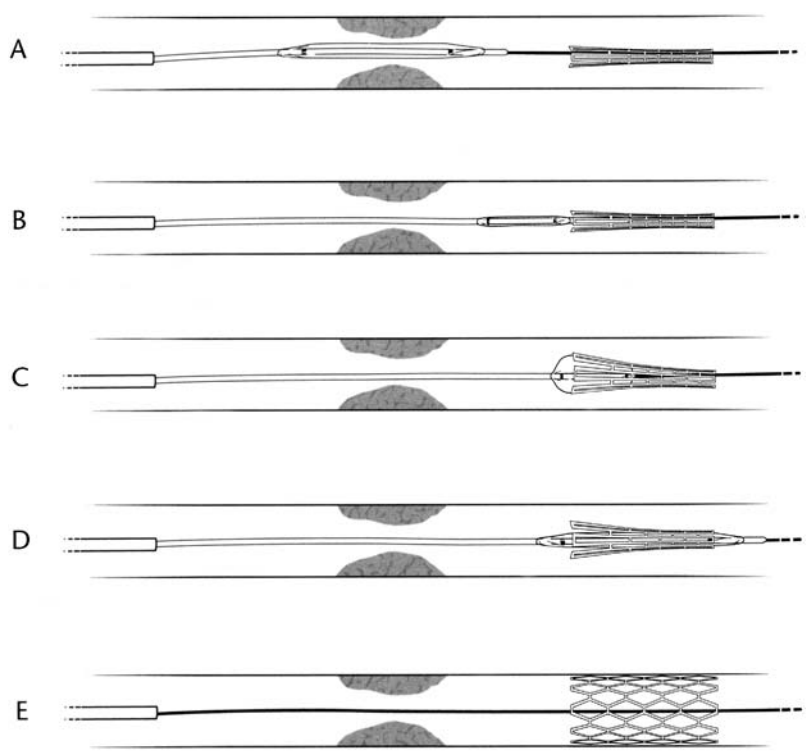

Fig. 13 Palmaz stent is loose on the guidewire. If improperly mounted, the stent may shoot forward off the balloon during inflation. The end of the stent may be partially flared and dangling on the guidewire. **A,** The guidewire is advanced to allow room to maneuver. **B,** A smaller, lower profile balloon is exchanged. **C,** One end of the stent is flared further. **D,** The appropriately sized balloon is substituted. **E,** The stent is deployed in a neutral position.

2. **Balloon with stent will not pass through the sheath.** The sheath may have kinked (Fig. 11). Consider pulling the kinked part of the sheath back into a straighter segment of the artery and try again to pass the balloon and stent. If unsuccessful, pull out the balloon and stent with the sheath but leave the guidewire in place. Change the sheath and start again. Consider using a self-expanding stent for tortuous arteries (Predilate the lesion; use a larger sheath and stiffer wire)
3. **Loose stent inside the sheath.** Pull out the sheath, balloon catheter, and stent. Leave the guidewire, if possible. Use fluoroscopy to ensure that the stent comes out with the sheath.
4. **Loose stent on the catheter shaft.** Pull the balloon back into the stent using the tip of the sheath to pin the stent. Pull the stent back into the sheath, if possible. Use a partially inflated balloon to pull the stent and remove the sheath. If the stent cannot be pulled back into the sheath, pin the back end of the stent with the tip of the sheath and deploy in a neutral location (Fig. 12).

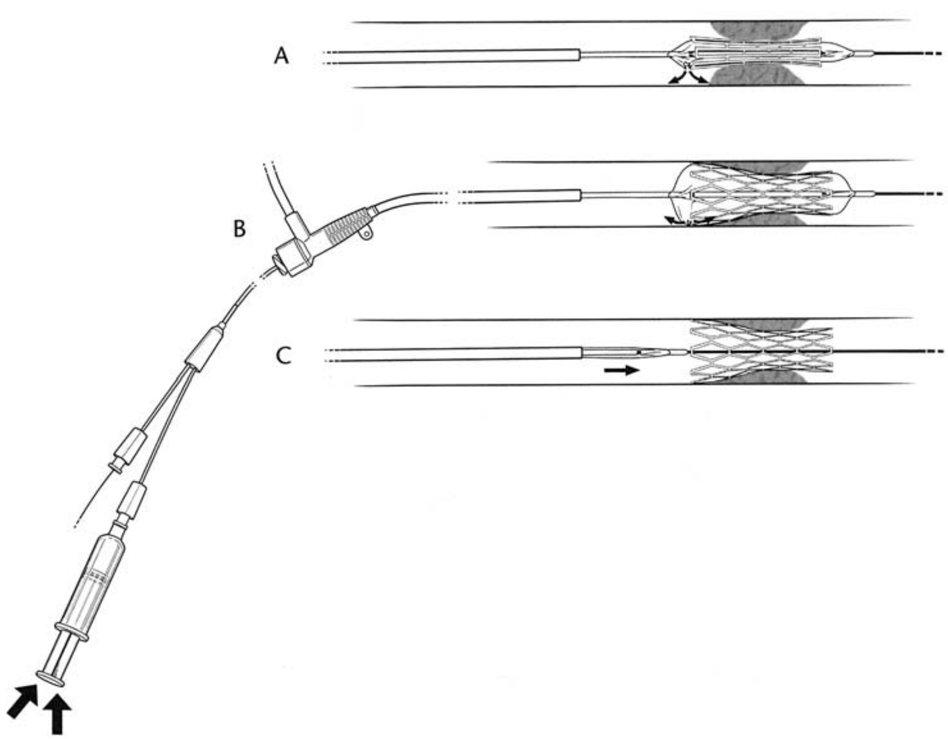

Fig. 14 Balloon ruptures during deployment of Palmaz stent. A, The angioplasty balloon ruptures on the sharp edge of the stent during deployment. **B,** A high-pressure, hand-powered inflation attempts to overwhelm the leak in the balloon. The ends of the stent flare enough to prevent immediate migration. **C,** A new balloon is placed to complete the deployment.

5. **Loose stent on the guidewire.** Advance small balloon into the stent to flare the end and stabilize. Deploy in a neutral location (Fig. 13).
6. **Stent embolizes.** Use a long sheath and cardiac biopsy forceps or a loop snare to pull or push into a favorable location to abandon (internal iliac, deep femoral, or tibial arteries) or to retrieve surgically (common femoral artery).
7. **Balloon ruptures during stent deployment.** Perform high-pressure, hand-powered balloon inflation with saline solution in an attempt to overwhelm the hole in the leaky balloon (Fig. 14). Advance the sheath to pin the stent so that it is not withdrawn with the balloon. Rotate and remove the ruptured balloon, cross the stent with another balloon, and inflate.
8. **Dissection at the end of the stent.** Place a new overlapping stent (Fig. 15).
9. **Stent tilts.** Some balloon-expanding stents are too rigid for tortuous arteries. Self-expanding stents are often a better choice (Fig. 16). Place another stent to straighten the curve.
10. **Balloon sticks in the expanded stent.** Material is caught in the struts. Do not yank because the material may fragment. Rotate the catheter, reinflate, push in to advance, then withdraw. If that does not work, advance the sheath so that the tip of the sheath can at once hold the stent in place and act as a funneling device to accept the torn balloon.
11. **Stent requires surgical removal.** If the stent is fully deployed, the artery probably requires reconstruction. An artery cannot be occluded with a clamp at the location of a stent. The ends of the stent are sharp!
12. **Avoid deployment of stent in the sheath.** Be sure that the tip of the sheath has been withdrawn adequately to avoid capturing the end of the stent.

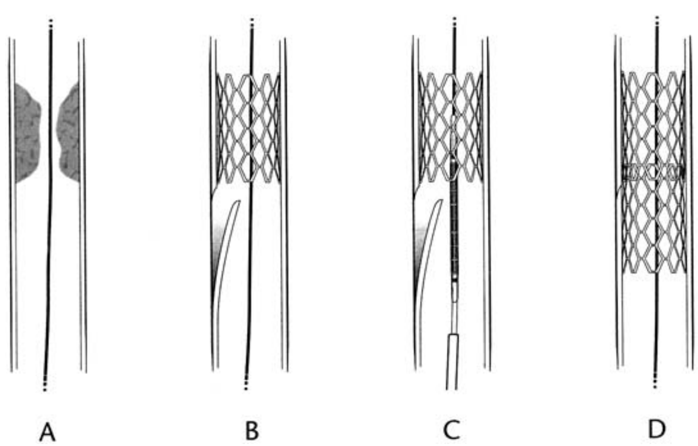

Fig. 15 Dissection at the end of the stent. A, A guidewire is placed across the lesion. **B,** A stent is placed but a dissection flap develops at the interface between the lesion and the adjacent nondiseased segment. **C,** Another stent is advanced into position with a slight overlap of the previously placed stent. **D,** Stent placement repairs the dissection.

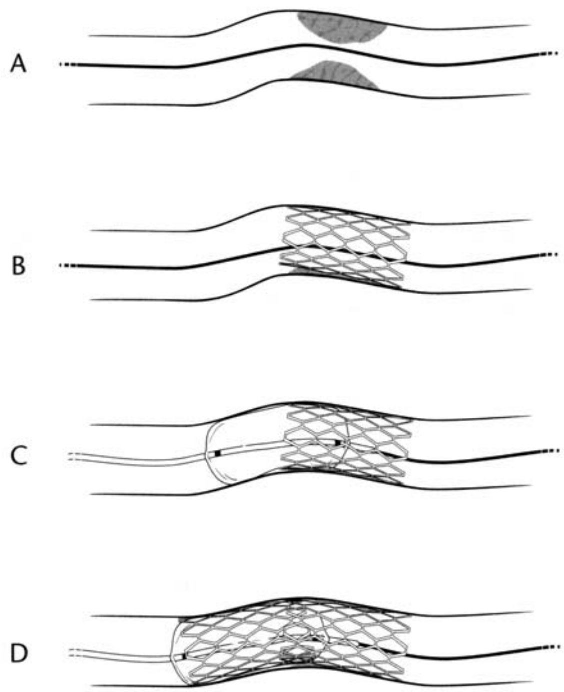

Fig. 16 Tilted Palmaz stent. A, A guidewire is passed through a stenosis along a curve in the artery. **B,** A Palmaz stent is placed across the lesion. The combination of the curvature of the artery and the location of the lesion prevents the edge of the stent from being well opposed to the arterial wall. **C,** Balloon angioplasty of the protruding end of the stent is performed. **D,** If angioplasty is not successful, another stent is placed to decrease the curvature of the artery and force the edge of the stent against the wall.

TECHNIQUE: Bailout Maneuvers for Self-Expanding Stents

1. **End of the stent is not fully expanded.** The hoop strength of the self-expanding stent may not be adequate to compress the lesion. Dilate the body of the stent to make sure it is properly seeded, then dilate the ends (Fig. 17).
2. **Stent is undersized for given artery.** The chosen stent is too small. There is no good solution.
3. **Stent extends into undesired location.** Dilate the stent to foreshorten it (Fig. 18). This works well with a Wallstent. Other types of self-expanding stents can sometimes be moved a very short distance by inflating a balloon and pulling gently on the catheter.
4. **Stent location is inaccurate.** The only way to avoid this is to deploy the end of the stent first that has the greatest precision requirement (Fig. 19).
5. **The end of the stent extends into the hemostatic introducer sheath.** The stent will not deploy. The tip of the sheath may not be visible.

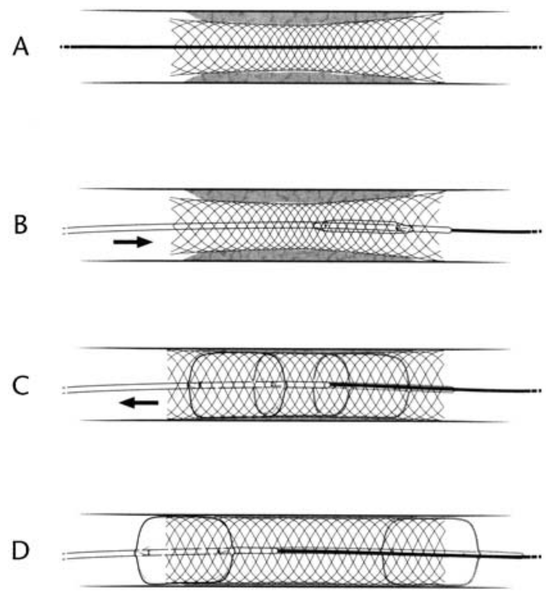

Fig. 17 End of the Wallstent is not expanded. A, A Wallstent is placed but one end does not fully expand to meet the vessel wall. **B,** A balloon catheter is passed. **C,** Angioplasty is performed along the entire length of the stent. The body of the stent is dilated first to ensure that it is well embedded into the vessel wall. As the stent is dilated, the length may change slightly. **D,** The ends of the stent are dilated last because the balloon may rupture on the sharp wire ends of the stent.

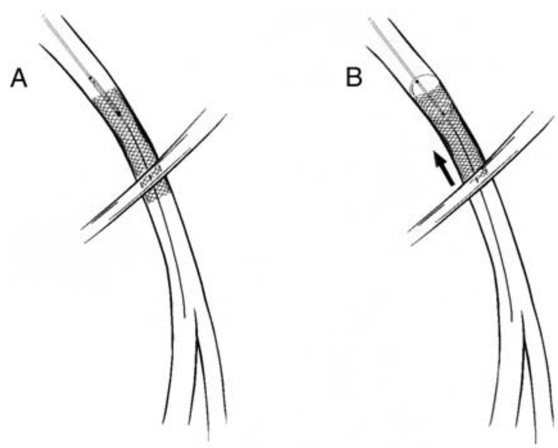

Fig. 18 Wallstent extends into undesired location. A, A Wallstent is placed in the distal external iliac artery. The distal end of the stent extends into the common femoral artery. The Wallstent is flexible enough to be placed across joints but it should be avoided when possible. **B,** Slight overdilation along the length of the stent with angioplasty causes the stent to shorten a few millimeters.

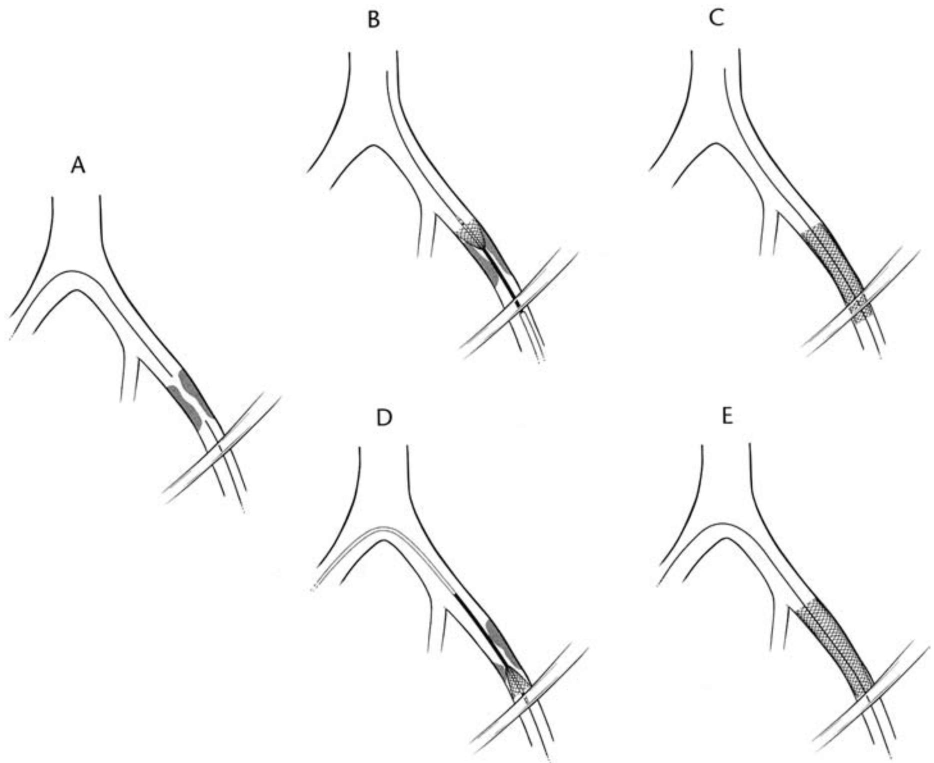

Fig. 19 Wallstent location is inaccurate. Deployment should be initiated at the end where the most accuracy is required. **A,** An external iliac artery lesion can be approached either antegrade or retrograde. **B,** Wallstent placement through a retrograde approach ensures precise placement of the proximal end of the stent. **C,** The final length of the stent may be difficult to predict. The distal end of the stent extends into undiseased common femoral artery. **D,** Wallstent placement through an antegrade approach places the distal end of the stent first because the working room between the inguinal ligament and the lesion is limited. **E,** The excess length of the upper end of the stent extends into the proximal external iliac artery.

Puff contrast through the sheath. Pull the sheath back slightly while holding the stent delivery catheter in place to release the crimped stent, but not out of the artery (Fig. 20).

6. **Stent collapses in its midsection.** Repeat angioplasty. If that is unsuccessful, place a balloon-expandable stent inside the self-expanding stent (Fig. 21). This is most likely to occur with a long Wallstent in a heavily calcified lesion.
7. **Balloon breaks on the end of the stent.** Balloon the end of the stent last or use a thicker polymer balloon.
8. **Artery with stent in it requires clamping.** Use large, shodded arterial clamp. The artery can be clamped enough to occlude inflow but may damage the stent.

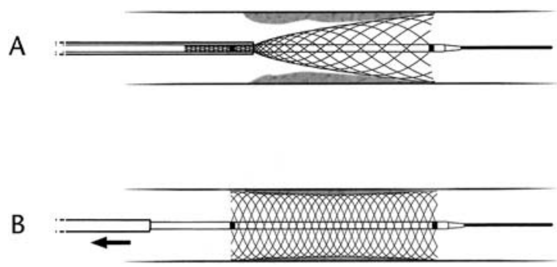

Fig. 20 Partially deployed Wallstent extends into hemostatic introducer sheath. A, Wallstent deployment begins but the second end of the stent cannot be deployed because the tip of the access sheath impinges on the stent. This occurs when working room between the deployment site and the arterial entry site is limited. **B,** The hemostatic access sheath is withdrawn enough to permit the stent to expand. A sheath with a radiopaque tip may help avoid this problem.

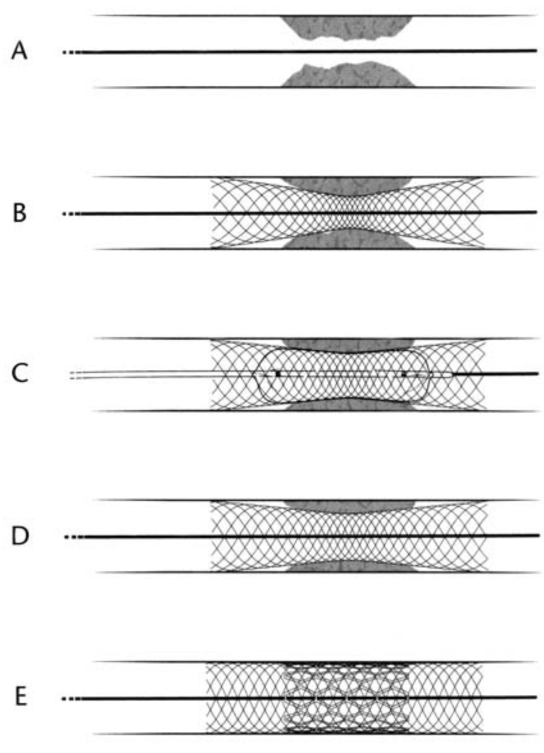

Fig. 21 Wallstent collapses in its midsection. A, A guidewire is placed across the lesion. **B,** A Wallstent is placed but remains partially constrained in its midsection. **C,** Balloon angioplasty is performed. **D,** Because Wallstent hoop strength is low, a recalcitrant lesion may impinge on the stent, which results in incomplete expansion. A central stent narrowing can also occur if the stent is placed across a segment with too sharp a turn. **E,** If angioplasty is unsuccessful, a Palmaz stent is placed to resolve the stenosis.

9. **Stent requires surgical removal.** The stent may be extracted by squeezing it, which narrows the whole stent.

Acute Complications of Stent Placement

Complications that occur during stent placement or immediately thereafter include arterial dissection and/or occlusion, arterial rupture, migration or embolization of the stent, or embolization of atherosclerotic material.

Arterial dissection. If acute arterial dissection occurs in juxtaposition to a stent, an additional stent is placed in this location (see Fig. 15). The lead point for arterial dissection associated with stent placement is usually within a centimeter of the end of the stent. A stent is placed in this segment even if it is not clear exactly where the lead point of the dissection is located.

Arterial occlusion. The stented site may occlude as a result of arterial dissection or as a result of placement of a stent that is not fully expanded. After stent placement, additional balloon dilatation is usually performed to ensure full expansion of the stent.

Arterial rupture. If arterial rupture occurs during stent placement and the stent has been fully deployed, a balloon catheter is inserted and placed within the stent along the area where the rupture is thought to have occurred and the balloon is inflated. A covered stent is placed in the same location or emergency operative repair is undertaken.

Migration or embolization of the stent. Migration of the stent may occur during deployment, usually because the size of the stent that was required was underestimated. If the stent has migrated enough that the area of interest has not been adequately stented, another stent is placed in this location.

Embolization of atherosclerotic material. Distal embolization may occur as a result of instrumentation of a friable atherosclerotic lesion. It is unusual for further embolization to occur after the entire lesion has been covered with stents.

Chronic Complications of Stent Placement

Chronic complications from stent placement that may develop over time include intimal hyperplasia, recurrent stenosis, infection, and damage to the stent from external forces.

Intimal hyperplasia. Intimal hyperplasia can be treated with repeat balloon dilatation, additional stents, directional atherectomy, or surgery.

Recurrent stenosis. If recurrent stenosis occurs in juxtaposition to a stent, an overlapping stent is placed.

Infection. Infection of a stent is rare and is managed by excising the stent and the arterial segment.

Stent damage. Stents can be damaged by external forces. Chronic repetitive shoulder motion with compression of a stented subclavian artery against the first rib leads to stent fracture. Stents can also be crushed, especially the balloon-expandable stents, by arterial clamps, blood pressure cuffs, motion at joints, and external blunt trauma.

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17

The Common Carotid, Subclavian, and Axillary Arteries

Advice About Balloon Angioplasty and Stent Placement

Common Carotid Artery
The Subclavian and Axillary Arteries
Selected Readings

This chapter includes information and discussion about endovascular intervention in the aortic arch branches. Be aware that no stents are approved for usage in these arteries as of yet. Angioplasty and stenting of the carotid bifurcation are not included in this chapter. There are significant differences between interventions in the carotid bifurcation and those in the common carotid and subclavian–axillary arteries. Carotid bifurcation intervention should be performed with very thorough anticoagulation and should include a stent. Most symptomatic carotid bifurcation lesions present as a result of cerebral embolization, and the potential for embolization with manipulation is higher than for lesions in other locations. In addition, present conditions include significant unknowns which indicate that carotid bifurcation angioplasty and stent placement should be performed under the auspices of studies approved by the institutional review board of the particular facility. Lesions of the common carotid and subclavian–axillary arteries are less common, are less likely to embolize, and will probably never be formally evaluated with a large-scale randomized therapeutic trial.

Chapter 6 provides a detailed discussion of selective catheterization of these arteries. Chapter 8 covers arch aortography and selective branch vessel

Table 1 Supplies for Brachiocephalic Intervention[a]

Guidewire	Starting guidewire	Newton	180 cm length	0.035 in diameter
	Selective guidewire	Glidewire	260 cm	0.035 (angled tip)
	Exchange guidewire	Amplatz Super-stiff	260 cm	0.035
Catheter	Flush catheter	Pigtail	90 cm length	5 Fr
	Selective cerebral catheter	H_1	100 cm length	5 Fr
		DAV	100 cm	5 Fr
Sheath	Cerebral guide sheath	Vitek	125 cm	5 Fr
		Simmons 1, 2	100 cm	5 Fr
		H_3	100 cm	5 Fr
		Shuttle	90 cm length	6 Fr, 7 Fr
Balloon	Balloon angioplasty catheter	Balloon diameter	5, 6, 7, 8, 9, 10 mm	
		Balloon length	2, 4 cm	
		Catheter shaft	120 cm length	5 Fr
Stent[b]	Balloon-expandable stent	Palmaz Corinthian (premounted)	Stent diameter	6, 7, 8, 10 mm
			Stent length	15–35 mm
			Shaft length	135 cm
	Self-expanding stent	SMART	Diameter	8, 10, 12, 14 mm
			Stent length	20, 40 mm
			Delivery catheter	120 cm

[a] Excluding carotid bifurcation balloon angioplasty and stenting.
[b] No stents are approved by the FDA for routine usage in this vascular bed.

arteriography. Supplies required for brachiocephalic interventions are listed in Table 1.

Common Carotid Artery

Focal lesions of the common carotid artery may be approached either antegrade through a femoral access or retrograde through a distal common carotid artery exposure. The best candidates for this procedure have no significant occlusive disease at the carotid bifurcation and are suboptimal candidates for surgery.

Whether planning an antegrade or a retrograde approach, arch aortography is performed through a femoral approach using a pigtail catheter and a pressure injector, as described in Chapter 8. The image intensifier is best placed in the LAO position (Fig. 1 of Chapter 6). An image of the arch, the origins of its branches, and the carotid bifurcation is saved on the monitor and the image intensifier is not moved until the artery origin is cannulated.

TRANSFEMORAL APPROACH TO THE COMMON CAROTID ARTERY

If proceeding with a transfemoral approach, a guidewire is inserted (Fig. 1). Heparin is administered intravenously, 50 to 75 U/kg. The tip of the guidewire is placed in the arch and the pigtail catheter is removed. A 7 Fr, 90-cm length, straight sheath with a radiopaque tip is passed and the tip is advanced to within a few centimeters of the origin of the artery. The guidewire is removed and exchanged for an angled-tip Glidewire. The appropriate selective cerebral catheter (see Chapter 6), 100 to 120 cm in length, is placed through the sheath. The head of the selective cerebral catheter extends beyond the end of the sheath. The cerebral catheter directs the guidewire into the origin of the common carotid artery.

The steerable guidewire is advanced carefully beyond the common carotid artery lesion and into the external carotid artery. The cerebral catheter may be advanced over the guidewire and into the external carotid artery. The steerable guidewire is exchanged for an Amplatz guidewire. After the stiff guidewire is in place in the external carotid artery, the cerebral or straight catheter is removed. The dilator is replaced within the long sheath and the sheath is advanced carefully into the artery origin. Avoid dottering the lesion with the dilator. After the tip of the sheath is in place, additional arteriography and heparin flushing may be performed through the sidearm of the sheath. The long sheath should be flushed regularly and care must be taken to avoid thrombus formation or microbubbles.

A carotid arteriogram is performed through the sheath with a small field of view. The usual balloon sizes are 6 to 8 mm. The most favorable lesions are

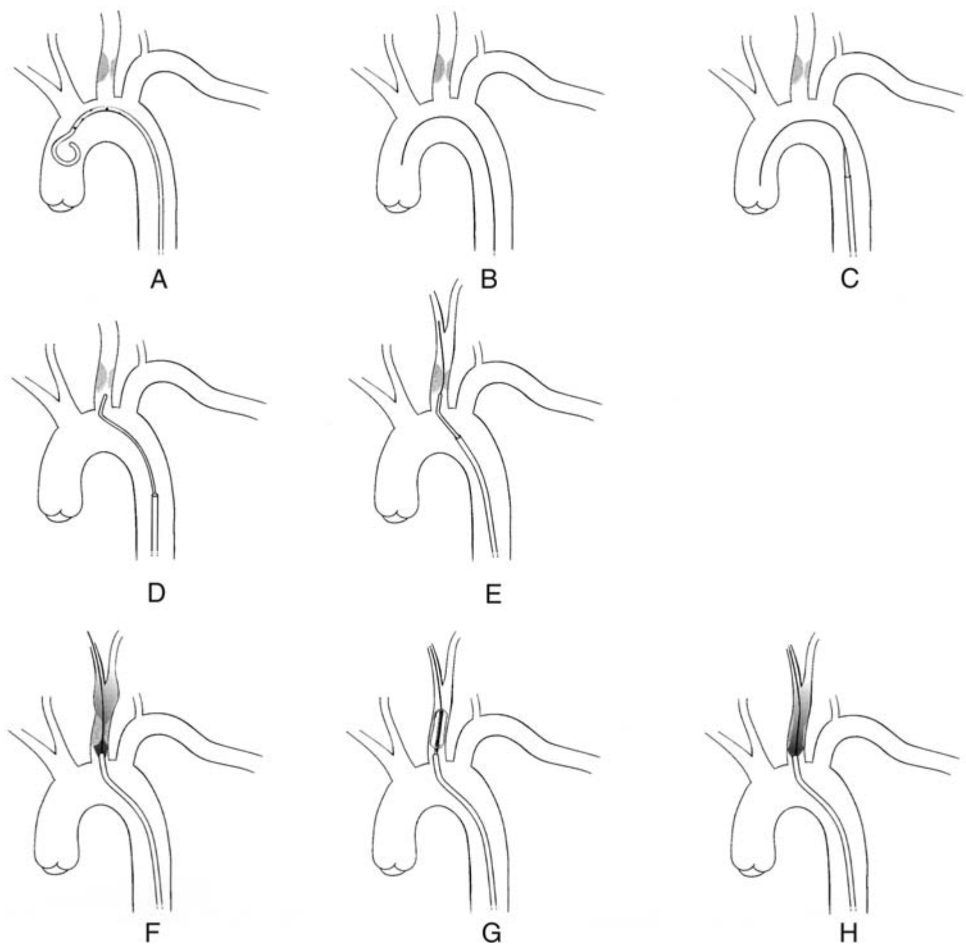

Fig. 1 Balloon angioplasty of the common carotid artery. A, An arch aortogram is performed with a flush catheter. **B,** The guidewire is replaced after the location of the common carotid artery origin and the lesion are identified. **C,** A long sheath is placed in the proximal descending aorta. **D,** A selective cerebral catheter is advanced through the sheath and used to cannulate the common carotid artery. The catheter must be at least 20 cm longer than the sheath. **E,** The guidewire is directed into the external carotid artery. **F,** The sheath is advanced into the proximal common carotid artery and an arteriogram is performed. **G,** Balloon angioplasty is performed. If the lesion is in proximity to the bifurcation, the guidewire should be placed in the internal carotid artery. **H,** Completion arteriography is performed through the sheath.

focal and a 2-cm-length balloon is usually adequate. The shaft length is 110 to 130 cm. The balloon catheter is passed over the guidewire and angioplasty is performed as described in Chapter 14. The balloon is removed and completion arteriography is performed through the sheath. The usual indications for selective stent placement are observed, as described in Chapter 16. An alternative approach is to proceed with primary stent placement through the 7 Fr sheath after arteriography. Common carotid artery orifice lesions are best treated with a balloon-expandable stent. Other lesions may be treated with either self-expanding or balloon-expandable stents, since it is a relatively straight conduit artery.

Self-expanding stent diameter should be 8 mm for a 5 to 7 mm common carotid artery or 10 mm for a 7 to 9 mm artery. The delivery catheters must be 120 cm, a size made by most of the companies, even though these stents are generally approved only for biliary use. The length of the stent should be kept to a minimum. The stent delivery catheter is passed over the guidewire, through the sheath, and into position across the lesion (Fig. 2). The stent is deployed and postplacement dilatation is performed, followed by completion arteriography.

A balloon-expandable stent may be placed by mounting a stent, usually a medium Palmaz, on the appropriately sized balloon with a 110- or 120-cm shaft. The dilator is placed back within the sheath and the tip of the sheath is advanced across the lesion. If the lesion is tight, predilatation should be performed to 4 or 5 mm. The dilator is removed and the balloon and stent are passed across the lesion. The sheath is withdrawn to uncover the stent, and the balloon is inflated to deploy the stent. If landmarks require rechecking, contrast may be injected through the sheath prior to stent deployment. Afterward, completion arteriography may likewise be performed through the sheath.

Orifice lesions require a very high degree of placement accuracy since the proximal end of the stent should protrude into the arch enough to contain any arch plaque that has spilled over into the common carotid artery. Orifice lesions may also be challenging from a femoral approach because when the sheath is pulled back to expose the stent, the tip of the sheath loses its purchase on the origin of the common carotid artery. The sheath must be withdrawn carefully and the tip should be parked as close to the end of the balloon as possible without impinging upon it. After deploying the stent, postdilatation of both ends of the stent is performed using the same balloon. Contrast should be puffed through the sheath to see if it refluxes adequately into the stented artery to evaluate the reconstruction. If it appears satisfactory, there is no need to pass the sheath into the artery again. A pigtail catheter may be placed and a completion study performed. When it is necessary to replace the sheath across the lesion, the dilator is placed in exchange for the balloon catheter and the sheath is advanced. It is common

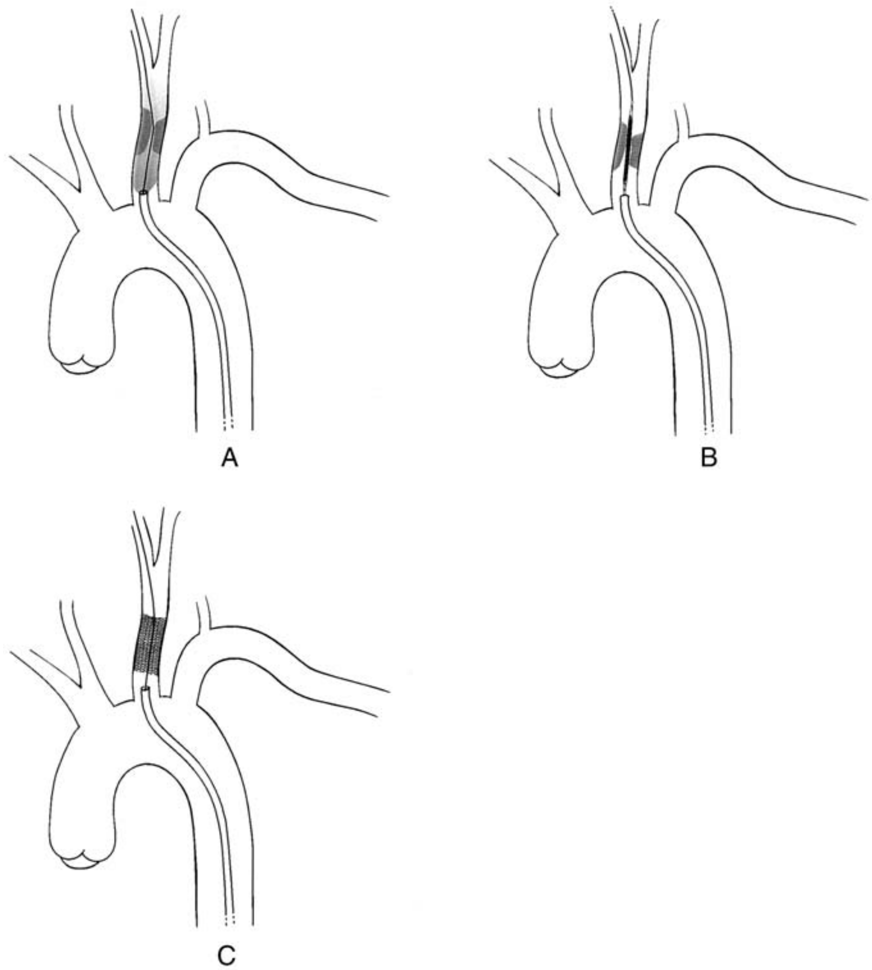

Fig. 2 Stent placement in the common carotid artery. A, After guidewire and sheath placement, an arteriogram is performed. **B,** A self-expanding or balloon-expandable stent is delivered to the site of the lesion or the angioplasty. **C,** The stent is deployed while maintaining access to the common carotid artery with the sheath.

for the tip of the dilator or the sheath to snag upon the end of the stent as it turns the tight corner from the arch into the common carotid artery. If the position of the sheath is precarious, due to angulation of the aorta, the arch, or the arch branch origin, consider advancing the sheath gently over the balloon catheter and the balloon.

RETROGRADE APPROACH TO THE COMMON CAROTID ARTERY

Common carotid artery lesions may also be approached retrograde, usually through open exposure of the distal common carotid artery. This approach is usually best in the following circumstances: angulated arch anatomy or arch disease that is not favorable for an antegrade approach; an orifice lesion; or a combined carotid bifurcation lesion that requires simultaneous endarterectomy.

The two key factors for consideration in this approach are the very short working room between the access and the lesion and the need to clamp the carotid for a short period of time without options for a shunt.

The common carotid artery exposure is performed through a short incision and the artery is looped. Heparin is administered. It is usually best to place a transfemoral pigtail in the arch of the aorta for arteriography, even if the intervention is to be performed retrograde. This is because retrograde carotid arteriography is suboptimal at delineating the origin of the artery, especially in the setting of an orifice lesion. The image intensifier is placed in the LAO position. The artery is punctured as distally along the common carotid artery as possible but in a location that allows clamping and avoids any bifurcation disease. This helps to maximize working room. The guidewire is inserted through the needle, and fluoroscopy is initiated immediately since the lesion will be encountered within a few centimeters. After the guidewire is across the lesion, attempt to steer it into the descending aorta. This is frequently unsuccessful since the natural tendency is for the guidewire to direct itself into the ascending aorta. A short, bent-tip selective catheter, such as a Kumpe or DAV, is used to direct the guidewire into the descending aorta. A very short access sheath preferably 8 cm or less, is placed in the retrograde position. A retrograde arteriogram is performed. If the image intensifier position has remained unchanged since the arch aortogram, this may be used for positioning. Otherwise, an arch aortogram may be repeated through the transfemoral pigtail catheter. The appropriate balloon and stent are selected and placed. The distal common carotid artery may be clamped during balloon angioplasty and stent placement. The artery is flushed and repaired after intervention.

The Subclavian and Axillary Arteries

Subclavian and axillary artery lesions can be approached antegrade (femoral artery access) or retrograde (brachial artery access). The best candidates for this procedure have symptomatic vertebrobasilar insufficiency or upper-extremity ischemia and a lesion that does not involve the origin of the vertebral artery. Whether planning an antegrade or a retrograde approach, arch aortography is performed through a femoral approach using a pigtail catheter. An image of the arch and the origins of its branches is used to guide catheter passage for lesions of the subclavian and proximal axillary arteries.

TRANSFEMORAL APPROACH TO THE SUBCLAVIAN AND AXILLARY ARTERIES

The lesion is usually identified during arch aortography. Heparin is administered, 50 to 75 U/kg. An Amplatz guidewire is placed and the pigtail catheter is removed. A 7 Fr, 90-cm length, straight sheath with a radiopaque tip is passed and the tip is advanced to within a few centimeters of the orifice of the subclavian artery. The Amplatz guidewire is exchanged for a steerable, angled-tip Glidewire. The dilator is removed and the appropriate selective cerebral catheter (see Chapter 6), 100 to 120 cm in length, is placed through the sheath. The tip of the selective catheter is placed beyond the end of the sheath. The steerable guidewire probes the orifice of the artery with support and direction provided by the selective catheter. The guidewire is advanced across the lesion and as far into the artery as possible to provide support for the catheter to be advanced (Fig. 3). The catheter is advanced into the subclavian artery. Selective arteriography may be performed if necessary. A stiffer guidewire, such as an Amplatz or a Rosen, is placed. The selective

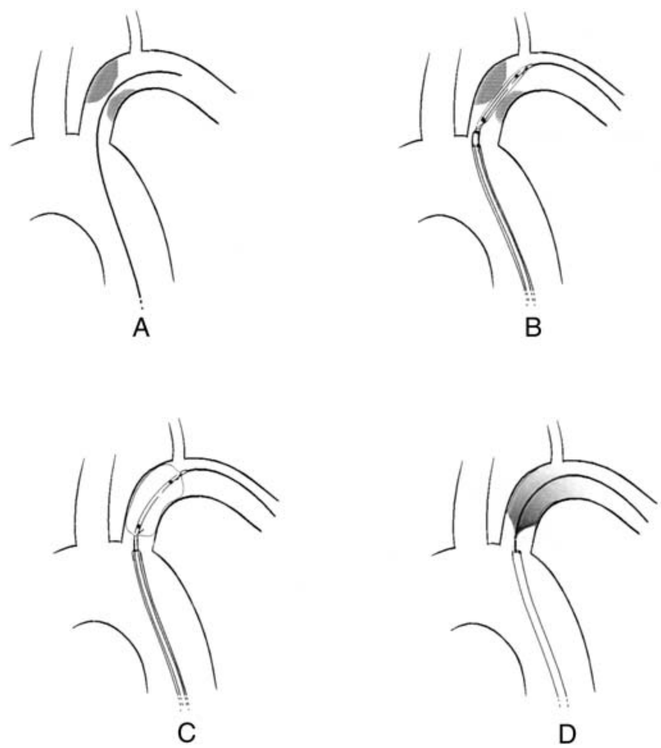

Fig. 3 Balloon angioplasty of the subclavian artery through a transfemoral approach. A, A guidewire is placed in the subclavian artery and across the lesion. **B,** A long sheath is placed with its tip in the subclavian artery. An angioplasty catheter is placed. **C,** Balloon angioplasty of the subclavian artery lesion is performed. **D,** Completion arteriography is performed through the sheath.

catheter is removed, the dilator is placed, and the sheath is advanced into the artery origin. Arteriography and heparin flush administration may be performed through the sidearm of the sheath.

The best lesions for angioplasty in this area are short and are located well proximal or distal to the vertebral artery. A lesion juxtaposed to the vertebral artery is better treated with open surgery. The balloon diameter is usually between 6 to 8 mm. The balloon catheter is placed across the lesion. The balloon is inflated and resolution of the atherosclerotic waist is observed using fluoroscopy (Chapter 14). Because the subclavian artery is soft and a rupture in this location has potentially disastrous consequences, it is important to avoid overdilatation. Completion arteriography is performed through the sheath. Selective stent placement is considered (Chapter 16). Subclavian artery orifice lesions are usually treated with balloon-expandable stents since these are often heavily calcified and spill over lesions from the aortic arch and the artery is relatively fixed in position at this site. Lesions in more distal locations are best treated with self-expanding stents, since the artery is more flexible and mobile in these areas and may be affected by external structures and forces. Stents should be avoided distal to the humeral head if possible since this is an area of very high flexibility.

Stent placement considerations in the subclavian artery are similar to those for the common carotid artery. If a balloon-expandable stent is required, a medium Palmaz stent may be mounted on the appropriately sized balloon with a 90- to 120-cm shaft length (Fig. 4). The balloon and stent are passed through the sheath and across the lesion and the stent is deployed. Advancing the sheath across the lesion for stent delivery may not be necessary as long as the sheath tip has a secure purchase on the artery

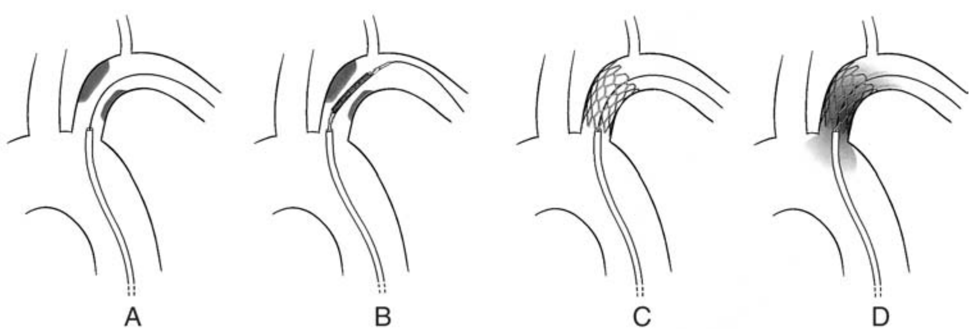

Fig. 4 Stent placement in the subclavian artery through a transfemoral approach. A, A long sheath is placed in the proximal subclavian artery. **B,** The stent is delivered to the site of the lesion. **C,** Stent deployment is performed. Caution is exercised during stent deployment to avoid engaging the tip of the sheath with the stent and to avoid deployment in proximity to the origin of the vertebral artery. **D,** Completion arteriography is performed through the sheath.

origin. Self-expanding stent diameter should be 8 or 10 mm and the delivery catheters are 120 cm. The delivery catheter is passed through the sheath and across the lesion, and the stent is deployed. Poststent balloon angioplasty is performed. Completion arteriography is performed through the sheath.

Lesions at the orifice of the subclavian artery pose similar challenges to those that occur at the common carotid artery origin. When the sheath is withdrawn to expose the stent, the tip of the sheath loses its purchase on the artery. When treating this type of lesion from a transfemoral approach, pull the sheath back slowly and place the tip of the sheath in the arch but close to the origin of the artery. Another option is to place the stent through a retrograde, transbrachial approach, which is usually simpler.

RETROGRADE APPROACH TO THE SUBCLAVIAN AND AXILLARY ARTERIES

The transbrachial, retrograde approach to the subclavian and axillary arteries is direct and does not require selective catheterization from a remote entry site, as does the transfemoral approach (Fig. 5). The patient's ipsilateral arm is extended at the side. A working table is placed at the end of the arm board to accommodate the guidewires and catheters. The transbrachial approach may be performed through either an open exposure of the artery or a percutaneous puncture (Chapter 2).

The guidewire is advanced retrograde using fluoroscopy. If stent placement is a likelihood, it is usually best to place a 7 Fr access sheath. Otherwise a 5 or 6 Fr sheath may be inserted. It is sometimes useful to place a longer sheath (20 to 40 cm), depending upon the location of the lesion, and perform retrograde arteriography through the sidearm of the sheath. Heparin is administered. The guidewire is advanced through the lesion. When the lesion of interest is at or near the origin of the subclavian artery, it is usually

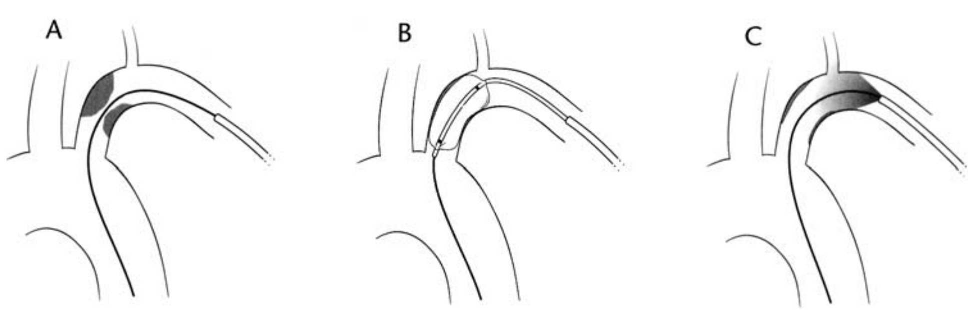

Fig. 5 Balloon angioplasty of the subclavian artery through a transbrachial approach. A, A guidewire and sheath are placed through a brachial artery puncture or cutdown. **B,** A balloon catheter is advanced through the sheath and into the lesion and balloon angioplasty is performed. **C,** The balloon is withdrawn and completion arteriography is performed using a retrograde approach through the sheath.

best to place a pigtail catheter through the femoral artery and perform an arch aortogram using a pressure injector. When a standard-length access sheath (12 to 15 cm) is used at the brachial artery entry site, retrograde arteriography through the sheath is usually not possible. After the guidewire is advanced across the lesion, a straight catheter with multiple side holes may be advanced over the guidewire until its tip is proximal to the lesion and this catheter may be used for arteriography.

If the lesion is proximal to the vertebral artery, the guidewire must be advanced into the descending aorta to maintain adequate control at the intervention site (Fig. 8 in Chapter 6). The guidewire is directed into the descending thoracic aorta using a selective catheter with a bend at the tip. The balloon catheter with a 75-cm shaft is placed and the balloon is inflated. Completion arteriography is performed. Subclavian artery lesions often exhibit significant recoil after angioplasty and origin lesions contain spillover plaque from the aortic arch that can be recalcitrant to angioplasty. Either situation may necessitate stent placement.

Stenting of the orifice of the subclavian artery should be performed with a balloon-expandable stent. If the artery is too tortuous to safely pass a 7 Fr sheath through the lesion, the sheath is advanced as far as possible and then a premounted medium Palmaz stent is passed beyond the end of the sheath. Tortuous segments of the artery can be stented with self-expanding stents as with the transfemoral approach. The shaft length for self-expanding stents through the brachial approach is 80 cm. Stent placement across the origin of the vertebral artery is contraindicated. The long-term success of stents in the highly mobile segment of the subclavian–axillary artery as it crosses the first rib is not known but may be poor. If a lesion juxtaposed to the first rib requires stent placement, use a self-expanding stent. Consider first rib resection at a later time.

Selected Readings

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18

The Renal Arteries

Advice About Balloon Angioplasty and Stent Placement

Selected Readings

The renal arteries are usually approached retrograde, but an antegrade approach through a brachial puncture site can be used when the angle of the renal artery takeoff from the aorta is narrow or when severe aortoiliac disease prohibits catheterization of this segment. Chapter 6 contains a detailed discussion of renal artery catheterization. Chapter 8 provides information about aortorenal and selective renal arteriography. Supplies required for renal artery intervention are listed in Table 1.

After retrograde femoral puncture, the guidewire is passed to the level above the upper abdominal aorta. A 4 or 5 Fr flush catheter is placed and the guidewire is removed. The catheter head is placed at the junction of the first and second lumbar vertebral bodies. It is best to perform a complete aortoiliac arteriogram if renal function permits. This allows accessory renal arteries and other variations to be identified, as well as disease that is present along the approach to the renal arteries. The operator then knows where other disease is located that may potentially cause complications during intervention. After this is performed, a magnified view of the aorta and renal artery origins should be obtained. The image intensifier usually has an obliqued orientation slightly toward the side of probable intervention. After the image intensifier is optimally located, it is usually best not to move it until after the artery is cannulated.

The renal arteries are unique in terms of their mobility with breathing. The origins of the renal arteries are relatively fixed in place by the

Table 1 Supplies for Renal Artery Intervention

Guidewire	Starting guidewire	Bentson	145-cm length	0.035 in. in diameter
	Selective guidewire	Magic Torque	180 cm	0.035 in. (marker tip)
		Glidewire	180 cm	0.035 in. (angled tip)
	Exchange guidewire	Rosen	180 cm	0.035 in. (J tip)
Catheter	Flush catheter	Omni-flush	65-cm length	5 Fr
	Selective catheter	Cobra C_1, C_2	65, 80	5 Fr
		Renal double curve	65, 80	5 Fr
		Renal curve 1, 2	65, 80	5 Fr
		SOS omni 2	80	5 Fr
Sheath	Selective guide sheath	Ansel 1, 2, 3	45-cm length	6 Fr, 7 Fr
		RDC	55 cm	7 Fr
Balloon	Balloon angioplasty catheter	Balloon diameter	4, 5, 6, 7 mm	5 Fr
		Balloon length	2, 4 cm	
		Catheter shaft	75 cm length	
Stent[a]	Balloon-expandable stent	Palmaz-Corinthian or Genesis (premounted)	Stent diameter	5, 6, 7 mm
			Stent length	12–29 mm
			Shaft length	80 cm

[a] No stents are approved by the FDA for routine usage in this vascular bed.

diaphragmatic crus. The renal parenchyma and surrounding tissues within Gerota's fascia are mobile with diaphragmatic excursion. The result of this anatomic arrangement is that the angle of takeoff of the renal arteries from the aorta varies with the ventilatory cycle. The anatomic picture portrayed with arteriography varies depending upon how the diaphragm was held during arteriography. A fully held breath tends to accentuate the acute angle at the origin of the renal artery by pushing the kidney caudad (Fig. 1).

There are two general approaches to renal angioplasty (Fig. 2). The first, which is not used much any more, involves placement of a balloon catheter over the guidewire and into the renal artery. This method is fast and simple but the access to the renal artery is not very secure. The second involves a guiding sheath or guiding catheter placed directly into the renal artery to secure the access and act as a conduit for contrast and medication administration and passage of a stent. This method is best because it is safer.

After the decision is made to proceed with treatment, a guiding sheath is selected that best fits the angle and curvature of the renal artery origin. There are numerous shapes, specially designed for renal artery intervention, which are available through different companies. The Ansel guiding sheaths are produced by Cook, Inc. There are three different curves to choose from (Fig. 3). The tip of the sheath is soft and radiopaque. The transition from dilator to sheath is smooth, and the distance that the dilator extends beyond the sheath is very short. This permits the tip of the sheath to be placed within the renal artery without a long segment of leading dilator tip

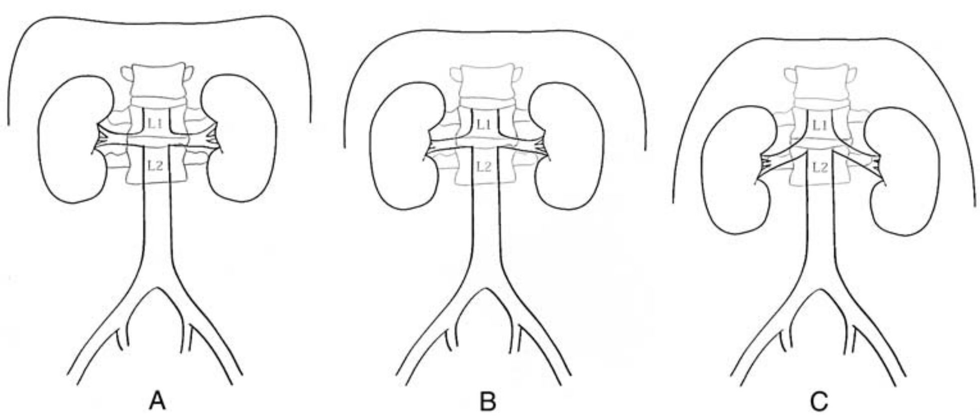
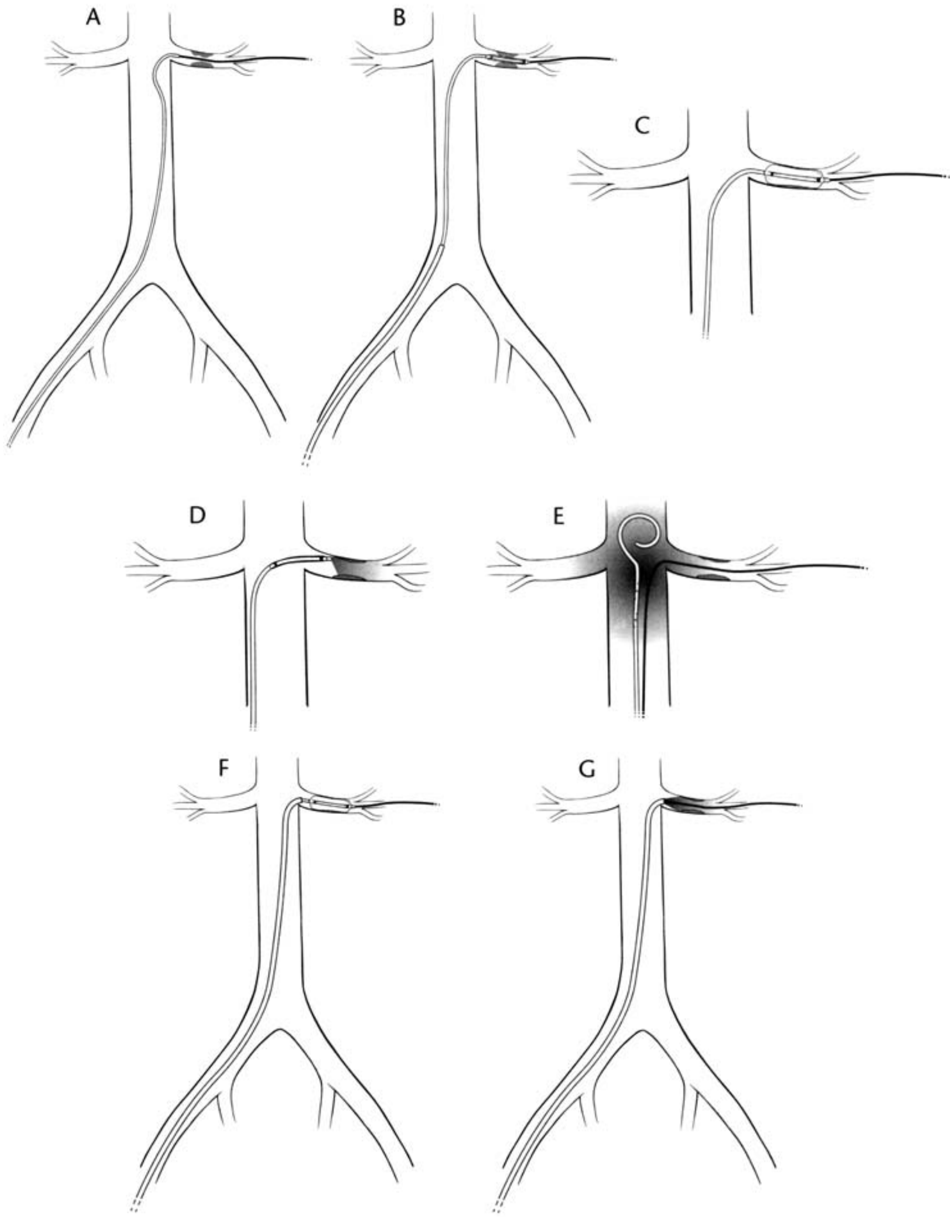


Fig. 1 Renal artery position is dependent upon diaphragmatic motion. A, At full exhalation, the kidney position is high in the retroperitoneum and the angle at the renal artery origin is affected accordingly. **B,** During mid-inhalation, the angle of takeoff at the renal artery origin becomes more acute. **C,** At full inspiration, the renal artery origin is at an even more acute angle.


A
B
C
D
E
F
G

advancing into the distal renal artery. A guiding sheath with a 6 or 7 Fr shaft and a 45-cm length is adequate.

Heparin is administered, 50 to 75 U/kg. A starter or exchange guidewire is passed and the flush catheter is removed. The femoral access site is dilated as needed. The guiding sheath is passed into the infrarenal aorta and its tip is placed just distal to the level of the renal arteries. The dilator is removed and a C2 cobra catheter is placed through the sheath with its tip extending beyond the end of the sheath and proximal to the renal arteries. An angled-tip Glidewire may be preloaded into the cobra catheter but it does not extend into the catheter head. The tip of the C2 cobra catheter is pulled along the posterolateral aortic wall. When the tip of the catheter falls into the orifice of the renal artery, the guidewire is advanced (Fig. 4). A critical orifice lesion may make it difficult to enter the renal artery. In this case, the steerable guidewire tip must be used to gently probe the origin of the artery. After the guidewire traverses the lesion, it is advanced into a secondary branch. This is done to maintain as much purchase on the artery as possible. However, the guidewire should not be forced or advanced against resistance because it can perforate the parenchyma.

The selective catheter is passed over the guidewire into the renal artery. If selective arteriography or pressure measurements are required, they are performed at this point. Nitroglycerine may also be administered through the catheter to help prevent renal artery spasm. A new guidewire is then inserted into the cobra catheter, instead of the angled Glidewire, which was useful for entering the artery and crossing the lesion. This new 0.035-in.-diameter guidewire, over which the renal artery intervention will be done, has more body and is less likely to move or become dislodged with catheter exchanges. Options include the Rosen guidewire, which has a tight, atraumatic, J-shaped tip, or the Magic Torque, which also has 1-cm markers along its floppy, atraumatic tip. Another choice is the McNamara guidewire, which is 0.018 in. in diameter and has a precurved mid-wire bend to accommodate the turn required to enter the renal artery. Keeping the guidewire in the

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Fig. 2 Balloon angioplasty of the renal artery. A, The left renal artery is cannulated with a cobra catheter and the guidewire is advanced across the stenosis. **B,** An angioplasty balloon is advanced over the guidewire and across the lesion. **C,** Balloon angioplasty of the left renal artery is performed. **D,** Completion arteriography is performed by removing the guidewire and withdrawing the balloon enough to administer contrast through the balloon catheter. This is a simple maneuver but if there is a problem at the angioplasty site, it must be recrossed. **E,** Another option for completion arteriography is to place another catheter through an alternate site, which ensures guidewire control of the lesion. **F,** Angioplasty can also be performed through a guiding catheter advanced into the renal artery orifice. **G,** A completion renal arteriogran is obtained by injecting contrast through the guiding catheter.

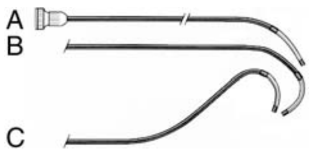

Fig. 3 Access for renal artery intervention. The Ansel (Cook, Inc.) renal guiding sheath tips are shown here. These sheaths have a hemostatic valve, a sidearm, and a dilator. The Ansel 1 (A), Ansel 2 (B), and Ansel 3 (C) sheaths are used for progressively more acutely angled renal arteries.

correct place is a challenge throughout the remainder of the case. Every maneuver tends to move the guidewire, and yet the end organ is so close that only a short length of relatively soft (atraumatic) guidewire can be maintained within the artery.

The guiding sheath may be advanced slightly toward, but not into, the origin of the renal artery over the selective catheter and new guidewire. If the lesion is located in the renal artery, distal to the ostium, the guiding sheath may be advanced by maintaining the guidewire in place, exchanging the selective catheter for the dilator, and advancing the sheath until its tip is within the renal artery. If the lesion is located at the ostium of the renal artery, it almost always requires stent placement and usually needs predilatation with a 4- to 6-mm angioplasty balloon prior to placement of the guiding sheath for stent placement. With the sheath tip close to the renal artery origin, the cobra catheter is removed and exchanged for a balloon angioplasty catheter.

The angioplasty balloon is usually 2 cm in length and mounted on a 5 Fr shaft. A diameter of 4 to 6 mm is usually adequate. Inflation is observed using fluoroscopy and may cause flank pain. If balloon angioplasty alone is intended, the guiding sheath is maintained in place, along with the guidewire, and the balloon catheter is withdrawn. Completion arteriography is performed through the guiding sheath.

Selective stent placement should be considered for nonostial lesions that do not respond to angioplasty or for postangioplasty dissections. Atherosclerotic renal artery origin lesions usually require stents to achieve a substantial improvement from endovascular intervention, and most operators perform primary stent placement in this situation. After balloon angioplasty, if the need for stent placement is clear, the guiding sheath may be gently advanced over the angioplasty catheter with the balloon deflated. Often the tip of the sheath may be advanced across the lesion using this approach. Once the sheath is across the lesion, the balloon catheter is removed and exchanged for an angioplasty catheter with a mounted balloon-expandable stent. Premounted Palmaz Corinthian stents are useful for this task. The stents range in length from 10 to 30 mm and in

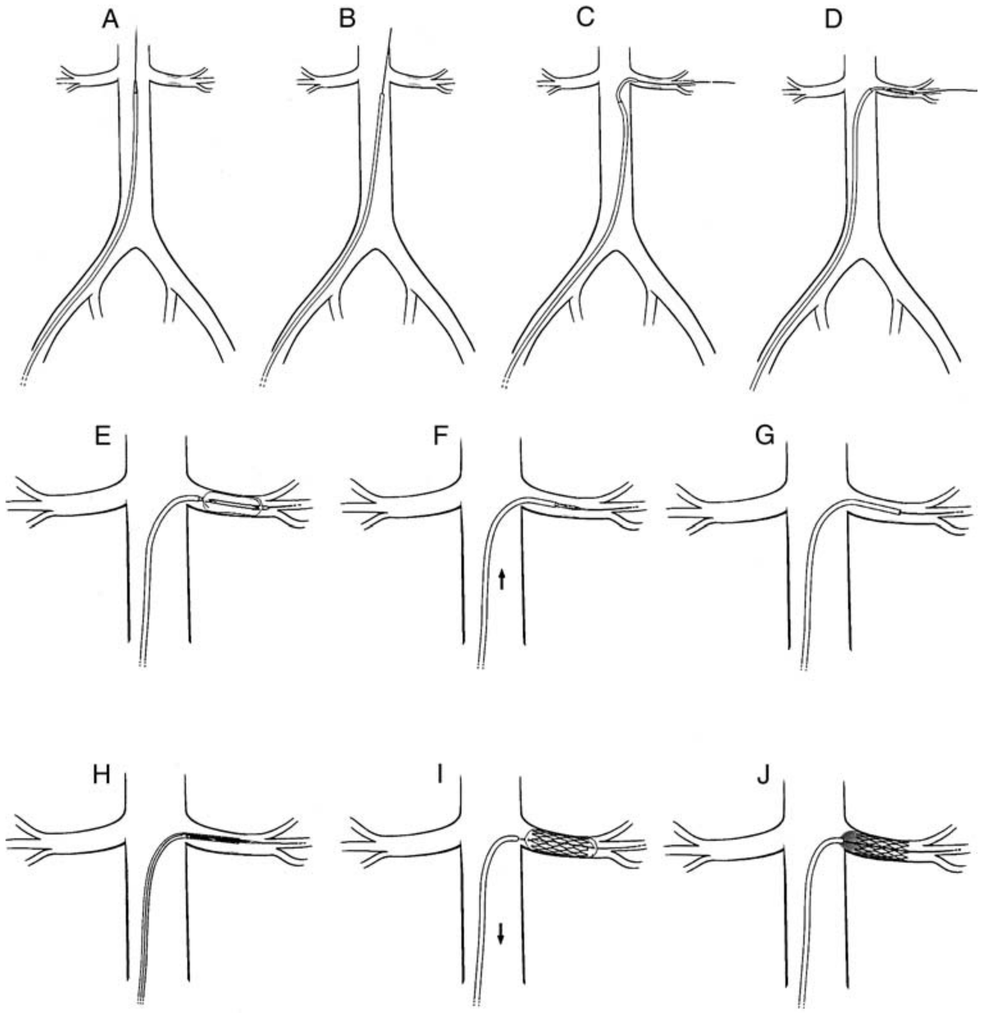

Fig. 4 Balloon angioplasty and stent placement through a guiding sheath. **A,** A guidewire and guiding sheath are placed in the aorta. **B,** The dilator is removed. **C,** A selective catheter, such as a C2 cobra, is placed through the sheath and into the renal artery. Guidewire access across the lesion is obtained. **D,** The balloon catheter is advanced through the guiding sheath and over the guidewire. The tip of the guiding sheath is maintained in proximity to the renal artery origin. **E,** Balloon angioplasty is performed. **F,** The sheath is advanced over the balloon catheter after the angioplasty. This permits the sheath to cross the lesion. **G,** The balloon catheter is removed. **H,** A premounted, balloon-expandable stent is advanced thorugh the sheath. **I,** The sheath is withdrawn slightly to provide clearance for the stent. The stent is deployed. If the lesion begins at the aorta, the stent is placed so that its leading edge is protruding slightly into the aorta to cover the aortic plaque. **J,** Completion renal arteriogram is performed through the guiding sheath.

diameter from 4 to 7 mm. In general, the shortest length stent that will cover the lesion should be deployed. If the Magic Torque guidewire is used, this can help estimate the required stent length. If the renal artery has substantial tortuosity, the stent will straighten a segment of the artery, leaving all the curvature over a shorter segment of remaining nonstented vessel. This can inadvertently create an undesired kink in the artery. Efforts should be made to avoid this situation.

The balloon and mounted stent are advanced through the sheath and across the lesion. The guiding sheath is gently withdrawn to uncover the stent. The correct position may be confirmed with a puff of contrast through the sheath. The stent is placed so that the aortic end is deployed to treat the aortic plaque as it spills over into the renal artery. Aortic wall calcium deposits often provide a good landmark for this deployment. Completion arteriography is performed through the sheath. If this is satisfactory, an aortorenal arteriogram may also be performed by pulling the sheath tip well back into the infrarenal aorta and placing the flush catheter through the sheath. Because stent placement limits options for later operative reconstruction, they should be used conservatively.

There is another stent delivery option that deserves mention but that is rapidly becoming outmoded. The stent, mounted on a balloon catheter, is preloaded into an 8 Fr guiding catheter. A Tuohy-Borst adapter (V. Braun Medical, Bethlehem, Penn.) is placed on the hub of the guiding catheter to make it hemostatic. A sidearm on the adapter may be used for arteriography, flush, or administration of medications. The entire apparatus is placed through an 8 Fr femoral artery access sheath. The loaded guiding catheter is passed through the hemostatic access sheath, over the guidewire, and into the orifice of the renal artery. The tip of the guiding catheter is advanced across the lesion to deliver the stent to the correct location. The balloon catheter is held in place and the guiding catheter is withdrawn enough to expose the stent. The balloon is inflated to deploy the stent. Completion arteriography is performed through the guiding catheter by injecting contrast through the sidearm of the Tuohy-Borst adapter.

Another approach to endovascular renal intervention that deserves mention and is likely to play an increasing clinical role is the use of smaller-caliber 0.018-in. and 0.014-in. systems. Guidewires, catheters, balloon catheters, and the sheaths that deliver them are being miniaturized. The smaller-caliber guidewire systems have the advantages of crossing critical lesions with smaller-diameter guidewires, permitting balloon angioplasty with a very low profile balloon, and allowing complex intervention through smaller-caliber sheaths. The disadvantages are the smaller-caliber guidewire is not as radiopaque; the smaller-caliber system does not provide as many guiding sheath choices so the larger sheath is usually used. As technology evolves, these low-profile systems will play an increasing role.

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19

The Infrarenal Aorta, Aortic Bifurcation, and Iliac Arteries

Advice About Balloon Angioplasty and Stent Placement

Aorta
Aortic Bifurcation
Iliac Artery
Selected Readings

Balloon angioplasty and stents have had a profound impact upon the management of atherosclerotic occlusive disease of the aortoiliac segment. The long-term results of endovascular intervention are not quite as good as with open surgery, but they are reasonable. However, the short-term risks of percutaneous interventions are generally fewer than with open surgery. There is a trend in current practice toward the use of open surgery only for

Table 1 Supplies for Aortoiliac Intervention

Guidewire	Starting guidewire	Bentson	145 cm, length	0.035 in. diameter
	Selective guidewire	Glidewire	150 cm	0.035 in. (angled tip)
	Exchange guidewire	Amplatz Super-stiff	180 cm	0.035 in.
Catheter	Flush catheter	Omni-flush	65 cm, length	4 Fr
	Selective catheter	Teg-T	65 cm	5 Fr
	Exchange catheter	Straight	70 cm	5 Fr
Sheath	Access sheath	Standard hemostatic access	12 cm length	6 Fr, 7 Fr, 9 Fr
	Straight sheath	Long straight with radiopaque tip	30, 35 cm	7 Fr, 9 Fr[c]
	Selective sheath[b]	Up-and-over	40 cm	6 Fr, 7 Fr
Balloon	Balloon angioplasty catheters	Balloon diameter	6, 7, 8, 9, 10, 12, 14, 16, 18 mm	
		Balloon length	4 cm	
		Catheter shaft	75 cm	5 Fr
Stent[a]	Balloon-expandable	Medium Palmaz		
		Stent diameter	P294 and 394 for diameters of 6–10 mm	
		Stent length	22–37 mm	
		Large Palmaz	(P308)	
		Stent diameter	10–14 mm	
		Stent length	25–28 mm	
		Delivery on 75-cm-length angioplasty balloon catheter		
	Self-expanding	Wallstent		
		Stent diameter	8, 10, 12 mm	
		Stent length	20, 40, 60 mm	
		SMART		
		Stent diameter	8, 10, 12, 14 mm	
		Stent length	20, 40, 60 mm	
		Delivery catheter length	80 cm	

[a] A 9 Fr sheath is used to introduce large-diameter balloons for aortic angioplasty (> 12 mm diameter) or a 12-mm-diameter Wallstent.
[b] An Up-and-over sheath is used for iliac intervention through contralateral femoral access.
[c] A 9 Fr sheath is used to introduce a large Palmaz stent (P308) for diameters of 10 to 12 mm.

patients who have failed endovascular intervention or in whom a percutaneous approach is not technically feasible. Chapter 6 provides a step-by-step approach for crossing the aortic bifurcation. Chapter 8 provides information about aortoiliac arteriography Supplies for aortoiliac intervention are listed in Table 1.

Aorta

Isolated, focal stenoses of the infrarenal abdominal aorta often respond to balloon angioplasty alone (Fig. 1). However, the availability of stents permits the treatment of more complex lesions with endovascular intervention.

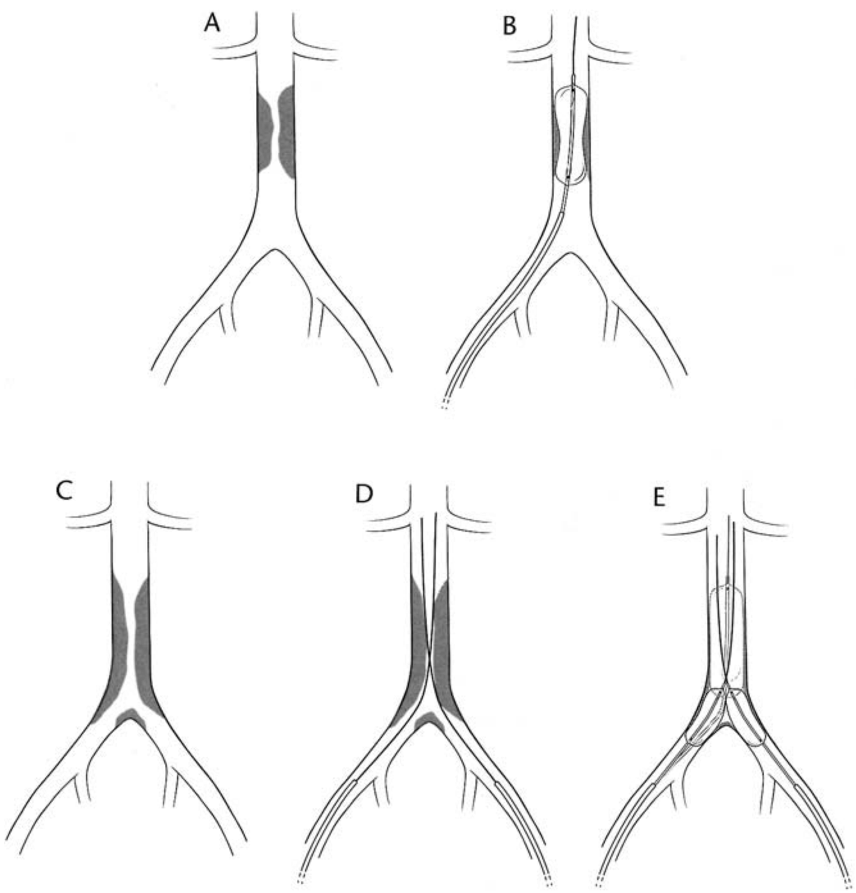


Fig. 1 Endovascular approaches to aortic lesions. A, A significant but focal lesion is isolated within the infrarenal abdominal aorta. **B,** Balloon angioplasty of the aortic lesion is performed. **C,** A more extensive lesion involves the infrarenal aorta and its bifurcation. **D,** The complex lesion is approached by placing a guidewire retrograde through each femoral artery. **E,** Balloon angioplasty is performed in the aorta and kissing balloons are used to dilate the bifurcation.

Stents provide the opportunity to approach lesions that would not be expected to respond to balloon angioplasty alone. Aortic lesions that extend to the bifurcation also require kissing balloons or kissing stents placed through each iliac artery.

Lesions that are limited to the infrarenal aorta may be accessed through a unilateral femoral approach on either side. Lesions of the aorta that extend near or into the aortic bifurcation should be accessed with a guidewire placed through each iliac artery. This is discussed in more detail in the next section. If there is coincidental, nonbifurcation, unilateral iliac disease that also requires treatment along with a separate aortic lesion, the access should be ipsilateral to the iliac lesion. This permits treatment of both the aortic and iliac lesions through the same approach without passing guidewires and sheaths over the aortic bifurcation.

Retrograde passage of the guidewire is performed from the femoral puncture site and an aortogram is performed using a flush catheter. After appropriate arteriography is completed and the decision is made to proceed with treatment, 50 U/kg of heparin is administered. The operator may consider a larger bolus of heparin when treating very complex or embolizing lesions or preocclusive stenoses or if longer indwelling catheter times are anticipated. The catheter is removed and the appropriately sized sheath is placed through the femoral entry site (Fig. 2). If there is significant tortuosity, the lesion is very complex, or a particularly large sheath is anticipated, the operator should consider placing an Amplatz guidewire to provide extra support during the intervention. Standard-length hemostatic access sheaths of 10 to 12 cm may be used for simple balloon angioplasty and placement of self-expanding stents. A longer sheath, 30 to 40 cm, is required for placement of a balloon-expandable stent. The size of the sheath depends upon the intended diameter to which the aorta is to be dilated and whether a stent will be placed. Balloon angioplasty without stent placement may be performed up to 10 mm diameter using a 5 Fr catheter shaft through a 6 Fr sheath. Dilatation to 12 mm is performed using a 5 Fr catheter shaft through a 7 Fr sheath. A 9 Fr sheath is required for 14- to 20-mm balloons. Balloon-expandable stents up to 9 or 10 mm in diameter may be placed through 7 Fr sheaths. A 9 Fr sheath is required for balloon-expandable stents up to 12 or 14 mm. Larger diameters require 10 or 12 Fr sheaths. Self-expanding stents up to 14 mm in diameter may be placed using 7 Fr sheaths, with larger stents placed through 9 Fr sheaths.

Accurate sizing of an artery for balloon angioplasty is usually simpler for other arterial segments since the usual range of diameter sizes varies from 2 to 4 mm in most vascular beds. Aortic angioplasty is performed with balloons ranging from 8 to 18 mm in diameter. Sizing the intended diameter of the aorta may be challenging because of the broad range of potential sizes, but there are several options. A flush catheter with 1-cm markers may be used for

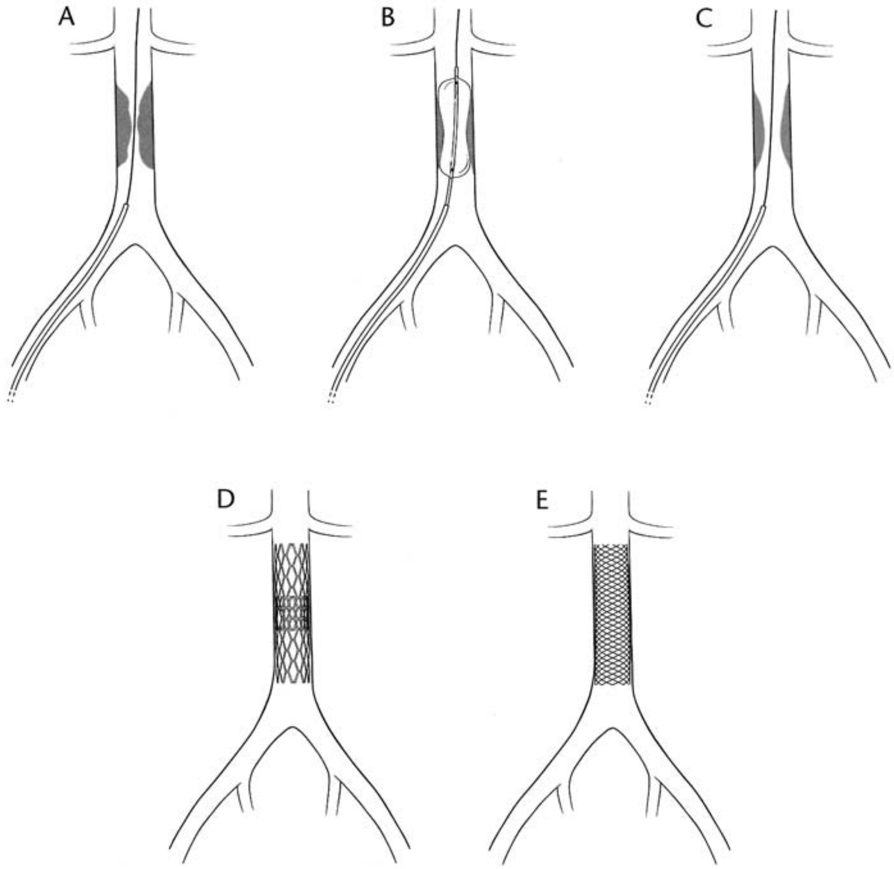


Fig. 2 Balloon angioplasty of the aorta. A, A guidewire is placed through a stenosis in the infrarenal aorta. **B,** Aortic balloon angioplasty is performed. **C,** A residual stenosis requires additional therapy. **D,** Palmaz stent placement requires the use of two overlapping stents to cover the entire lesion. **E,** A single Wallstent placed in the infrarenal aorta is another option.

the aortogram, and the known distance between markers may be used to calculate the desired diameter of the aorta for angioplasty. If intravascular ultrasound is available, this method probably provides the most accurate representation of vessel diameter. This modality requires a moderate-sized sheath that would also be required for aortic angioplasty. Another method is to proceed with balloon angioplasty using a balloon that is an underestimation of the probable aortic diameter and compare the inflated balloon profile to the preintervention aortogram. The selected balloon is advanced over the guidewire and into position using externally placed or bony markers.

The balloon is inflated under fluoroscopy. The aorta may rupture at lower pressure than smaller-diameter vessels so inflation is performed cautiously. Initial inflation with a slightly undersized balloon may be performed to evaluate how the lesion will respond to dilatation. Less than 8 atm of pressure is usually required to dilate aortic lesions. Larger balloons tend to have longer shoulders that extend a centimeter or more beyond the location of the radiopaque marker. The shoulders of the balloon must be placed so that they do not extend into an area not intended for dilatation, such as the proximal iliac artery. Balloon inventory for diameters larger than 10 mm is usually limited, so catheter availability should be confirmed prior to the procedure. If the appropriately sized balloons are not available, two equally sized balloons of half the desired diameter are placed retrograde, one through each femoral artery, and inflated together.

The balloon is brought to full profile and is then deflated. Repeat inflations may be performed if the waist has not resolved. The balloon catheter is withdrawn. Balloon deflation takes longer because the large balloon must empty through a relatively small lumen. Completion aortography is performed by exchanging the balloon catheter for an arteriographic catheter.

Because the infrarenal aorta is a large vessel, clinical success is often achieved despite an angiographically suboptimal appearance. In practice, a lumen of 10 to 12 mm is usually sufficient to support bilateral iliac flow. A major risk of aortic angioplasty, especially with a large plaque load, is lower-extremity embolization. A lesion that presents with embolization or appears to be prone to embolize can be treated with primary stent placement with outflow control (Fig. 3). However, it is important to ensure that the lesion is not contained within a small aneursym.

A large plaque load also increases the likelihood of a residual stenosis. The pressure is measured if it is not clear whether a bulky, residual plaque constitutes a hemodynamically significant lesion. If the lesion is significant, stent placement is a reasonable option (see Table 5 of Chapter 16). Many operators favor primary stent placement for aortic lesions, especially if there is a high degree of irregularity of the surface or a substantial amount of plaque. Primary stent placement permits the plaque to be caged by the stent and may decrease the likelihood of embolization or fragmentation during angioplasty. Choosing which stent to use can be a challenge. Self-expanding stents offer the advantage that the final resting diameter need be estimated to within 2 to 3 mm, as long as the selected stent is oversized and not too small in diameter. The balloon-expandable stents have better hoop strength and the precision of placement is slightly better.

When planning stent placement, a super-stiff guidewire should be used to take slack out of the system and improve placement accuracy. The appropriately sized sheath should be placed. A long sheath (35 cm) with a radiopaque tip is useful. Supplemental arteriography may be performed

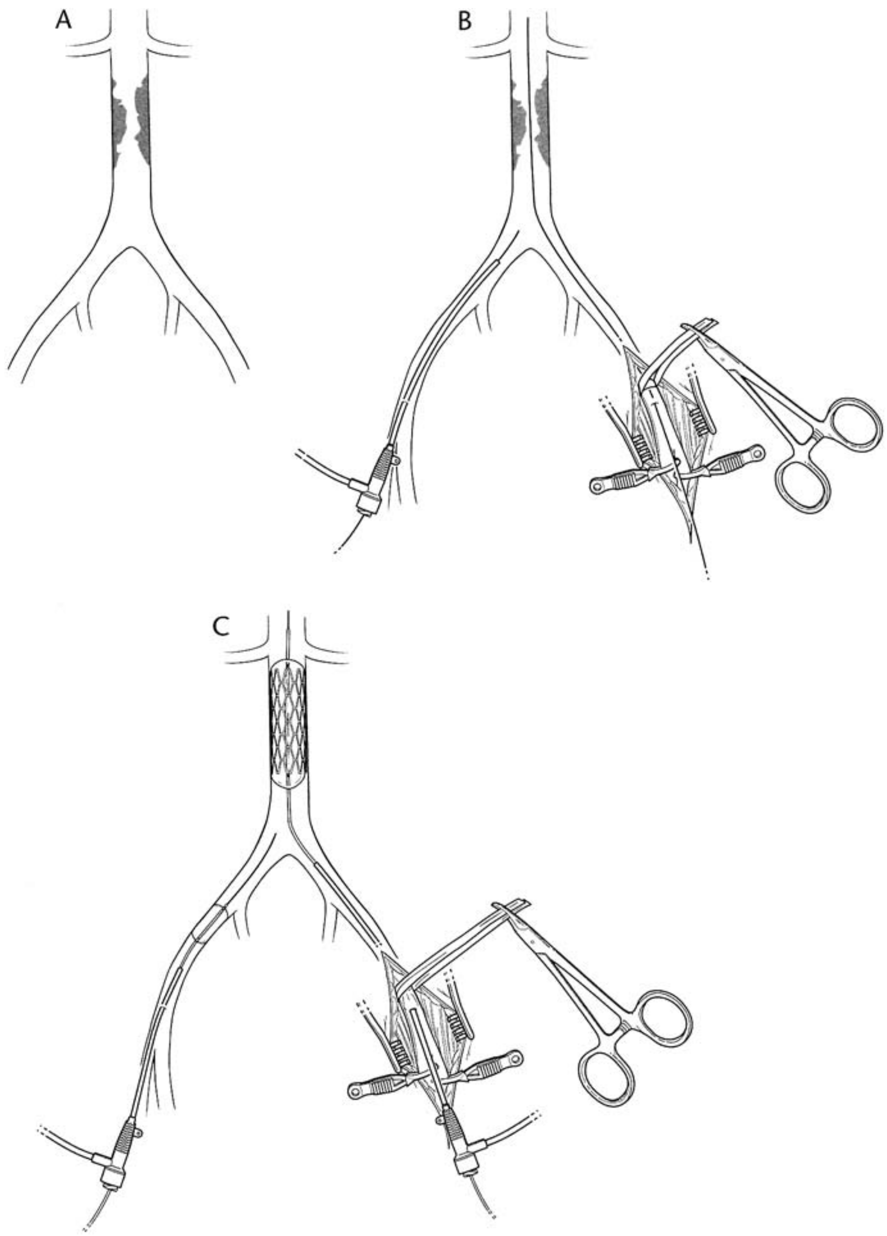


Fig. 3 Management of an embolizing aortic lesion. A, An ulcerated aortic lesion presents with embolization. **B,** Percutaneous access is obtained through one femoral artery and open access is obtained through the other femoral artery. **C,** An occusion balloon is placed in the proximal right external iliac artery using percutaneous access to prevent distal embolization. A stent is placed through the open left femoral access. The left lower-extremity outflow is clamped to prevent embolization.

through the sheath during stent deployment. Landmarks must be carefully considered and distances measured. Distance from the renal arteries and the aortic bifurcation should be considered. If the lesion extends to the aortic bifurcation, and this segment also requires treatment, it is probably best to place the aortic stent first, with single-guidewire access in the aorta (Fig. 4). A sheath is placed in the proximal common iliac artery on the contralateral side. After the aortic stent is placed, the contralateral guidewire is advanced very carefully through the aortic stent. Kissing iliac stents can then be placed, advancing inside the distal end of the aortic stent if necessary. Placement of the stent too close to renal arteries should be avoided, if possible. If the patient requires an aortofemoral bypass at a later time, stents placed in the very proximal infrarenal aorta will necessitate suprarenal cross-clamp of the aorta.

Self-expanding stents offer the advantage of a relatively larger stent diameter for a given sheath size. For example, a 7 Fr sheath accommodates 12- to 14-mm diameter self-expanding stents, whereas the largest balloon-expandable stent that can be placed through this sheath is 8 to 10 mm. Self-expanding stents should be oversized for the intended final diameter by about 2 to 3 mm. Wallstent length changes significantly with placement. The final resting length must be carefully estimated to ensure that the distal end of the Wallstent does not extend beyond the aortic bifurcation. Any location along the length of the Wallstent that does not reach its estimated final diameter causes the length of the stent to increase. Nitinol self-expanding stents, such as the Smart stent and the Symphony, do not have a significant length change with expansion. When placing a self-expanding stent across a ledgelike lesion, place the leading end of the stent 2 cm or more proximal to the ledge. This allows the proximal end of the stent to be opposed to the aortic wall proximal to the lesion. If the stent is placed too low, it will be constrained by the lesion and may even pop down distal to the lesion before it can be fully dilated. Self-expanding stents have an advantage at the larger diameters of 20 mm or more. In this range, self-expanding stents are available up to 28 mm that can be placed through an 11 Fr sheath. The only corresponding balloon-expandable stent available is a large Palmaz stent that is 5 cm in length and requires a very large sheath, at least 12 Fr, which can accommodate the large-diameter balloon and the stent simultaneously. Chapter 16 contains a detailed discussion of stent placement technique. After placement of a self-expanding stent, balloon angioplasty fully dilates the stent and embeds it into the aortic wall.

When using a balloon-expandable stent, the dilator and sheath are advanced carefully through the aortic lesion. If the residual lumen within the lesion is inadequate to permit sheath placement, predilatation is required. A 9 Fr sheath requires at least a 3 mm lumen for placement. A slightly undersized balloon may be used to place the stent initially, as long as it expands enough

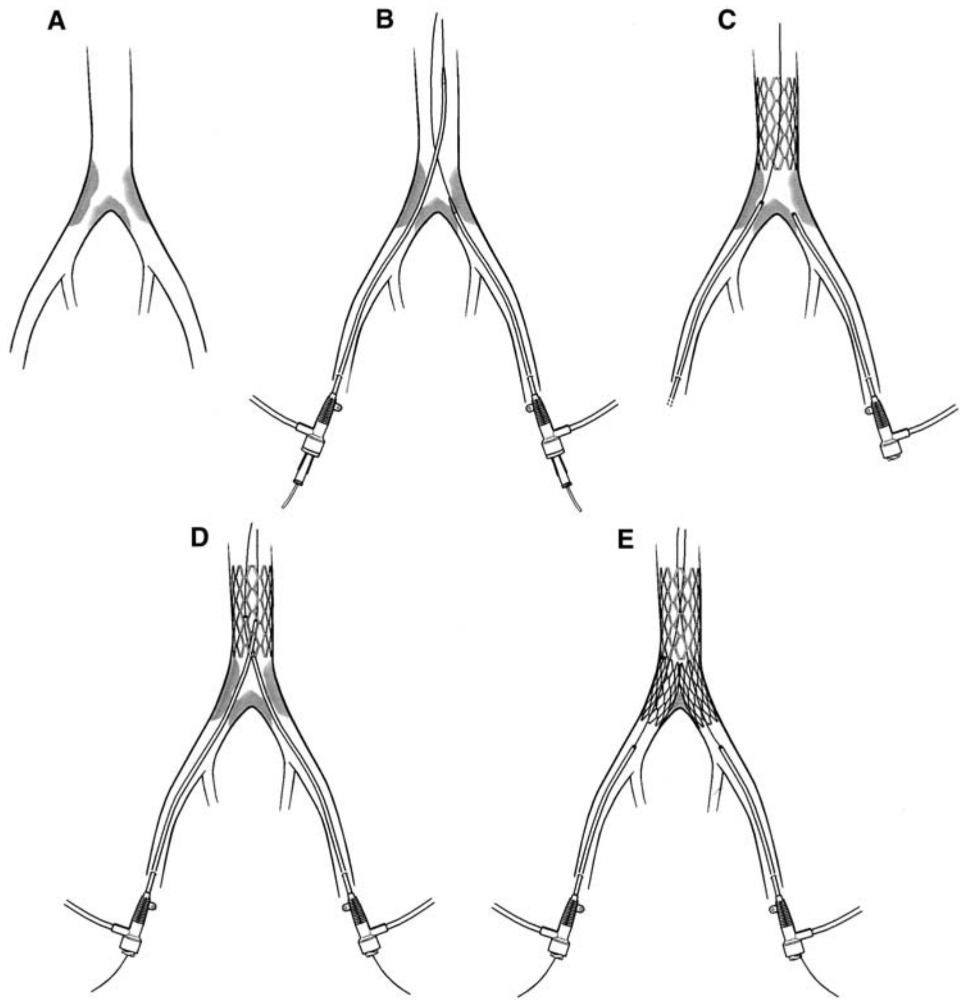


Fig. 4 Endovascular aortoiliac reconstruction. A, A lesion that involves the infrarenal aorta and the iliac arteries can be treated with a multistent reconstruction. **B,** Sheaths and guidewires are placed through each iliac artery. The sheath intended for delivery of the aortic stent (the right side in this example) is advanced into the aorta. **C,** The guidewire is withdrawn from the contralateral (left) side so that it will not be trapped behind the aortic stent. A stent is placed in the aorta. **D,** The contralateral guidewire is advanced through the aortic stent and both sheaths are advanced. **E,** Kissing stents are placed with their leading edges up to or even inside the aortic stent.

to be held in place by the lesion. The stent can then be further expanded with a larger balloon. If the intended aortic diameter is 10 mm or less, a medium Palmaz stent (P294 or P394) and a 7 Fr sheath can be used. Larger diameters, up to 12 mm, require a larger P308 stent and a 9 Fr sheath. Although the stated diameter upper limit for the P308 stent is 12 mm, it can be pushed up to 14 mm, but with additional foreshortening (to about 2 cm). If the lesion is longer than 2 cm, more than one Palmaz stent is used or a self-expanding stent is selected. After placement of the Palmaz stent, each end of the stent is dilated to be sure that it has assumed a cylindrical shape. If the lesion is close to aortic bifurcation, the stent will tend to lean toward the side opposite the femoral access when deployed because of the guidewire and balloon orientation. Consider placing a guidewire through a contralateral femoral access and using kissing balloons in the lower end of the stent. These balloons should be one-half the diameter of the stent. A 16-mm stent can be dilated with bilateral 8-mm balloons. Completion arteriography is performed by placing a flush catheter over the guidewire and administering contrast proximal to the stent site.

Aortic Bifurcation

Aortic bifurcation stenoses that extend into the proximal common iliac arteries are treated with a kissing-balloon technique (Fig. 5). This is usually aortic plaque, concentrated especially along the posterior wall, which has extended into the common iliac arteries. A guidewire is placed through each femoral artery and advanced into the aorta. If the femoral arteries are

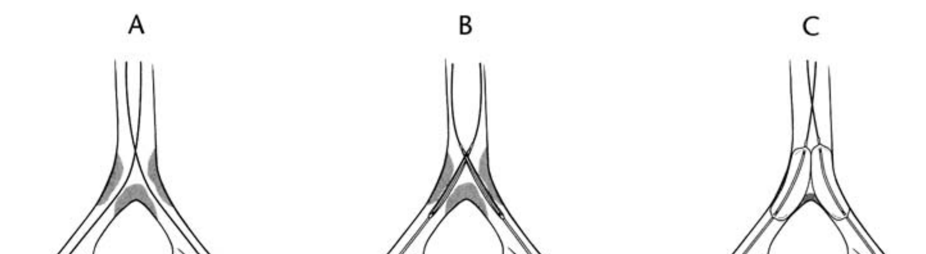


Fig. 5 Management of a lesion in the aortic bifurcation using kissing balloons. A, Bilateral guidewires are placed across a stenosis in the aortic bifurcation. **B,** One balloon catheter is placed retrograde through each femoral artery and the proximal radiopaque markers are placed so that they overlap. **C,** The equally sized balloons are inflated simultaneously to the same pressure to dilate the lesion in the bifurcation.

pulseless, use can be made of the techniques described in Chapter 2 for percutaneous puncture of a pulseless femoral artery. A micropuncture approach may be used, as described in the same chapter. Systemic heparin administration is not absolutely required for simple balloon angioplasty, but 25 to 50 U/kg should be considered. If a complex reconstruction, prolonged catheter time, or stent placement is anticipated, 50 to 75 U/kg of heparin should be administered. Starting guidewires are exchanged for Amplatz guidewires (0.035-in. diameter, 180-cm length) through a straight exchange catheter.

Sheaths are chosen as described in the previous section. If balloon angioplasty alone is planned, 6 Fr, standard-length access sheaths are adequate for balloons up to 8 mm in diameter, and 7 Fr sheaths are used for 9- or 10-mm-diameter balloons. Appropriately and equally sized balloons are advanced over the guidewires. The balloons are positioned so that the proximal radiopaque markers on each balloon overlap each other. The balloons are simultaneously inflated to the same pressure using dual inflation ation devices. This allows the entire aortic bifurcation and proximal iliac segments to be dilated simultaneously to the same pressure. This approach facilitates fracture of the often circumferential cast of plaque that develops at the aortic bifurcation.

The kissing-balloon technique is usually performed with balloons in the range of 6 to 10 mm in diameter. The size of the balloon must match not only the proximal common iliac arteries, but also the distal aorta. If there is significant narrowing in the distal aorta, it is important to remember that two separate balloons expanded simultaneously reach a large additive diameter. If 10-mm kissing balloons are used, the distal aorta must be 20 mm. If the aorta cannot quite accommodate that diameter, the balloons can be withdrawn just slightly to decrease to overlap between the two balloons in the distal aorta.

If results are not satisfactory, or if residual stenosis is significant following angioplasty, kissing-stent placement can be used to reconstruct the aortic bifurcation (Fig. 6). This technique raises the aortic flow divider by a few millimeters to a centimeter. Although either self-expanding or balloon-expandable stents may be used, balloon-expandable stents provide the advantage of better hoop strength to treat these orifice lesions. In addition, the proximal ends of the stents, which create the new aortic flow divider, are easier to match up during deployment. Bilateral 7 Fr sheaths are usually adequate in size to handle either self-expanding or balloon-expanding stents.

Matching balloon-expandable stents are mounted on the same size balloons as were used for the angioplasty. The same balloons that were used for angioplasty can also be used for stent placement, but this must be done cautiously. The reshaped balloon must be smooth so that when the stent is placed over it, the balloon is not pierced. If this is a concern, new balloons

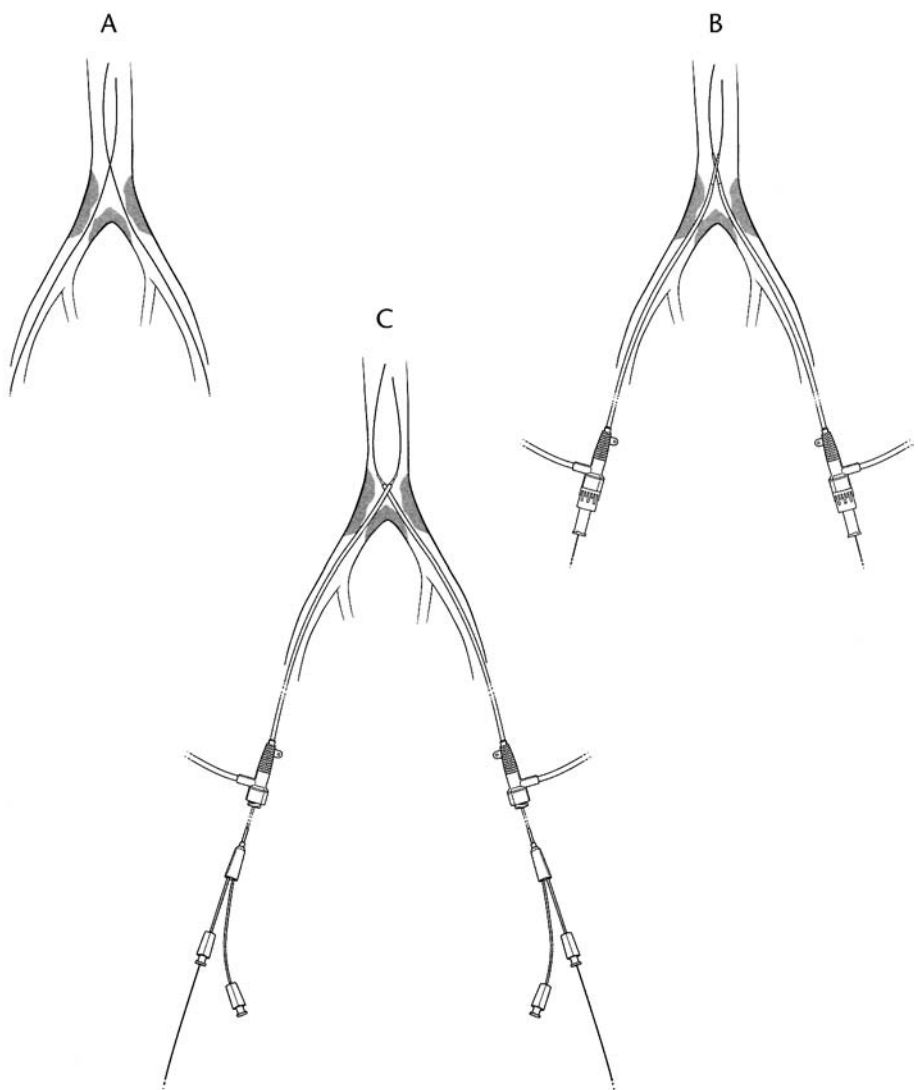


Fig. 6 Kissing stents. A, A significant residual stenosis remains after angioplasty. **B,** Long access sheaths are advanced into the distal aorta. **C,** The dilators are removed. **D,** Equally sized balloons with mounted stents are advanced through each sheath. **E,** The stents are deployed bilaterally by inflating the balloons simultaneously to the same pressure. **F,** Kissing stents can raise the aortic flow divider to reconstruct the bifurcation.

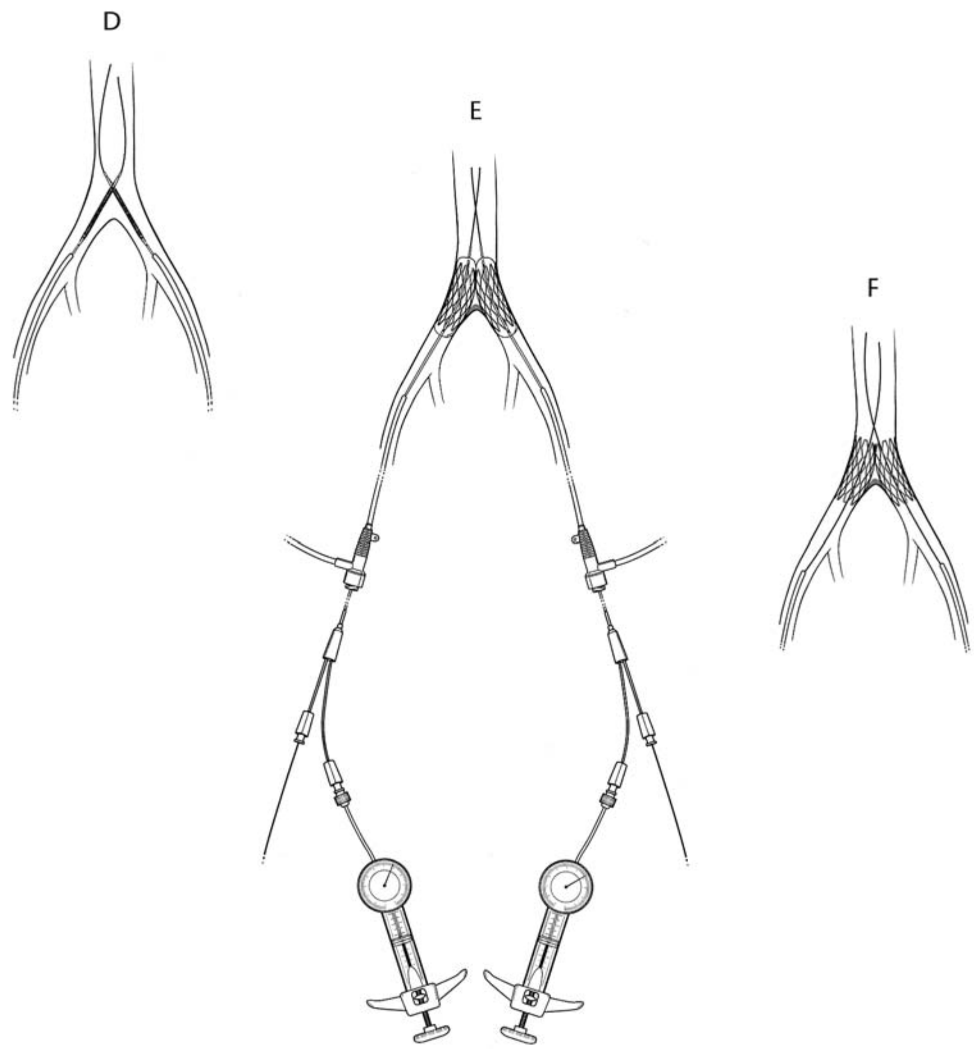


Fig. 6 (Continued)

should be used to avoid a false start during simultaneous stent deployment. A stent is mounted on the front of each balloon, up to the lead first radiopaque marker. Bilateral long sheaths, with dilators in place, are advanced into the distal aorta. Using fluoroscopy, the unexpanded stents are positioned so that the proximal radiopaque markers on the balloon catheters are parallel to each other, but not overlapping, as they are for kissing balloons alone. Examine the stents under fluoroscopy to be sure that they have not migrated on their respective balloons. The sheaths are gently withdrawn to expose the bilateral stents. The proximal ends of the stents are usually 2 to 10 mm proximal to the aortic flow divider, depending upon the amount of aortic plaque that must be treated. Road mapping may be used to outline the aortic bifurcation so that the stents are not placed more proximally than desired. Careful consideration should be given to the length of distal aorta to be stented. If the lesion extends more than a centimeter up into the aorta, a separate aortic stent secures inflow for the kissing stents at the bifurcation.

Kissing stents are best deployed with an assistant because balloon expansion must be performed simultaneously. Although an inflation device is not required to place all balloon-expandable stents, it is essential in this situation to maintain the balloon pressure at an equal level bilaterally. After stent placement, the balloons are reinflated at more proximal and distal positions to be sure that the stents have fully expanded. The balloon catheters are removed. A flush catheter is placed through one side and completion arteriography is performed.

Iliac Artery

Iliac artery balloon angioplasty is *the* index endovascular procedure. It is a common procedure and has had a profound impact upon the management of atherosclerotic occlusive disease. This procedure has a three-decade track record and has been refined and improved along the way. Technical modifications, such as stents, have dramatically expanded the complexity of the pathology that can be treated with endovascular intervention. It has superceded its surgical predecessor, aortofemoral bypass, in number, and in many practices has largely replaced this operation. In appropriately selected patients, overall results are quite good and risks are acceptable. The durable results of this operation have been extrapolated to angioplasty of other vascular beds in hope of justifying the broader use of balloon angioplasty at sites where there is much less long-term evidence of success. Failure of this procedure can often be treated with secondary endovascular procedures, and these rarely if ever take away later surgical options if they should become necessary.

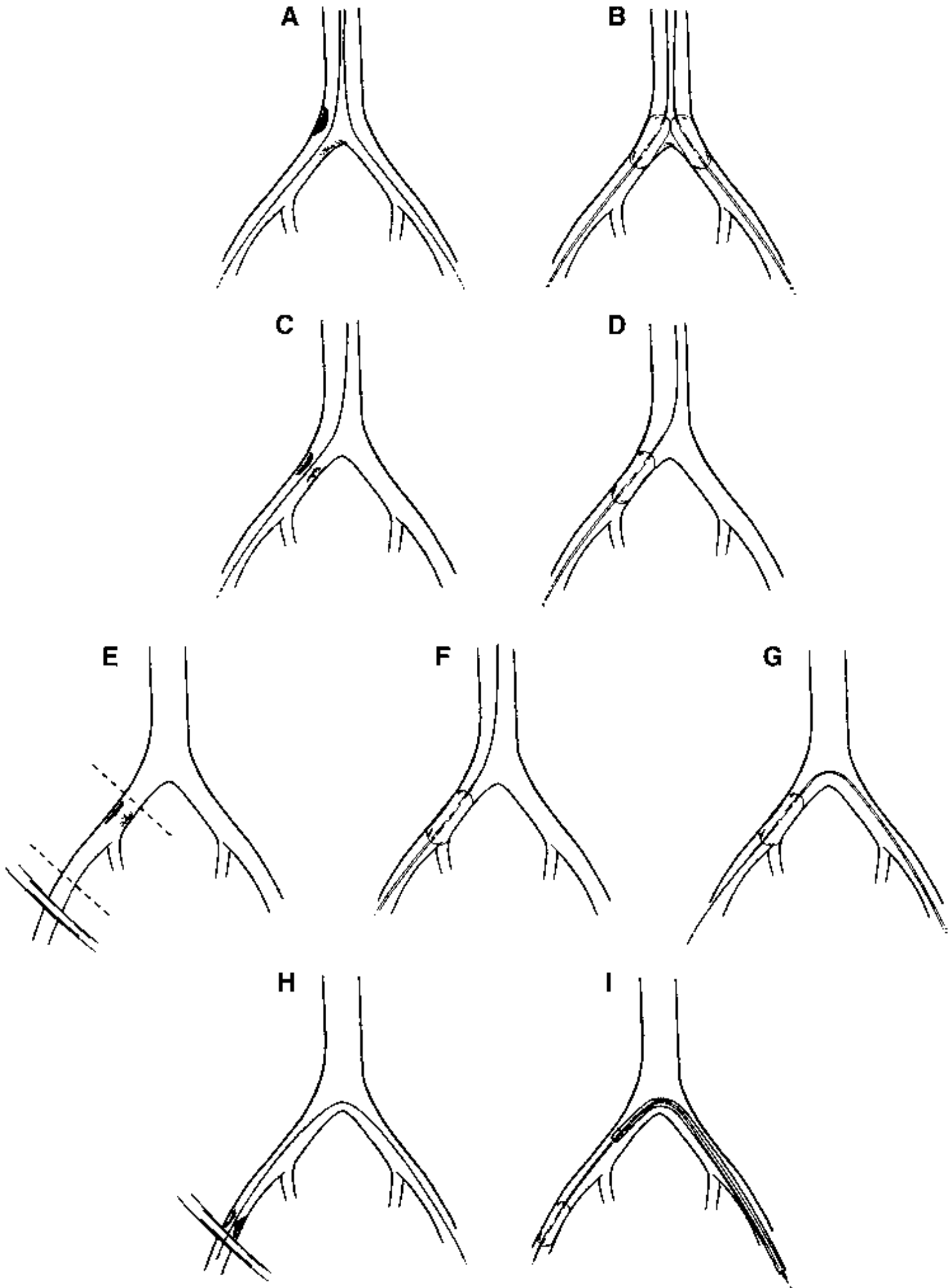
An iliac artery lesion can be approached either retrograde, through the ipsilateral femoral artery, or antegrade, through the contralateral femoral artery or an upper-extremity puncture site (Fig. 7). The location of the lesion determines the approach. Lesions of the aortic bifurcation, which are discussed in the preceding section, are treated with kissing balloons. Non-orifice lesions of the proximal common iliac artery are treated with a retrograde approach. There is not adequate working room between the aortic bifurcation and the lesion to treat these with a contralateral, up-and-over approach. Midiliac lesions, from the middle section of the common iliac artery to the middle section of the external iliac artery, may be treated by using either an ipsilateral retrograde approach or a contralateral antegrade approach. Lesions of the distal several centimeters of external iliac artery must be treated with an antegrade approach, usually through the contralateral femoral artery, since there is not enough working room to maneuver through an ipsilateral femoral access.

A retrograde approach is performed by puncturing the common femoral artery distal to the iliac artery lesion. The femoral artery pulse may be diminished or absent (see Chapter 2 for a detailed discussion and specific maneuvers for percutaneous access of the pulseless femoral artery). The ipsilateral retrograde approach is the most simple and direct once access has been obtained. The retrograde approach is useful for all iliac artery lesions except those in the very distal external iliac artery.

Standard, single-balloon angioplasty can be performed on iliac artery stenoses that begin a centimeter or more distal to the origin of the common iliac artery. Lesions that begin in the orifice of the common iliac artery impose a significant risk of pushing plaque into the contralateral iliac artery during balloon angioplasty. The kissing-balloon technique protects the contralateral side, even if there is no significant stenosis in the contralateral iliac origin. The challenging situation that often arises is a nonorifice proximal common iliac artery lesion that requires dilatation and the adjacent iliac artery origin is mildly or moderately diseased. In these cases, if the origin of the common iliac artery requires dilatation, kissing balloons should be used.

IPSILATERAL RETROGRADE APPROACH TO THE ILIAC ARTERY

After the strategic arteriogram has been evaluated and the approach is selected, the lesion is crossed with a guidewire if it has not already been traversed. When arteriography has been performed through the ipsilateral femoral artery, the guidewire has already been placed across the lesion When arteriography has been performed through a contralateral femoral puncture, the operator has the option of passing the guidewire over the aortic bifurcation or placing a retrograde guidewire through a new ipsilateral puncture site. If the lesion is complex, the approach is tortuous, the femoral access is difficult, or a multilevel intervention is anticipated, consider placing a super-stiff guidewire. Guidewires that are 0.035 in. in diameter and 150 to 180 cm in length are used. The appropriate sheath is selected and inserted using the same guidelines as in the previous section. Usually a 6 or 7 Fr sheath is adequate depending upon whether a stent is required. Short access sheaths of 10 or 12 cm are adequate for balloon angioplasty and for placement of self-expanding stents. Sheaths that are long enough to reach the lesion, usually 25 cm or more, are inserted if balloon-expandable stent placement is likely. Heparin is not always required, but may be administered at 25 to 75 U/kg at the discretion of the operator.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If there has been a significant change in the location of the image intensifier since the strategic arteriogram was performed, or the landmarks need to be rechecked, retrograde arteriography can be performed through the sheath. The image intensifier is placed in the best position and the appropriate field of view is used to get the optimal degree of magnification. The image intensifier is placed close to the abdominal wall. External iliac artery lesions and sometimes those in the distal common iliac artery are often well visualized using a contralateral anterior oblique projection. Radiopaque markers such as tape with 1-cm markers may be placed parallel to the guidewire on the patient's abdominal wall after the location of the image intensifier has been established. This type of external marker is particularly helpful when a small field of view is used for more magnification, since this field size tends to exclude some of the surrounding bony landmarks. The linear centimeter-length markers will not be accurate for exact length at the angioplasty site due to parallax.

The balloon is selected and passed over the guidewire through the lesion (Fig. 8). Common iliac artery angioplasty is performed with balloons between 6 and 10 mm in diameter. The balloons are usually either 2 or 4 cm in length and are mounted on 5 Fr catheters that are 75 or 80 cm in length. External iliac artery angioplasty is usually accomplished with 6- to 8-mm balloons. If it is difficult to pass the balloon catheter, the guidewire is exchanged with an Amplatz Superstiff. Occasionally, predilatation with a

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Fig. 7 Approaches to angioplasty of the iliac artery. A, A very proximal common iliac artery lesion is present that requires treatment. **B,** Proximal lesions are treated with kissing balloons, even if there appears to be minimal disease in the proximal contralateral iliac artery. **C,** Proximal common iliac artery lesions that are distal to the iliac artery origin by a centimeter or more are also treated through an ipsilateral retrograde femoral approach. **D,** This type of proximal common iliac artery lesion does not require a contralateral or kissing balloon. A balloon placed through the contralateral iliac artery and passed over the aortic bifurcation is not a good option for dilatation of this lesion, since there is not adequate working room between the aortic bifurcation and the lesion. **E,** Midiliac lesions are located between the mid–common iliac artery and the mid–external iliac artery and may be treated through a choice of multiple approaches. **F,** These lesions may be treated through an ipsilateral retrograde femoral approach. There is adequate working room for an ipsilateral femoral access and the lesion is not too near the aortic bifurcation. **G,** Midiliac lesions may also be treated through a contralateral approach. The guidewire and balloon catheter are passed over the aortic bifurcation. This may also be performed through an up-and-over sheath with the tip placed in the proximal common iliac artery. **H,** Distal external iliac artery lesions are located so that there is inadequate working room for an ipsilateral femoral approach. **I,** Distal external iliac artery lesions are approached through the contralateral femoral artery using an up-and-over sheath.

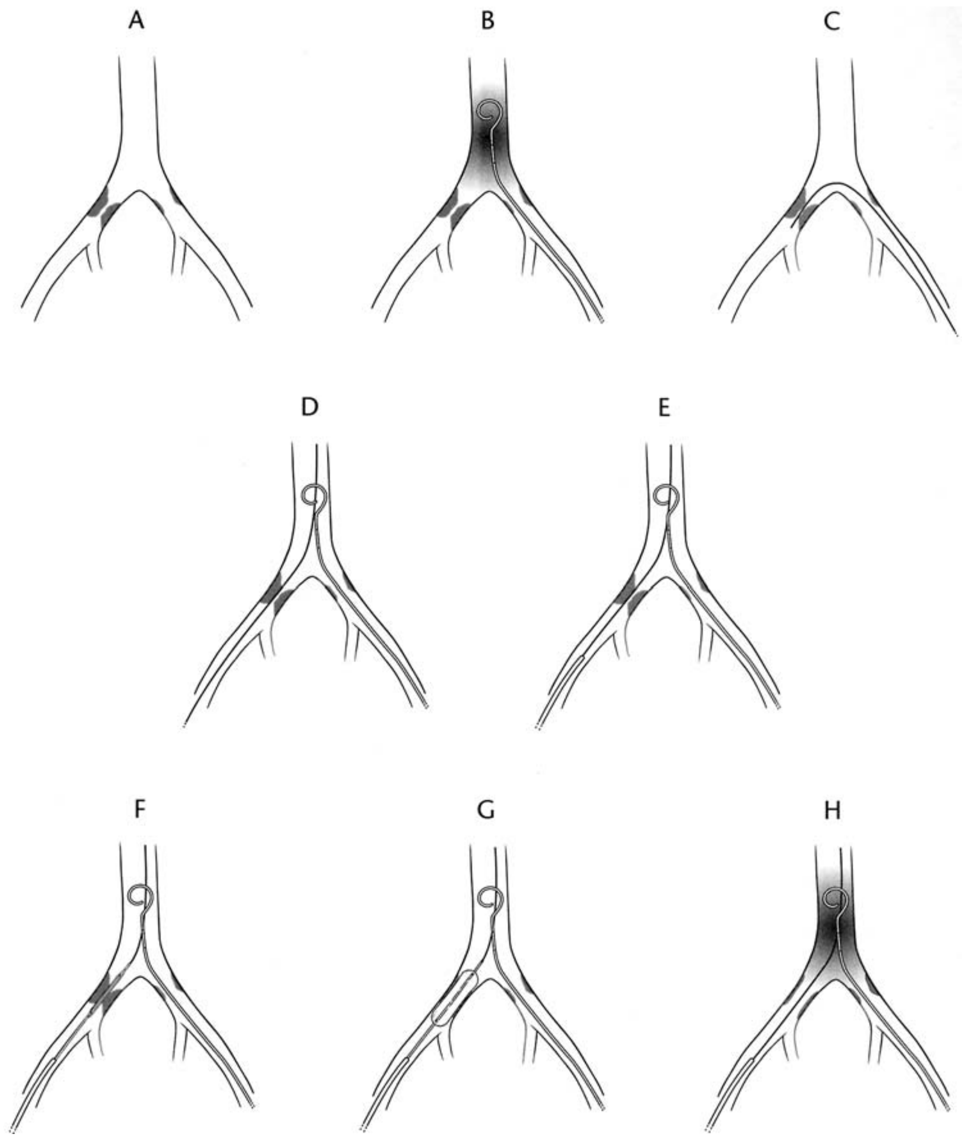

Fig. 8 Options for angioplasty of the iliac artery. A, A significant right iliac artery stenosis requires treatment. **B,** Aortography is performed through a contralateral femoral artery approach if the location of the lesion is not known precisely prior to arteriography. **C,** A lesion of the middle iliac artery segment is dilated by passing the guidewire and catheter over the aortic bifurcation. **D,** Another option is a second puncture site on the side ipsilateral to the lesion. If the location of the stenosis is known before arteriography, an ipsilateral retrograde puncture is used as the initial approach. **E,** An access sheath is placed to simplify catheter passage for angioplasty. **F,** A balloon catheter is passed across the lesion. **G,** The balloon is inflated to dilate the lesion. **H,** A contralateral catheter from the initial arteriogram is used for completion arteriography.

lower-profile, smaller-diameter balloon is required. This may occur in the setting of a heavily calcified but preocclusive lesion. The balloon is centered so that the radiopaque markers straddle the lesion. The location of the worst stenosis should be along the central segment of the balloon.

Iliac balloon angioplasty often causes flank discomfort, which should resolve when the balloon is deflated. Overdilatation may cause rupture. Lesions of the external iliac artery, especially origin lesions, are more likely to result in dissection following angioplasty. Completion arteriography can be performed through the sheath or with a flush catheter placed in the aorta proximal to the lesion.

Stents are placed for specific indications (see Chapter 16 for a detailed discussion of the indications for stents)(Fig. 9). There is more clinical experience and better results with stent placement in the iliac artery than at any other location. Most iliac artery lesions may be treated satisfactorily with either balloon-expandable or self-expanding stents (see Table 5 in Chapter 16). Long lesions and arteries with significant taper or tortuosity are best treated with the self-expanding stents. Focal lesions or lesions located at the origin of the common or external iliac arteries are treated with balloon-expandable stents. After the stent is selected, double-check the size of the sheath in place to be certain it is adequate in caliber. The appropriately sized sheath is placed. The intended location for stent placement is identified by external markers or bony landmarks. The area to be covered by the stent may be slightly different than for the preceding balloon angioplasty, especially if there has been a dissection that requires treatment. Greater precision is required for stent deployment than for balloon angioplasty alone.

After placement of either stent type, additional balloon angioplasty is performed. A stent can be placed across the origin of the internal iliac artery and patency is usually maintained (see Chapter 16 for a detailed discussion of the techniques of stent placement).

CONTRALATERAL APPROACH TO THE ILIAC ARTERY

The usual scenario for the contralateral approach is the setting of a contralateral puncture for a strategic aortoiliac arteriogram that then proceeds to treatment. The locations of the lesions are considered and an approach is selected (Fig. 7). A hook-shaped catheter is placed in the infrarenal aorta and used to direct the guidewire over the aortic bifurcation. This maneuver is described in some detail in Chapter 6. The guidewire is passed over the aortic bifurcation and into the contralateral femoral artery. The catheter is advanced into the femoral region and the guidewire is exchanged for a slightly stiffer one, such as a Rosen guidewire, which is used to support the passage of an up-and-over sheath. Heparin is administered. Insertion of an up-and-over sheath is detailed in Chapter 12. These sheaths are 40 cm in length and the caliber is selected in the same manner as for an ipsilateral retrograde approach. The up-and-over sheath has a radiopaque tip and can be advanced well into the contralateral iliac if the lesion is distal. The sheath should not be inadvertently advanced into the lesion.

After sheath placement, a repeat iliac arteriogram is usually performed after the image intensifier has been optimally positioned. External marking tape may also be placed. Arteriography is performed through the sheath. The appropriate balloon catheter is selected, as described in the previous section. Catheters 75 to 80 cm in length are usually adequate to reach to the contralateral groin. Balloon angioplasty is performed. The contralateral femoral area should be prepped into the field and the pulse is available for palpation. The

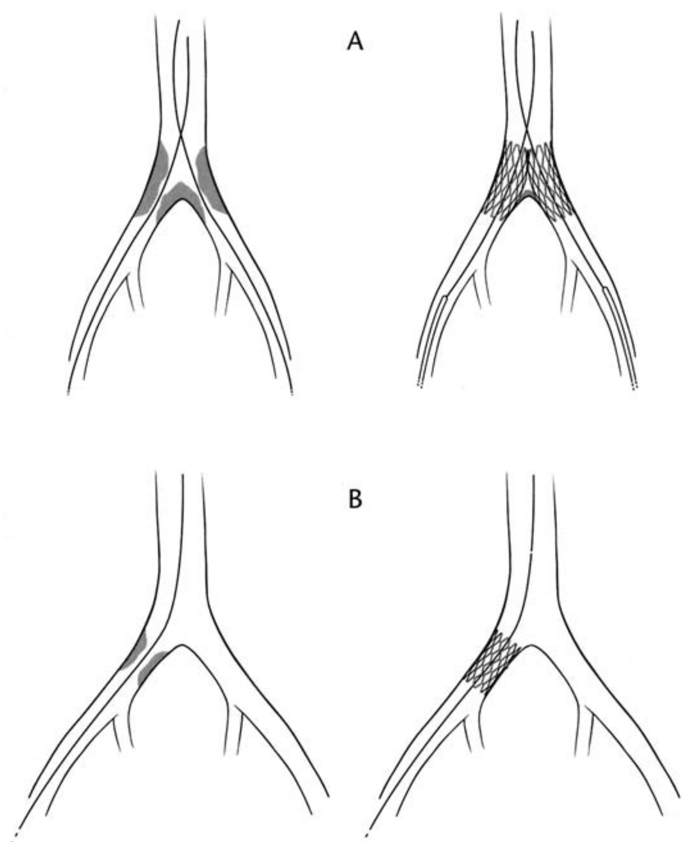

Fig. 9 Placement of an iliac artery stent. A, Aortic bifurcation lesions that spill over into the proximal iliac artery require kissing Palmaz stents. **B,** A short, focal iliac artery stenosis is treated with a single Palmaz stent. **C,** A lesion in a tortuous iliac artery is best treated with a flexible Wallstent. **D,** A long iliac artery stenosis is treated with a single Wallstent. **E,** A lesion that requires stent placement from over the aortic bifurcation is best treated with a self-expanding stent. The delivery catheter is passed over the aortic bifurcation.

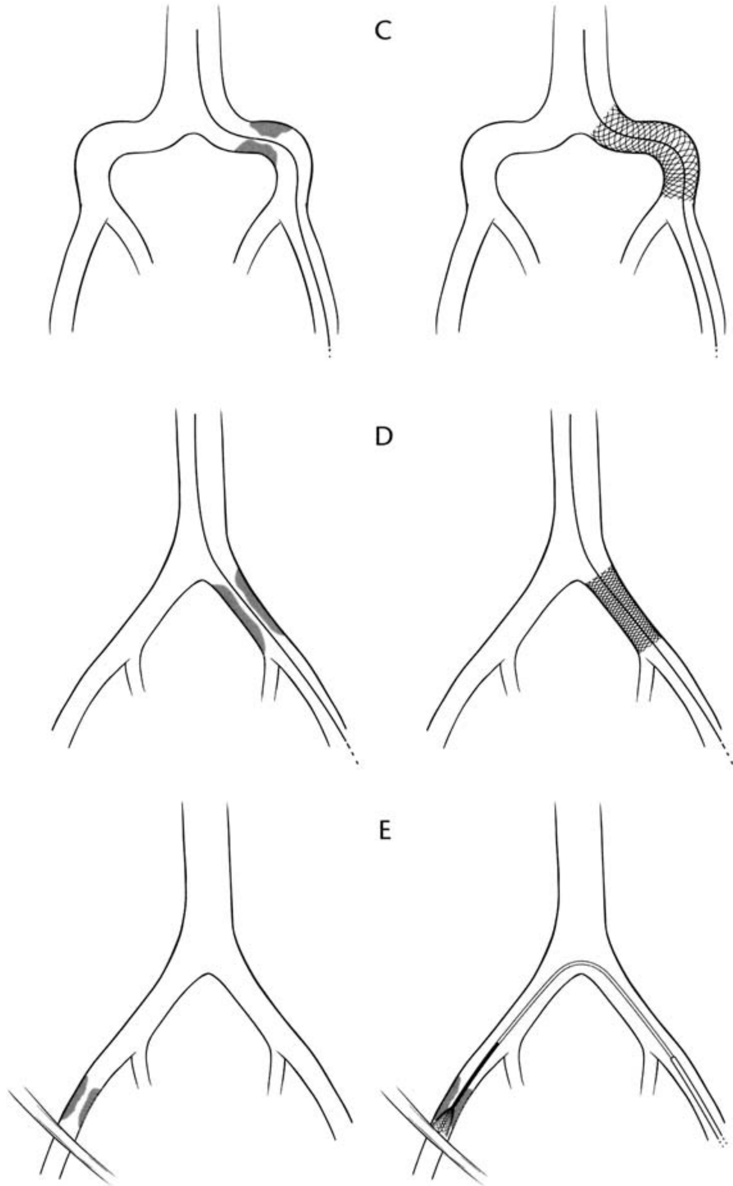

Fig. 9 (Continued)

balloon catheter is withdrawn but guidewire position is carefully maintained. Completion arteriography is performed through the sheath.

Self-expanding stents can be placed through a 7 Fr sheath placed over the aortic bifurcation. The sheath must be held in place as the stent is deployed since traction on the stent delivery catheter tends to pull the sheath back. Balloon-expandable stents are more of a challenge to pass over the aortic bifurcation because of their rigidity. If a balloon-expandable stent is desired, it is still possible, but the following should be considered. Use a shorter stent, 2 or 3 cm, instead of 4 cm. Use a balloon-expandable with less metal in it, for example, Corinthian instead of standard Palmaz. Use a larger sheath, 8 Fr instead of 7 Fr.

Balloon angioplasty of nonorificial proximal common iliac artery lesions is difficult with an up-and-over sheath in place since the tip of the sheath requires several centimeters of purchase in the proximal contralateral iliac system to maintain its curvature. A short distance of clearance, about 1 centimeter, is required distal to the end of the sheath to accommodate the shoulder of the angioplasty balloon. Contralateral iliac angioplasty was performed for many years without an up-and-over sheath. The balloon catheter is placed over the guidewire and angioplasty is performed without a guiding sheath. The disadvantage of this approach is that there is no simple way to obtain a completion arteriogram. The usual method is to replace the balloon catheter with a multi-side-hole straight catheter. The guidewire is removed but the straight catheter still maintains control at the angioplasty site. Arteriography through the catheter shows the velocity of forward flow distal to the angioplasty site. If it is satisfactory, the catheter is gently withdrawn and arteriography is repeated to illuminate the angioplasty site. The risk with this approach is that control of the lesion may be lost prematurely and could be difficult to regain while working from the contralateral side. It is even more challenging to place stents into the proximal contralateral iliac system. Self-expanding stents are the only option in this setting and the concern is that the second end of the stent may be deployed too close to the bifurcation.

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20

The Infrainguinal Arteries

Advice About Balloon Angioplasty and Stent Placement

Superficial Femoral and Popliteal Arteries
Tibial Arteries
Selected Readings

Balloon angioplasty and stents provide options that expand the scope of patients who are eligible for treatment of infrainguinal occlusive disease. Endovascular infrainguinal techniques are most useful in patients who are poor candidates for open surgery and in those with focal, short segment disease. The long-term results of femoropopliteal angioplasty are not generally as good as those for surgery and vary significantly based upon the severity and extent of the occlusive disease. This is likely to change soon if drug-eluting stents improve long-term results. The current practice of infrainguinal intervention may differ substantially from institution to institution based upon the level of enthusiasm for these techniques. Infrainguinal arteries may be approached through an ipsilateral antegrade femoral puncture or a contralateral femoral puncture followed by passage of the catheter over the aortic bifurcation. Chapter 2 shows how to perform an antegrade puncture. Chapter 6 provides methods for antegrade passage into the ipsilateral superficial femoral artery (SFA) and also crossing the aortic bifurcation. Chapter 8 details techniques for including the lower extremity in an arteriographic runoff study and for performing femoral arteriography and selective lower-extremity and pedal arteriography.

Superficial Femoral and Popliteal Arteries

Table 1 compares the up-and-over approach to infrainguinal disease to the ipsilateral, antegrade approach. The ipsilateral, antegrade approach provides better control of guidewires and catheters and excellent access to distal

Table 1 Approaches to Infrainguinal Interventions: Ipsilateral Approach Versus Up-and-Over Approach from Contralateral Femoral

	Up-and-over approach	Antegrade approach
Puncture	Simple retrograde femoral	More challenging, less working room
Catheterization	Up-and-over catheterization is challenging with tortuous arteries, narrow, or diseased aortic bifurcation; easier to catheterize SFA when going up and over	Entering SFA from antegrade approach requires proximal femoral puncture and selective catheter
Guidewire/catheter control	Fair	Excellent
Catheter inventory	Need more supplies	Minimal, shorter catheters
Specialty items	Up-and-over sheath, long balloon catheters	None
Indications	Proximal SFA disease, CFA disease ipsilateral to infrainguinal lesion, obesity	Intrapopliteal disease, patients with contraindication to up-and-over approach

SFA, superficial femoral artery; CFA, common femoral artery.

infrainguinal arteries. The inventory is simple, and once the guidewire is in the SFA, the procedure tends to be fairly straightforward. The antegrade puncture can be a challenge, and entering the SFA from the common femoral artery often requires patience. Aortoiliac disease must be ruled out prior to this approach. The antegrade approach is not appropriate in obese patients due to the risk of puncture site complications. It is not used in patients with common femoral or proximal SFA disease because of the proximity of the puncture site to the disease. The up-and-over approach to infrainguinal disease from the contralateral femoral is advantageous in obese patients, those with proximal SFA disease, and those in whom aortoiliac disease must be evaluated prior to infrainguinal intervention. Entering the SFA is usually simple with this approach, but tortuous aortoiliac anatomy or occlusive disease can make the up-and-over catheterization difficult or even dangerous. The up-and-over approach requires an inventory of longer catheter sizes. Control of longer catheters and guidewires after they take multiple turns is not as satisfactory but most cases can be performed using this method at the discretion of the surgeon.

IPSILATERAL ANTEGRADE APPROACH TO THE SUPERFICIAL FEMORAL AND POPLITEAL ARTERIES

After antegrade puncture, the guidewire is directed into the origin of the SFA with a bent-tip selective catheter (Chapter 6). The guidewire must be advanced far enough into the artery to secure the access. When a Wholey guidewire has been passed, this is usually firm enough to support the passage of a 5 Fr sheath. If a Glidewire has been passed into the SFA, advance a 4 or 5 Fr dilator over it and exchange for a stiffer guidewire and then pass the access sheath. If there is concern that the guidewire will cross the lesion prior to arteriography (e.g., with a lesion in the mid-SFA), follow the advancing guidewire carefully using fluoroscopy, then pass a 4 or 5 Fr dilator and perform a femoral arteriogram. A radiopaque ruler or external marker is placed on the drapes to mark the location of the lesion.

A 5 Fr sheath can be placed after secure guidewire access to the superficial femoral artery has been obtained (Fig. 1). After femoral arteriography, which includes distal runoff, the guidewire is passed antegrade through the lesion. Large collaterals are juxtaposed and often parallel to femoropopliteal lesions and should be avoided. A steerable guidewire is often required. After the guidewire is placed, a repeat arteriogram through the sidearm of the sheath is performed to ensure that the lesion has been appropriately crossed. Heparin is administered for infrainguinal angioplasty. Consider 25 to 50 U/kg for simple, focal lesions. When the catheter is in the artery a short time, no stent is required, and flow is interrupted for only a few seconds, a lower dose of heparin usually suffices. Consider 50 to 75 U/kg heparin for more complex cases.

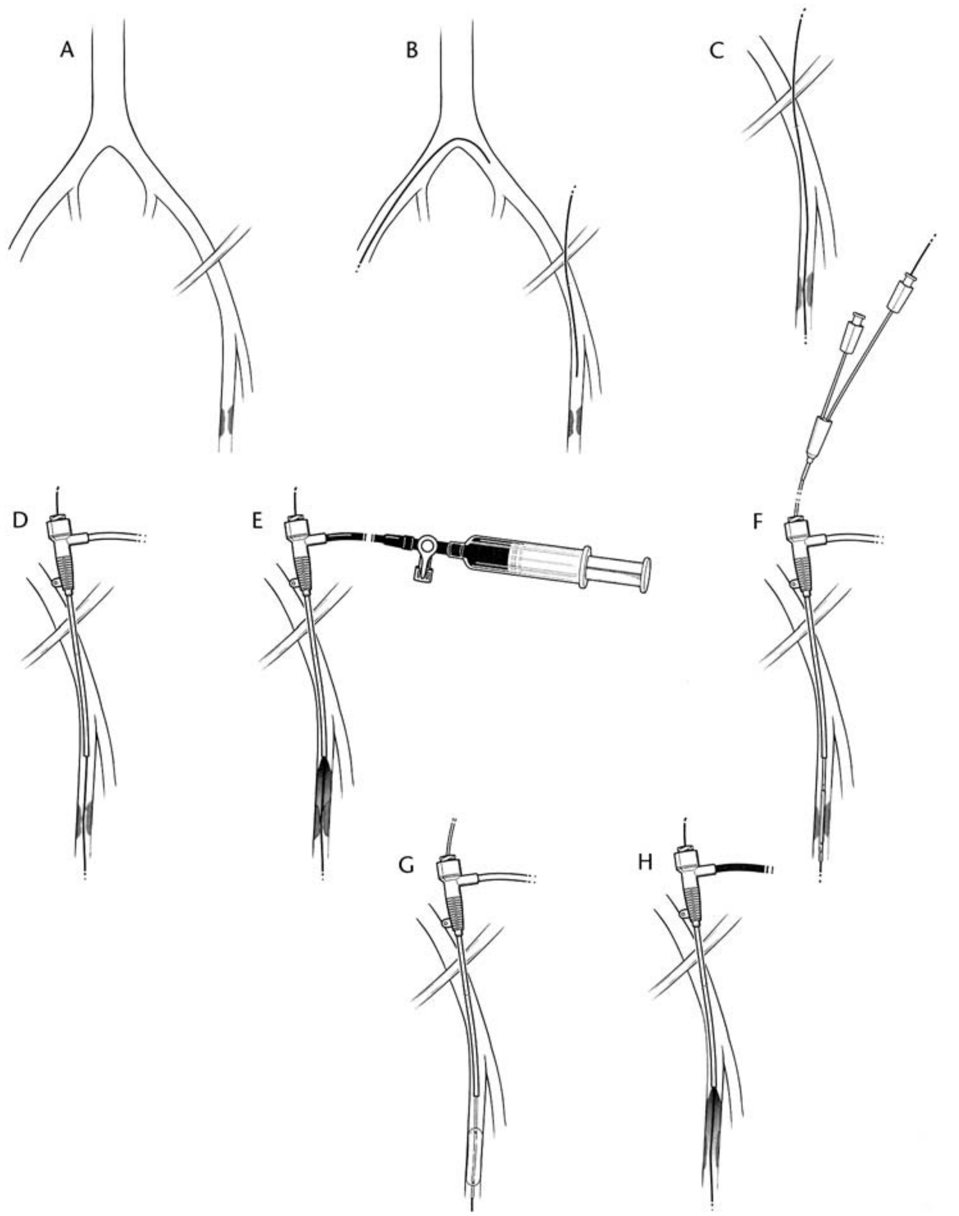


Fig. 1 Balloon angioplasty of the superficial femoral and popliteal arteries. **A,** A stenosis of the superficial femoral artery is deemed suitable for angioplasty. **B,** The stenosis is approached antegrade through an ipsilateral femoral artery puncture or across the aortic bifurcation. **C,** An ipsilateral antegrade femoral artery puncture is usually the most simple. The guidewire is placed across the stenosis. **D,** A hemostatic access sheath is placed over the guidewire into the proximal superficial femoral artery. **E,** Femoral arteriography through the sidearm of the sheath evaluates the lesion and confirms guidewire position. **F,** The angioplasty balloon is selected and passed through the stenosis. **G,** The stenosis is dilated. **H,** The balloon is removed but the position of the guidewire is maintained. Completion arteriography is performed through the sidearm of the sheath.

Guidewires in the range of 145 to 180 cm in length are used with angiographic catheters that are 65 to 70 cm in length (Table 2). Balloon angioplasty catheters that are 75 or 80 cm in length are adequate to reach the mid-tibial level in most patients through an antegrade approach. If a longer balloon catheter is used, a longer guidewire may be required. Once the intended site of intervention is marked with an external marker, the distance can be measured outside the limb to estimate the length required. Balloon diameters range from 4 to 7 mm in the superficial femoral artery and 3 to 6 mm in the popliteal artery. A 5 Fr sheath will accommodate balloons up to 6 mm in diameter. The rare case that requires a 7-mm-diameter balloon will require a 6 Fr sheath to pass the balloon catheter. If no cut film arteriogram is available to measure the diameter, it is usually best to begin with a balloon of lesser diameter than will probably be required.

The tip of the guidewire is usually placed in the distal popliteal artery. If the balloon angioplasty site is below the knee, the guidewire should be

Table 2 Supplies for Antegrade Femoral Approach to Infrainguinal Intervention

Guidewire	Starting/selective guidewire	Wholey	145 cm, length	0.035 in. diameter (steerable, shapeable tip)
	Selective guidewire	Glidewire	180 cm	0.035 in. (angled tip)
	Exchange guidewire	Rosen	180 cm	0.035 in. (J tip)
Catheter	Selective	Kumpe	40 cm	5 Fr (short, bent tip)
	Exchange	Straight	70 cm	5 Fr
Sheath	Access	Standard hemostatic access	12 cm	4 Fr, 5 Fr, 7 Fr[a]
Balloon	Balloon angioplasty catheters	Balloon diameter	2, 3, 4, 5, 6 mm	
		Balloon length	2, 4 cm	
		Catheter shaft	75 cm, distal tibial may require 90 cm	
Stent	Self-expanding	Wallstent		
		Stent diameter	6, 8 mm	
		Stent length	20, 40, 45, 60 mm	
		SMART		
		Stent diameter	6, 8 mm	
		Stent length	20, 40, 60, 80 mm	
		Delivery catheter length	80 cm	

[a] Use 4 Fr sheath for tibial balloon angioplasty with 3.8 Fr catheters. Use 5 Fr sheath for balloon angioplasty up to 6 mm on a 5 Fr shaft. A 7 Fr sheath is required for stent placement using a 0.035 in. system.

advanced into the tibial arteries. During exchanges of catheters, occasional fluoroscopy of this area is performed to ensure that the guidewire is not allowed to move from its position. Once the balloon angioplasty catheter is in place, the balloon is inflated using fluoroscopy. Following deflation, the balloon is withdrawn and completion arteriography is performed through the sidearm of the sheath. If a 5 Fr balloon catheter shaft is used with a 5 Fr hemostatic sheath, the sheath lumen is completely obstructed by the catheter. The balloon catheter must be completely withdrawn before arteriography is performed. If the sheath is 6 Fr or larger, the balloon catheter is withdrawn from the angioplasty site and contrast is injected around the shaft of the balloon catheter through the sidearm of the sheath. When a deflated 6-mm-diameter balloon is removed through a 5 Fr sheath, the fit is very snug. The balloon should be aspirated continuously with a syringe to decrease its profile.

Completion arteriography is used to assess the size of the lumen after balloon angioplasty and the flow through the intervention site and to look for extravazation, contrast trapping in the vessel wall, or evidence of extensive dissection. Best results are obtained with angioplasty of focal, critical lesions. Long-segment femoropopliteal angioplasty is complicated by a higher incidence of acute occlusion, dissection, and lower long-term patency rates.

Angioplasty of the superficial femoral artery, especially at the adductor canal, almost routinely produces some evidence of a dissection plane on completion images, and most dissections heal. A stent is placed if an acute dissection has caused an occlusion or threatens imminently to occlude the artery (Fig. 2). A 7 Fr sheath is required for stent placement using a standard 0.035-in. system. If a stent must cross the knee joint, a self-expanding stent is appropriately flexible. A standard 12-cm length access sheath is used with an 80-cm delivery catheter. The stent is oversized 2 mm from the intended placement site. An 8-mm stent is usually placed in a 6-mm-diameter artery to maintain constant outward radial force. The constrained stent is passed beyond the lesion by a few millimeters. The leading end of the stent is allowed to flare. The delivery catheter is then withdrawn slightly to land the stent in the appropriate location. Poststent balloon angioplasty is routinely performed and often reveals a residual waist. In other areas, either stent type is adequate. However, most operators prefer self-expanding stents because of their ease of placement, longer available lengths, flexibility within the artery, and contourability along a tapering artery. A balloon-expandable stent requires placement through a sheath long enough to reach and extend through the lesion (a 30- to 50-cm sheath may be required). It is possible to crush balloon-expandable stents with external compression, so sequential lower-extremity pressure measurements must subsequently be avoided. Stent placement does not enhance long-term results and primary stent placement is not indicated. Completion arteriography is performed through the sidearm of the steath.

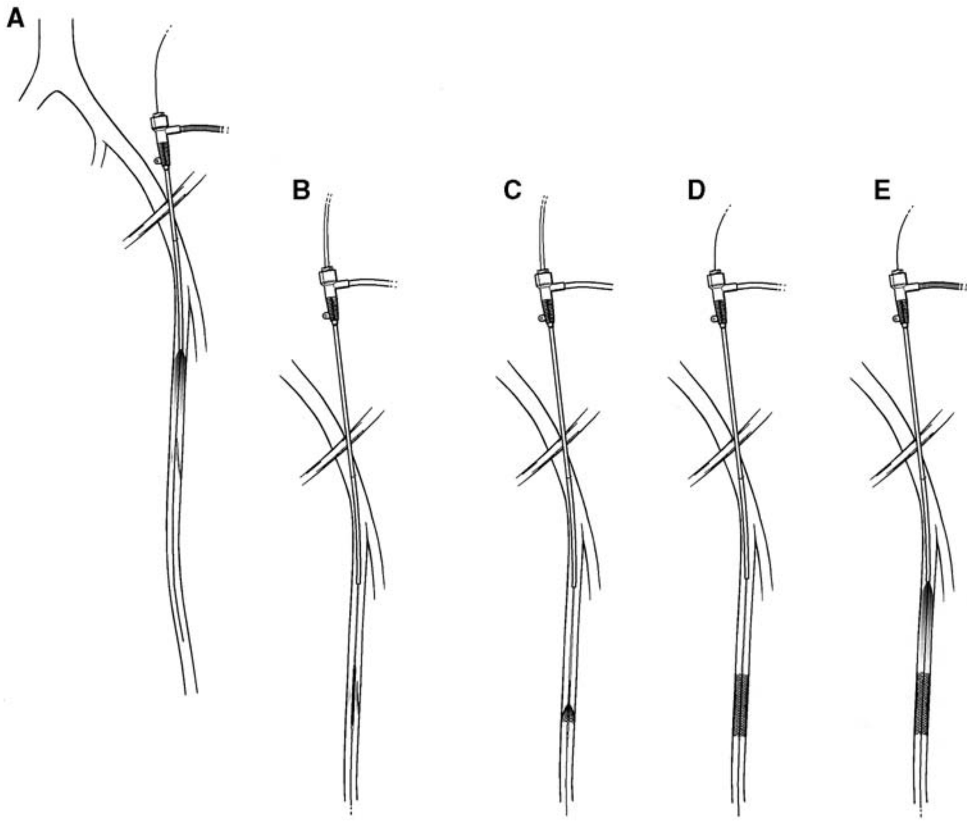


Fig. 2 Stent placement in the superficial femoral artery. A, Postangioplasty dissection is present on completion arteriography. **B,** A self-expanding stent is delivered to the site. **C,** The stent is deployed from the distal end of the lesion to its proximal end. **D,** Poststent balloon angioplasty is performed to bring the stent to its appropriate profile. **E,** Completion arteriography is performed through the sheath while maintaining guidewire access.

UP-AND-OVER APPROACH TO THE SUPERFICIAL FEMORAL AND POPLITEAL ARTERIES

Selective catheterization of the aortic bifurcation and antegrade passage of a catheter into the contralateral iliac artery are discussed in Chapter 6. Details of the passage of an up-and-over sheath are presented in Chapter 12. Equipment required for an up-and-over approach to infrainguinal intervention is listed in Table 3.

Contralateral intervention can be performed without an up-and-over sheath but there are substantial disadvantages. Guidewires and catheters passed over the aortic bifurcation without a guiding sheath lose pushability. After intervention, guidewire control of the lesion must be relinquished in

Table 3 Supplies for Up-and-Over Approach to Infrainguinal Intervention

Guidewire	Starting	Bentson	145 cm, length	0.035 in. diameter
	Selective	Glidewire	150 cm	0.035 in. (steerable)
		Glidewire	260 cm	0.035 in. (steerable)
	Exchange	Rosen	180 cm	0.035 in. (J tip)
		Amplatz Super-Stiff	180 cm	0.035 in.
Catheter	Flush/selective	Omni-flush	65 cm	4 Fr
	Exchange	Straight	90 cm	5 Fr
Sheath	Selective sheath	Up and over	40 cm	5.5 Fr, 6 Fr, 7 Fr
Balloon	Balloon angioplasty catheters	Balloon diameter	2, 3, 4, 5, 6 mm	
		Balloon length	2, 4 cm	
		Catheter shaft	75, 90, 110 cm[a]	
Stent	Self-expanding	Wallstent		
		Stent diameter	6, 8 mm	
		Stent length	20, 40, 45, 60 mm	
		SMART		
		Stent diameter	6, 8 mm	
		Stent length	20, 40, 60, 80 mm	
		Delivery catheter length	120 cm	

[a] A 75-cm catheter shaft for balloon angioplasty to mid-SFA. Longer catheters are required for contralateral approach to distal SFA, popliteal, and tibial intervention.

order to obtain a completion arteriogram. This can be performed by exchanging the balloon catheter for a multi-side-hole straight catheter. The guidewire is removed and the straight catheter is slowly withdrawn as contrast is injected through the catheter. This maneuver provides some information about flow at the intervention site and also can identify a major dissection before the catheter is completely removed from the angioplasty site. It is usually better to use an up-and-over sheath if possible.

When the up-and-over guiding sheath is passed, it is usually best to advance it to its hub: this will usually place the tip of the sheath somewhere between the mid-iliac artery and the groin. If balloon angioplasty alone is anticipated, a 5.5 Fr sheath is adequate for angioplasty up to 6 mm in diameter. If stent placement is anticipated or it becomes necessary to treat a postangioplasty complication, a 7 Fr sheath is required to place a self-expanding stent using a 0.035-in. guidewire system. A femoral arteriogram may be performed through the sidearm of the sheath (Fig. 3). If the amount of contrast administration must be limited, a straight catheter may be passed through the sheath and into the proximal SFA and an arteriogram may be performed. The exchange guidewire over which the sheath has been passed is exchanged for a steerable guidewire, usually a 260-cm angled-tip Glidewire,

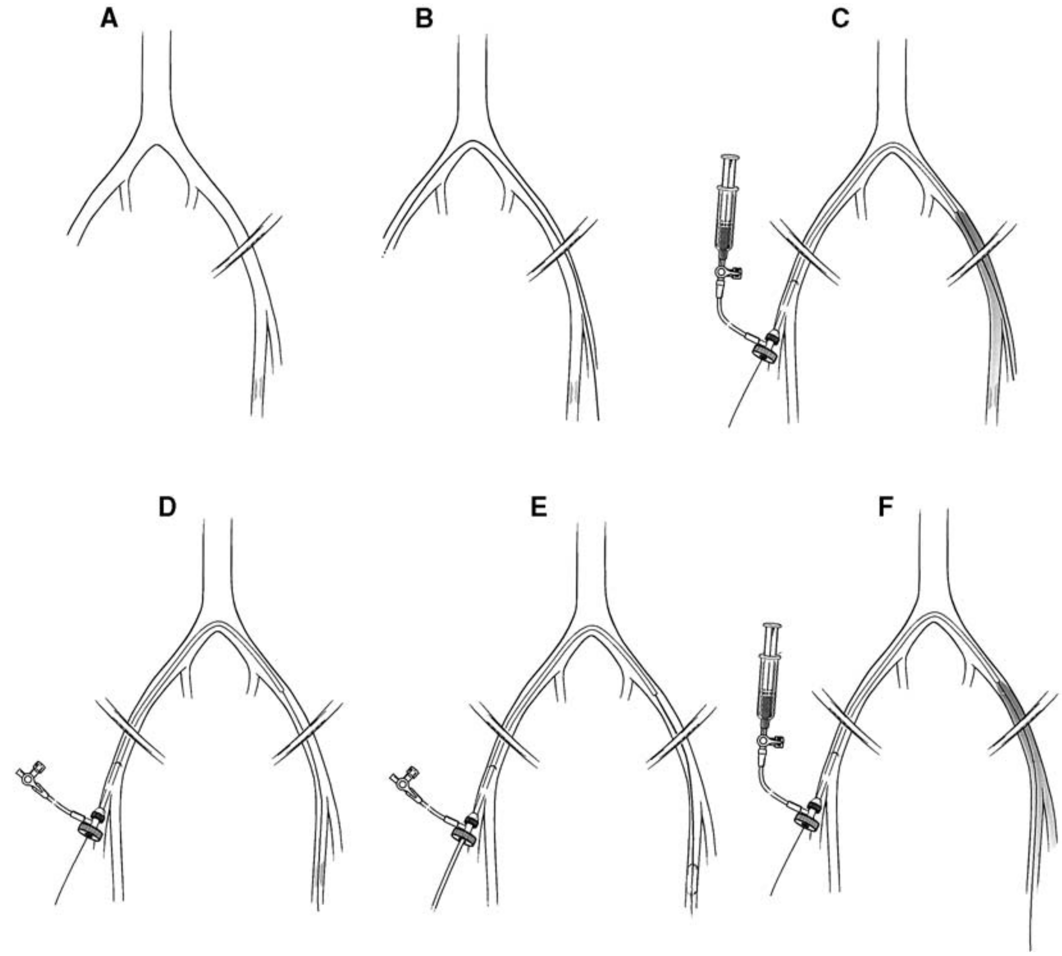


Fig. 3 Balloon angioplasty of the femoral and popliteal arteries through an up-and-over approach. A, A superficial femoral artery lesion is identified. **B,** A guidewire is introduced through the contralateral femoral artery and placed over the aortic bifurcation. The guidewire may be placed in either the profunda femoris or superficial femoral arteries. If the guidewire is placed in the superficial femoral artery, care should be taken to prevent unintended encounters between the guidewire and the lesion during sheath placement. **C,** An up-and-over sheath is placed and arteriography is performed. **D,** The guidewire is advanced across the lesion. **E,** Balloon angioplasty is performed. **F,** Completion arteriography is performed through the sheath.

which is used to cross the infrainguinal lesion. Heparin is administered, 25 to 75 U/kg.

The length of the balloon catheter shaft is selected based upon the location of the lesion. The proximal SFA can be reached with a 75- or 80-cm length catheter. In a patient of short stature, it will reach the mid-SFA. More distal lesions require a 90- or 110-cm catheter. An estimate of the required catheter length can be made using the straight exchange catheter, which is used to exchange the guidewires. The straight exchange catheters are usually 70 or 100 cm in length. Care must be taken to maintain the guidewire in a stationary position so that its leading edge does not advance into the distal infrageniculate runoff arteries during passage of long catheters. Intermittent fluoroscopy is required.

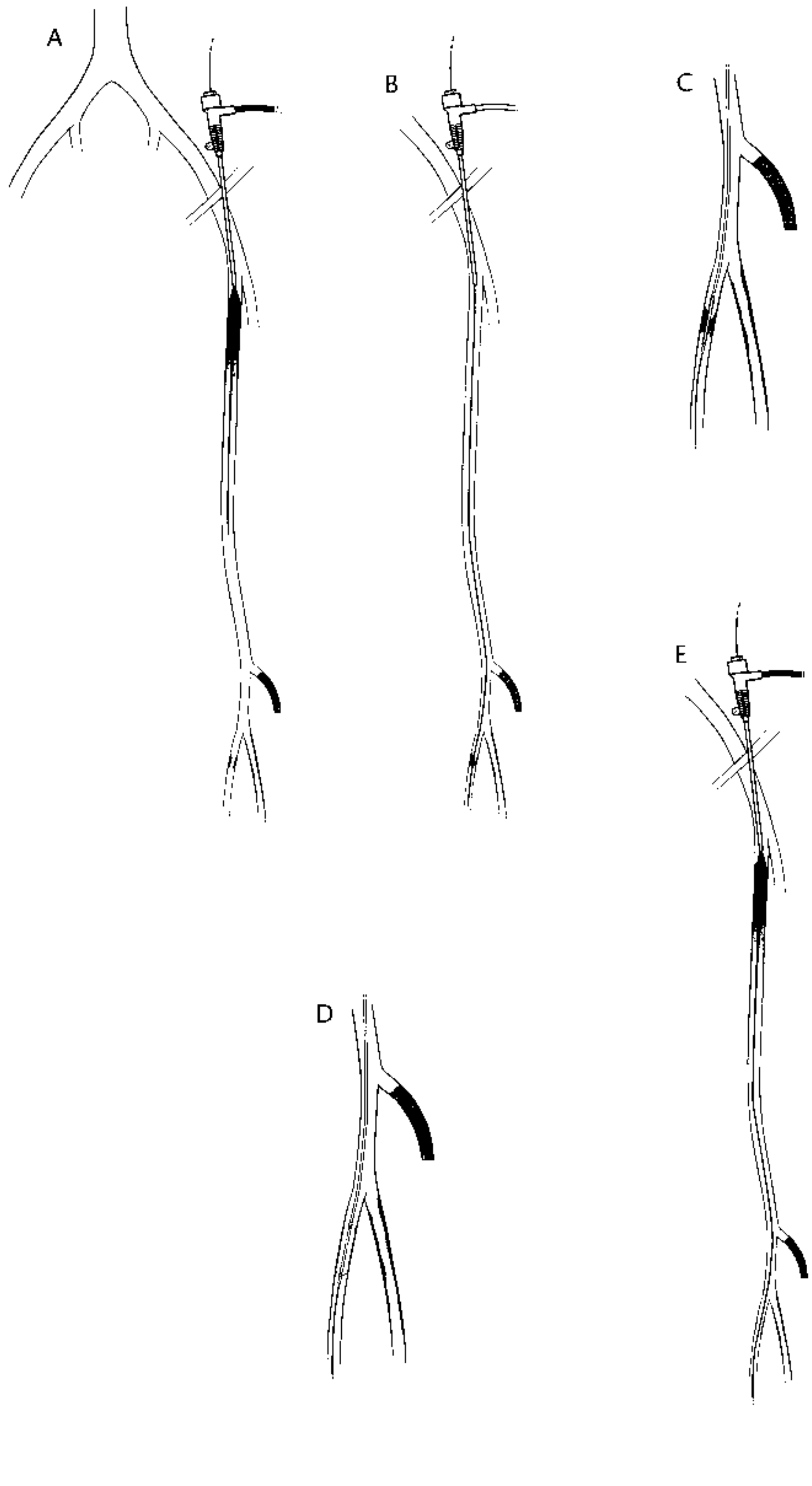
After balloon angioplasty, the catheter is withdrawn while the guidewire is maintained in place. A completion arteriogram is performed through the sidearm of the sheath. The angioplasty site is assessed in the same way as described in the previous section. If a stent is required, the sheath must be upsized to 7 Fr if not already in place. Most self-expanding stents are delivered on catheters that are either 80 or 120 cm in length. The required distance may be estimated based upon the length of the balloon catheter required. After stent placement, balloon angioplasty is performed along the length of the stent followed by completion arteriography.

Tibial Arteries

Focal tibial artery lesions that cause limb-threatening ischemia are rare and can be treated with angioplasty in an attempt to achieve at least temporary limb salvage.

An ipsilateral antegrade approach is simple and direct and helps to maintain control of guidewires and catheters (Fig. 4). Selective catheterization is described in Chapter 6. Tibiopedal arteriography is discussed in Chapter 8. Longer guidewires (at least 150 cm) and a hemostatic sheath (4 or 5 Fr) are required to accomplish selective tibial artery catheterization. Heparin (50 to 75 U/kg) is administered prior to balloon placement. If spasm occurs in the tibial arteries, nitroglycerine is administered through the access catheter.

Fig. 4 Balloon angioplasty of the tibial artery. A, Femoral arteriography is performed. **B,** The guidewire is advanced through a posterior tibial artery stenosis. **C,** The angioplasty catheter is positioned across the lesion. **D,** Balloon dilatation of the posterior tibial artery is performed. **E,** The balloon is removed and completion arteriography is performed.


A
B
C
D
E

Balloons range from 1.5 to 4 mm in diameter. A standard 0.035-in. guidewire can be used for balloons 3 or 4 mm in diameter. If a balloon smaller than 3 mm is required or there is difficulty passing the standard higher profile 3 or 4 mm balloons (5 Fr shaft), a 0.018-in. guidewire is used with a lower-profile balloon on a 3.8 Fr shaft (Symmetry; Boston Scientific Corp., Medi-Tech Division, Natick, Mass.). This system may be passed through a 4 Fr sheath. Completion arteriography is performed through the sidearm of the antegrade sheath. A 5.5 Fr up-and-over sheath may also be used for a contralateral approach. However, the 3.8 Fr catheter shaft on a 0.018-in. guidewire lacks pushability and trackability.

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21

Advice About Endovascular Salvage of Previous Reconstructions

Previous Endovascular Reconstruction: Balloon Angioplasty, Stents
Infrainguinal Bypass Graft
Extra-Anatomic Bypasses: Axillofemoral and Femoral–Femoral Bypasses
In-Line Reconstructions for Aortoiliac Disease: Aortofemoral Bypass, Iliofemoral Bypass, and Aortoiliac Bypass
Selected Readings

Endovascular intervention may be integral in the salvage of previous endovascular and open surgical reconstructions. The mechanisms of failure of previous reconstructions, whether open or endovascular, are similar. These include failure of inflow due to new or residual lesions, failure at the site of previous intervention, or new lesions involving the outflow. Failure at a site of previous balloon angioplasty or surgical bypass may be due to intimal hyperplasia during the early phase or recurrent atherosclerosis if it occurs later. Although the record of endovascular intervention for intimal hyperplasia is variable, this may be the method of choice in patients who are poor candidates for open surgery. Cutting balloons may play a future role in the endovascular treatment of intimal hyperplastic lesions.

Previous Endovascular Reconstruction: Balloon Angioplasty, Stents

When recurrent stenosis occurs at a site of previous balloon angioplasty, it can usually be treated with repeat balloon angioplasty and stent placement. Arteriograms from the previous procedure should be reviewed for evidence of untreated residual stenosis that may have been evident at the completion of the initial procedure. Care should be taken to avoid passing the guidewire into an area of partially healed dissection at the intervention site. If the lesion is heavily calcified, a stiff exchange guidewire should be used for control of the lesion. A balloon-expandable stent should be employed in this instance.

Patients with failing endovascular sites may require surgery, and care should be taken to avoid compromising surgical options. Avoid large-bore or repeat punctures in femoral areas that may require surgery. Failing endovascular sites are more likely to acquire fresh thrombus or other material that could form an embolus. Consider administering adequate heparin and avoid crossing lesions that appear likely to embolize.

When the previous reconstruction was a stent, the key maneuver in repeat treatment is to be certain that the guidewire is placed across the stent within the lumen. Guidewires in general and Glidewires in particular may pass through the struts of a stent and potentially lead to a stent-deforming balloon angioplasty. Passing a guidewire through a previously stented segment is discussed in Chapter 16. If the operator cannot be certain about the guidewire position, a catheter may be passed over the guidewire to be certain the catheter does not catch on the side wall of the stent. If the end of a previously placed stent is at the origin of an artery, such as the common iliac or the renal artery, additional care should be taken when crossing the stent. A soft-tipped guiding catheter or sheath may be used to encounter the end of the stent. Repeat balloon angioplasty within a previously placed stent may cause balloon rupture, especially if it is a stainless steel, balloon-expandable stent, such as a Palmaz. The balloon may occasionally catch on the stent, which prevents the balloon from being withdrawn. If additional stents need to be placed, consider overlapping slightly with the previously placed stent.

Infrainguinal Bypass Graft

Failing infrainguinal bypasses present a common application of endovascular intervention for salvage. One of the most difficult facets of bypass graft angioplasty is locating and entering the graft from its proximal end (see Chapter 6 for a detailed discussion of the technique for entering an infrainguinal graft). If the graft is placed subcutaneously, such as an in situ graft, a percutaneous puncture of the graft in the subcutaneous position can be performed. If this is chosen as the access method, a 4 Fr sheath and a 0.018 in. guidewire system should be used. Most grafts are entered through the proximal anastomosis.

The method for approaching an infrainguinal bypass graft is dependent upon the location of its proximal anastomosis. Grafts that originate from the anterior wall of the common femoral artery are accessed through a contralateral femoral artery puncture and passage of the guidewire and catheter over the aortic bifurcation (Fig. 1). Grafts originating from the superficial femoral artery, popliteal artery, or deep femoral artery are usually cannulated after an antegrade ipsilateral femoral artery puncture (Fig. 2).

A steerable, hydrophilic-coated guidewire is useful to enter the orifice of the graft. If the stenosis is preocclusive, it may be difficult to identify the proximal origin of the graft because of very low flow. Since most anastomoses are placed on the anterior side of the artery of origin, steep oblique views may be helpful in localizing the area of interest. A stump or hood of graft is sometimes visible when local contrast is injected. This area should be probed with a steerable guidewire.

Arteriography and confirmation of guidewire placement is performed through the sidearm of the hemostatic sheath which has been placed to provide an antegrade approach to the infrainguinal bypass. Heparin is administered (50 to 75 U/kg) prior to passage of the balloon catheter, since the catheter itself may stop flow in the graft. Consider placing the guidewire through the length of the bypass graft before beginning balloon angioplasty, just in case low flow in the graft progresses to thrombosis of the graft. After the graft is entered, the balloon angioplasty catheter is passed over the guidewire.

High pressures (up to 20 atm) may be required to reopen a segment of intimal hyperplastic disease. Stenoses within the graft or at an anastomosis generally require higher pressures and longer inflation times. The

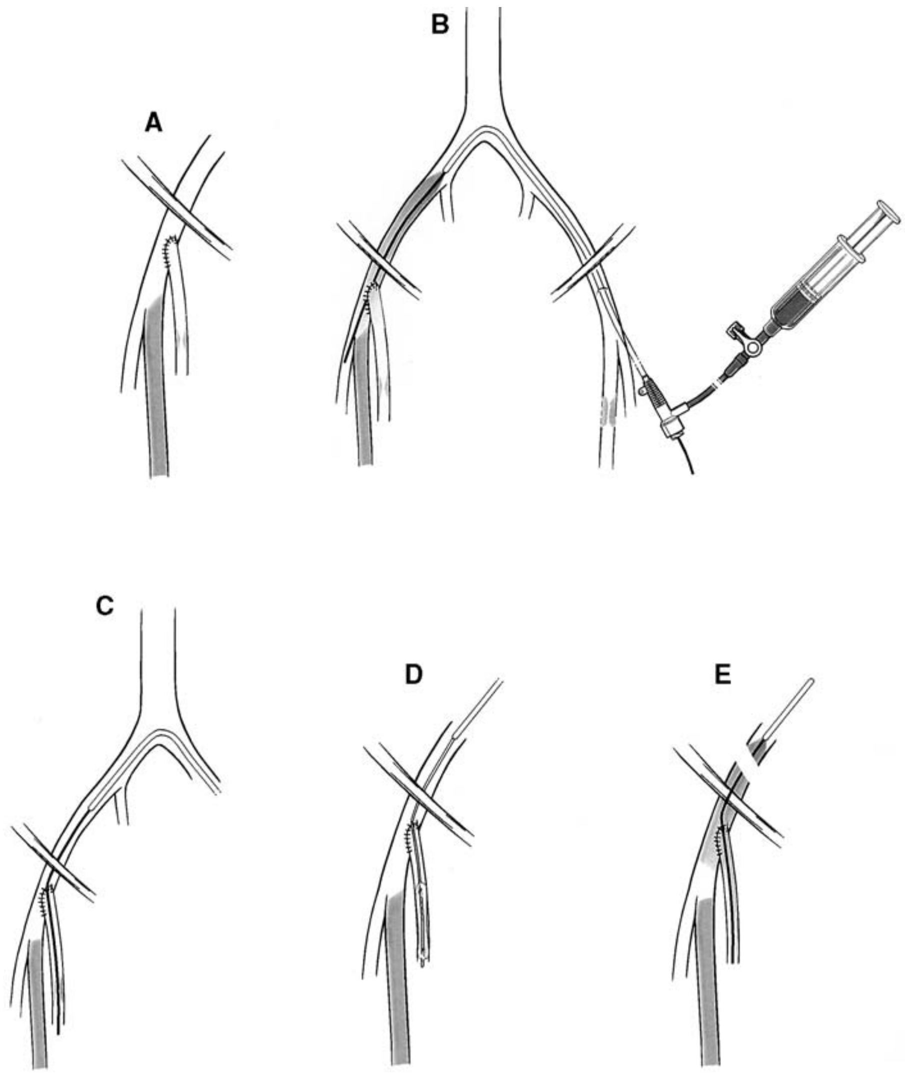

Fig. 1 Balloon angioplasty of infrainguinal bypass graft through an up-and-over approach. A, An infrainguinal bypass graft that originates from the common femoral artery has developed a proximal graft lesion. **B,** An up-and-over sheath is placed and arteriography is performed. **C,** The guidewire is passed through the graft lesion. **D,** Balloon angioplasty is performed. **E,** Completion arteriography is performed through the sheath.

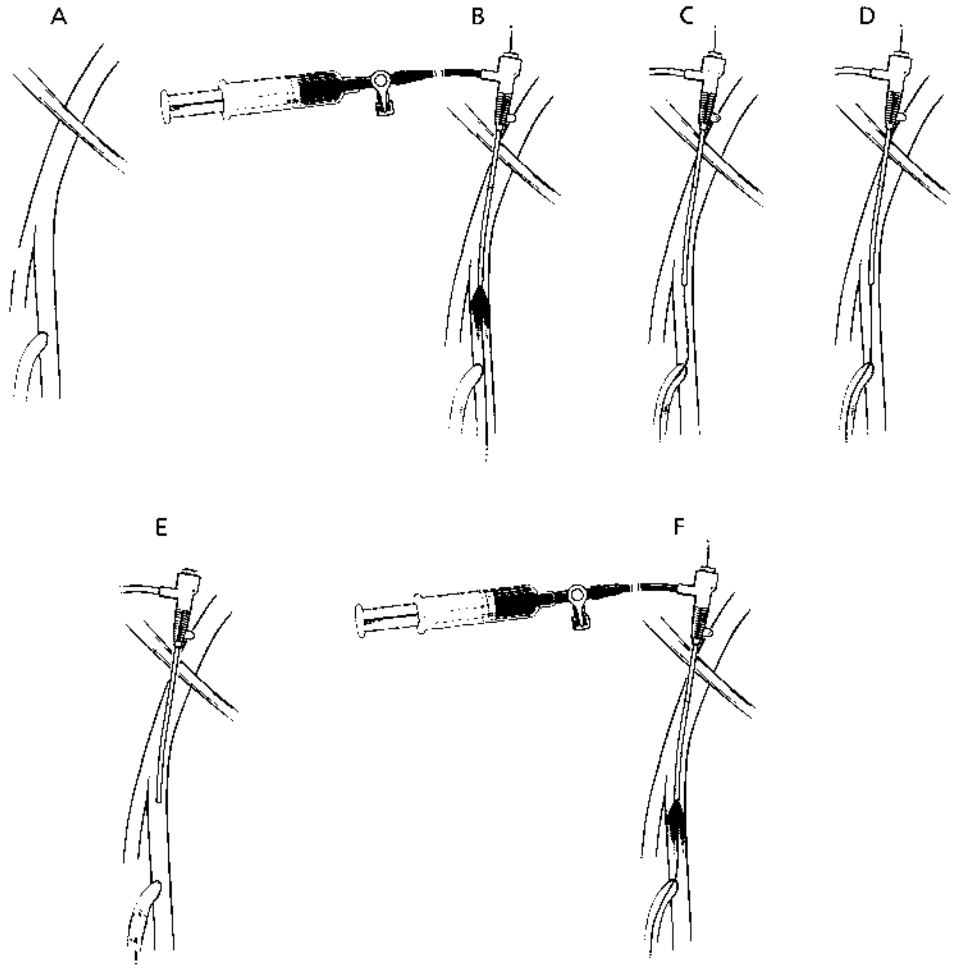

Fig. 2 Balloon angioplasty of infrainguinal bypass graft through an antegrade ipsilateral approach. **A,** This approach is useful for interventions in infrainguinal bypass grafts that originate from the superficial femoral, popliteal or profunda femoris arteries. **B,** An antegrade femoral sheath is placed and arteriography is performed. **C,** The guidewire is directed into the vein graft using a selective catheter and passed across the vein graft lesion. **D,** The selective catheter is removed. **E,** Balloon angioplasty of the infrainguinal bypass graft is performed. **F,** Completion arteriography is performed while maintaining guidewire access.

likelihood of a localized dissection is low but the graft may rupture if it is overdilated. After angioplasty, the balloon is removed while the guidewire is maintained and completion arteriography is performed through the sheath.

Information on the use of stents is insufficient to determine whether stenting of recalcitrant graft lesions is appropriate. These should generally be

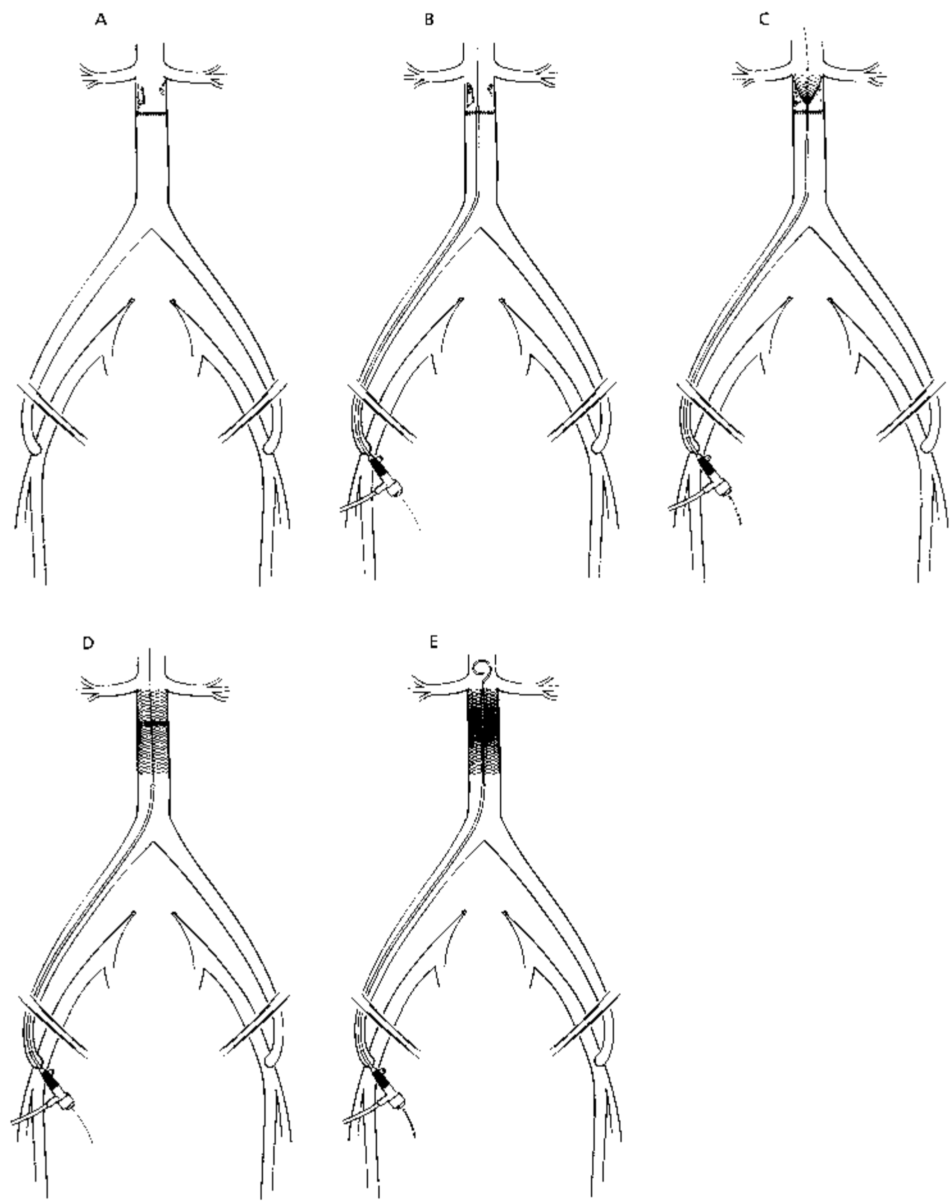

Fig. 3 Endovascular salvage of an aortofemoral bypass graft. A, Disease has progressed in the residual infrarenal aorta after prior aortofemoral graft placement. **B,** A femoral sheath and guidewire are placed. **C,** Stent placement is performed distal to the renal arteries. **D,** Poststent balloon angioplasty expands the stent to its correct profile. **E,** Completion arteriography is performed through a proximally placed flush catheter.

treated by surgical repair. However, a stent may be considered as a bridge to surgery in situations where the graft flow is so poor that failure is likely before surgery can be performed.

Extra-Anatomic Bypasses: Axillofemoral and Femoral–Femoral Bypasses

Extra-anatomic bypass grafts may be evaluated arteriographically by direct puncture and catheter placement or through entry into the native vasculature proximal or distal to the graft. Selective catheterization of prosthetic grafts is detailed in Chapter 6. Interventions to salvage axillofemoral grafts usually involve distal lesions, either at the femoral anastomosis or in the runoff. After arteriography, an access sheath is placed. Dilators must be used to permit the entry of the sheath, and the smallest caliber sheath that is adequate for the intervention should be placed. A balloon catheter is passed over the guidewire and angioplasty is performed. After the intervention, pressure is held at the site of the puncture so that the graft itself maintains flow and a platelet plug is permitted to form.

In-Line Reconstructions for Aortoiliac Disease: Aortofemoral Bypass, Iliofemoral Bypass, and Aortoiliac Bypass

Most failing in-line grafts that were originally performed for aortoiliac occlusive disease should be treated with repeat surgery. The most common lesions affecting these grafts are at the distal anstomoses. Nevertheless, endovascular intervention is well suited to treat lesions that are at the proximal anastomosis and would be difficult to reach surgically. Fig. 3 demonstrates an aortic graft that is failing due to progression of aortic disease. Balloon angioplasty and stent placement in the infrarenal aorta are used to prevent repeat open aortic surgery.

Inflow disease may also occur proximal to an iliofemoral bypass graft. This may be reached through an ipsilateral or contralateral femoral puncture, depending upon the site of the proximal anastomosis. Grafts that end in the iliac arteries may be difficult to cannulate through an ipsilateral femoral puncture (Fig. 4). The guidewire naturally tends to remain within the native circulation. An oblique view and steerable guidewire and angled-tip selective catheter are used to locate and enter the graft. Aortofemoral bypass graft bifurcations are manufactured at a fairly narrow angle, and crossing the graft bifurcation may be a challenge. It is much simpler to cross with an

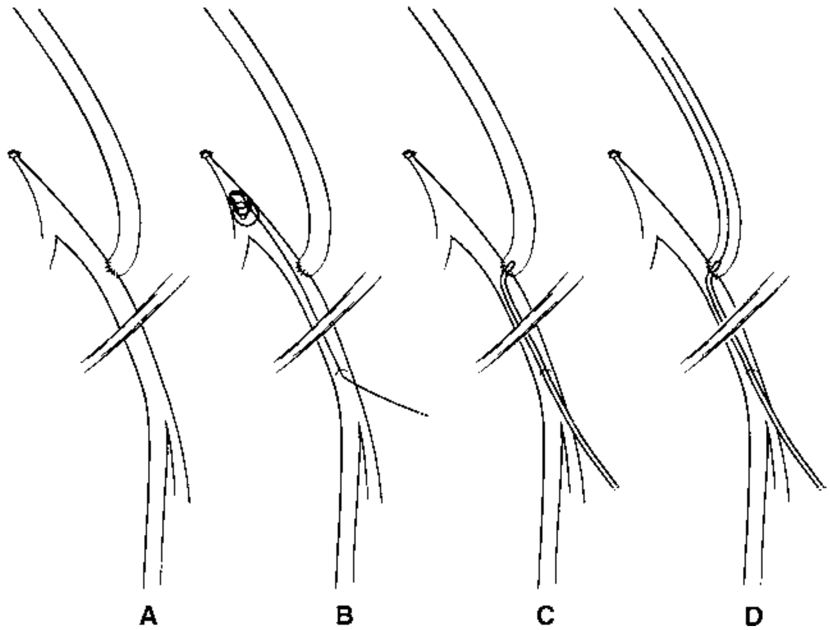

Fig. 4 Retrograde guidewire placement after iliac anastomosis. The iliac artery is the recipient artery of a previously placed bypass graft and the common iliac artery has been ligated. **B,** The tendency of a guidewire placed retrograde is to remain in the native circulation. **C,** A selective catheter is placed and is used to direct the guidewire. **D,** The guidewire is passed across the anastomosis.

angiographic catheter than with an access sheath, since the catheter is more flexible. A selective catheter with a tight hook, such as a Rim catheter, may be used with a steerable 0.025 in. Glidewire. The 0.025 in. guidewire is more flexible and permits a tighter turn.

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22

Making a Clean Getaway

Puncture Site Management

Obtaining Hemostasis
Holding Pressure
Timing the Sheath Removal
Managing Puncture Site Complications

Obtaining Hemostasis

In a manner similar to the performance of open surgery, wound complications present a low-level but constant problem. These complications are not usually threatening but they may add substantially to the morbidity of the procedure. Obtaining hemostasis after a percutaneous intervention has the same importance as surgical wound closure. Percutaneous closure devices are not covered in this text. These have been touted as the solution to post-intervention hemostasis. Although these devices may yet improve further, infected pseudoaneurysms, ischemic limbs, and limb loss have been reported and closure devices should be introduced into clinical practice cautiously.

Obtaining hemostasis is made safer and simpler when the arteriotomy site is well managed during the procedure. Puncturing the artery at the access site properly, holding pressure during exchanges, and using dilators when upsizing the sheath all help to maintain the arteriotomy. A damaged sheath tip may injure the artery at the access site. Avoid inflating a balloon in the end of the sheath. Fully deflate an angioplasty balloon before withdrawing it into the sheath.

Ensure that the patient is comfortable prior to pulling the sheath. Drain the bladder if needed. Avoid agitation and discomfort due to bladder distension after the diuresis caused by contrast administration. Some patients are uncomfortable after lying on the angio table because of back or limb pain. These patients may need a short break or additional sedation. If blood pressure is elevated, it can make hemostasis more difficult to achieve. Consider antihypertensive medication. If any significant amount of heparin was administered, measure the activated clotting time and wait to remove the sheath until it is 180 or less.

Holding Pressure

The hemostatic access sheath or the catheter is removed in the recovery room rather than in the angiographic suite or operating room. The patient is placed in the supine position. If there is a large pannus, an assistant retracts the skin fold to achieve a horizontal working surface. Pressure is applied before the catheter or sheath is removed. The fewest number of gauze pads possible are used to hold pressure so that the pulse is readily palpable while holding pressure.

Following a retrograde femoral artery puncture, digital pressure is held at the location of the arteriotomy that is proximal to the skin puncture site (Fig. 1). The ipsilateral foot is exposed while pressure is held so that the color of the foot can be continuously assessed. The goal is to prevent bleeding from the artery while maintaining flow through it and permitting a

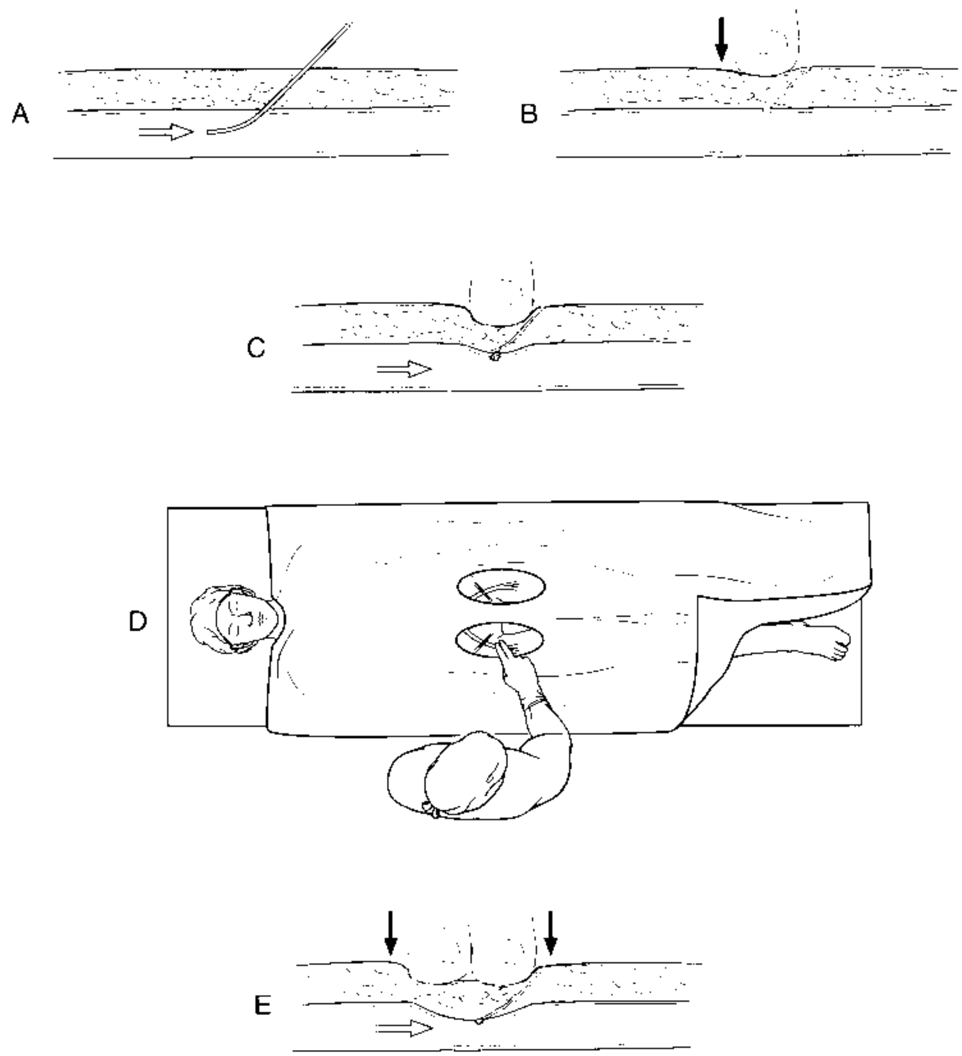

Fig. 1 Puncture site management. A, A percutaneous catheter is placed. **B,** Pressure is held at the arteriotomy site after the catheter is removed. **C,** Digital pressure does not occlude flow. Platelets deposit at the arteriotomy site as digital pressure prevents leakage of blood from the artery. **D,** The ipsilateral foot is exposed during pressure application to continuously evaluate the color of the foot. **E,** Even if greater pressure is required for hemostasis, flow is not occluded.

platelet plug to form on the flow surface. Too much pressure applied occludes the artery while too little pressure applied in the wrong place allows continued hemorrhage or may even promote it. Applying pressure to the artery distal to the puncture site increases resistance, which forces more extravasation.

Antegrade femoral artery puncture requires a two-handed technique. One hand is placed proximal to the inguinal ligament to apply pressure over the distal external iliac artery to decrease the head of pressure flowing through the punctured segment and to diminish any oozing into the retroperitoneal space (Fig. 2). The goal is not to occlude arterial flow, even temporarily. The other hand places point pressure over the area of arterial puncture just distal to the inguinal ligament. The distal hand can also assess the pulse and ensure that the pressure exerted by the proximal hand is not significant enough to stop flow. Pressure is usually held for 15 min after routine arteriography with 4 or 5 Fr catheters. After routine angioplasty with a 5 or 6 Fr sheath (6 or 7 Fr outside diameter), consider holding pressure for more than 15 min to ensure hemostasis. If a larger sheath was used (7 to 10 Fr) or heparin was administered, up to 30 min of pressure may be necessary. Managing the puncture site is a routine task, but doing it improperly guarantees a complication.

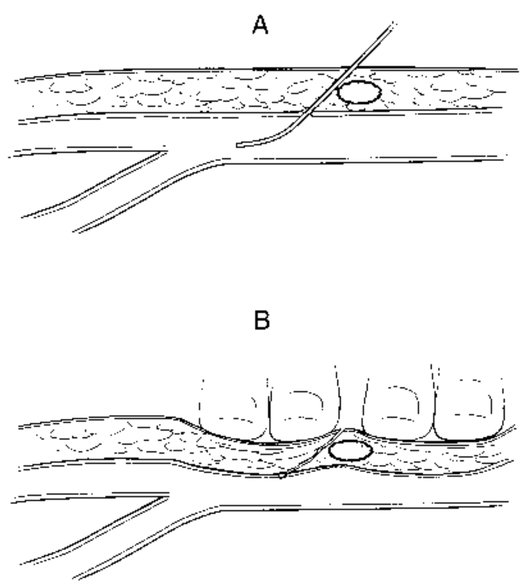

Fig. 2 Hemostasis after antegrade puncture. A, An antegrade catheter is placed. **B,** After the catheter is removed, pressure is applied both above and below the inguinal ligament.

Timing the Sheath Removal

The sheath is usually removed at the completion of the study unless heparin was administered. An activated clotting time may be useful to help time sheath removal. If the sheath is to remain in place for more than an hour, consider a low-dose heparin drip through the sidearm of the sheath.

Managing Puncture Site Complications

Several factors contribute to percutaneous femoral artery puncture site hemorrhage: anticoagulation or bleeding disorders; presence of severe common femoral artery calcification; high puncture, involving the distal external iliac artery; low puncture, involving the crotch of the femoral bifurcation or proximal deep femoral artery; a puncture site that lacerates the side of the artery; or a large-caliber arteriotomy (especially 10 Fr or larger). Puncture site management is often relegated to a member of the team with the least experience or understanding of the procedure performed. However, managing a complication after it has occurred requires more energy and expertise than is needed when the puncture site is managed well to begin with.

23

Endovascular Complications Can Be Avoided!

Selecting the Appropriate Physician
Selecting the Appropriate Patient
Selecting the Appropriate Technique
Selecting the Appropriate Approach
Spotting a Nasty Lesion Before It Spots You
Knowing When to Quit
Deciding What Kind of Facility Is Adequate

Selecting the Appropriate Physician

Endovascular skills and the interventions derived from them are most effective in serving patients in need when they are used in a fashion that is complementary to, rather than exclusive of, other treatment options. From the standpoint of the patient, selecting the appropriate physician is a crucial factor in determining how an illness is managed. Physicians must be dedicated to the treatment of patients with vascular problems, not to one type of procedure or another. When the operator is committed to using one therapeutic approach, two results are likely: unnecessary complications arise and some patients are denied better treatment options. One of the significant judgment challenges in endovascular interventions is that the natural history of some vascular processes may be the same as or better than the outcomes possible with intervention. The clinician must understand that and be willing to implement that into clinical management when it is best.

Selecting the Appropriate Patient

The best candidates for endovascular intervention have either lesser forms of disease or strong indications for intervention with prohibitive operative risk. Endovascular surgery provides valuable therapeutic options in these two groups of patients, but the temptation is never ending to apply endovascular intervention to all other groups of patients in whom the benefits are not so clear-cut. As endovascular interventions are refined and become more applicable to severe forms of occlusive and aneurysm disease, identifying patient groups that are most likely to benefit from these procedures will become even more challenging.

Selecting the Appropriate Technique

After endovascular intervention has been selected as the best among available options, there are many techniques from which to choose. In general, the simplest intervention that gives the longest-term solution to the clinical problem is best. At present, balloon angioplasty with the selective use of stents is usually the best solution for a variety of vascular problems. It is easy to become sidetracked with the latest and greatest, only to realize afterward that its clinical value was marginal, or worse, that the patient suffered because of it. The continuing developments in atherectomy, angioscopy, complex or repeated thrombolysis, multistent recanalizations, and other techniques form the basis of a stimulating postgraduate course but the clinical applicability of each must be carefully evaluated. Stent–grafts for aortic aneurysm have reached a level of clinical utility, but long-term performance is still under evaluation. Stent–grafts and covered stents for other indications require more study.

Most patients who undergo endovascular procedures can also be treated with standard surgery. The reason that standard surgery is not performed, even though it is generally more durable, is because an endovascular procedure holds the promise of lower complication rates. If an endovascular procedure has a high risk of complications, it should not be performed, or at least this should be included in the risk/benefit analysis. Many new techniques do not have well-established complication rates and each has a learning curve.

Selecting the Appropriate Approach

After selecting the appropriate patient and technique, choosing the right approach ensures a smooth entry and exit. The best approach is almost always the shortest and most direct route to the target. The more understanding the operator has about the presentation, physical findings, and noninvasive physiologic data, the more likely he or she is to choose the simplest approach with the fewest surprises.

The entry artery, not just the pulse, should be palpated prior to cannulation. A severely calcified artery can lead to puncture site complications. The operator should work on the forehand side as much as possible. A double-wall puncture creates extra holes and is almost never required. An alternative approach is occasionally required and is always better than forcing a complication. When converting an arteriographic procedure to a therapeutic one, a second well-placed puncture site that provides direct access to the target is often simpler.

If pressure is not held adequately and precisely at the puncture site after the procedure, a complication is virtually guaranteed. This mundane task must be well performed to avoid trouble. Pressure must be sufficient to occlude the arteriotomy without stopping flow.

Spotting a Nasty Lesion Before It Spots You

The addition of stents to the endovascular armamentarium has permitted very complex (and nasty-appearing) lesions to be treated with transluminal therapy not previously considered possible. This potential regularly adds to the mix a much more dangerous and potentially complicated group of lesions. The results of endovascular reconstruction of very complex lesions are not yet known. Degrees of lesion complexity are difficult to define. Most of the data on which angioplasty is recommended come from simple angioplasty of clear-cut, focal lesions. Most of the data on which stent implantation is based come from either selective stenting of focal lesions that were inadequately treated with angioplasty alone or from primary stent placement in patients who may not have needed stents at all. The treatment of complex disease patterns is associated with longer, more expensive endovascular procedures, higher complication rates, and lower long-term patency.

Rupture, occlusion, and embolization must be avoided in approaching a complex lesion. Rupture is rare and usually results from overdilatation. Concluding the procedure with a reasonable result and not attempting cosmetic perfection usually minimizes this potential. Occlusion most often results from dissection and is treatable with stents. It does not usually carry the ominous prognostic factor of an immediate emergency operation. Embolization is not usually fatal but it may be the worst complication of endovascular intervention. Treatment options are limited and the risk of end organ loss is high. Outflow control should be obtained by balloon occlusion or by arterial cutdown if embolization appears likely.

Knowing When to Quit

Not every lesion should be treated with endovascular techniques. When the risk of an endovascular procedure is too high or the potential for success is low, other alternatives should be considered. Sometimes this point in the decision tree arises during an endovascular procedure! This is a major reason why the techniques of endovascular intervention should be performed by those managing vascular patients.

The quest for the perfect cosmetic result of a reconstruction is seductive, but it does not guarantee long-term patency and may cause a short-term disaster. The temptation to become a lesion-oriented physician, rather than a patient-oriented physician, is counterproductive. Clinical orientation is crucial because the best results come from doing only what is indicated by the clinical condition of the patient.

Deciding What Kind of Facility Is Adequate

In most institutions, the highest-quality imaging is available in the angiography suite. Unfortunately, the angiography suite often presents other limitations in terms of patient care and the need for open access to the arterial system. To date, the most complicated endovascular reconstructions performed, including endoluminal stent–graft repair of aneurysms, have been performed in the operating room using a variety of imaging systems, including portable digital imaging systems. Portable imaging is tremendously inconvenient and cumbersome, but the quality is adequate to obtain reasonable results with complex procedures. The longer term will require that the best possible angiographic imaging be available to clinicians hoping to achieve ever better results for patients.

The ideal endovascular surgical suite is being developed. Angiography suite conversion to operating room capability or the installation of better x-ray imaging in the operating room is a beginning. In the meantime, the endovascular surgery team must be somewhat flexible. The type of procedure must be matched to the location where it is to be performed, keeping in mind the advantages and limitations of the imaging quality available.

24

Knowing Your Inventory and Equipment

Basic Inventory: Needles, Guidewires, Catheters, Sheaths, Balloons, and Stents
Radiographic Equipment
Radiographic Terms
Radiation Exposure

Basic Inventory: Needles, Guidewires, Catheters, Sheaths, Balloons, and Stents

Basic inventory includes as many as you can get of the guidewires listed in Table 1 in Chapter 3, catheters listed in Table 4 in Chapter 3, and balloons, in lengths of 2 and 4 cm, listed in Table 1 in Chapter 14. Different sizes of both balloon-expandable and self-expanding stents should also be available. Table 1 includes a partial list of the manufacturers of these items.

The inventory available must complement or exceed the ability of the endovascular surgeon. The availability of inventory to perform a challenging case is just as important as the technical know-how to do the case. Each operator must understand what is available in order to be effective. Look before the case starts. Be sure there is an extra one of the key items you need for the case. Pay attention to what you have and continuously update it. New products come out several times a year. The level of attention you pay to inventory depends upon the environment in which you work. In a friendly environment, the technicians are a resource and you can order what you need. Some operators must work in a marginal environment where no one wants to help you get one more catheter and any bad result is big news. Gear the personal level of involvement with inventory to the type of environment in which the work is carried out. The less support is available, the more hands-on control the operator needs to keep track of the inventory.

Table 2 contains tips for inventory management. Use all the available resources to your advantage. See what others are using for various purposes and copy their inventory lists. When visiting colleagues, look through their closet and see if they have anything you can use. Focus your purchasing on two or three companies that are chosen on the basis of geography, price, and service. Most companies want to sell supplies to doctors of all different disciplines and the reps are caught in the middle. Don't take it out on the reps. Get to know them. They have a tremendous wealth of knowledge and are a potential resource. They know what everyone else is doing and what the latest approaches are. They know what is selling. Get all the catalogues you can from companies that make endovascular supplies and have them available. When the endovascular journals come in, be sure to read the Materials and Methods section. Authors often share technique and inventory advice that can be put to good use. Each of the major cases should be summarized using case cards, the same as it would be for any surgical case. Tables that appear in the chapters on endovascular therapy may be converted into case cards. Table 1 in Chapters 17, 18, and 19, and Tables 2 and 3 in Chapter 20, list the guidewires, catheters, sheaths, balloons, and stents that one might have on hand for an endovascular intervention. It must be clear who is in charge of the inventory and who is accountable for replenishing any item that is used. The inventory should be reviewed every six months.

Table 1 Who Makes It?[a]

Manufacturer	Needle	Guidewire	Catheter	Sheath	Balloon	Vascular stent
AngioDynamics, Inc. 603 Queensbury Queensbury, NY 12804 800-772-6446	X	X	X	X	X	
Argon Medical 1445 Flat Creek Road Athens, TX 75751 800-927-4669		X	X	X		
Arrow International, Inc. 2400 Bernville Road Reading, PA 19605 800-523-8446		X	X	X		
C.R. Bard USCI Division 129 Concord Road Billerica, MA 01821 800-225-0898		X	X	X	X	X
Boston Scientific Corp. Medi-Tech Division 1 Boston Scientific Place Natick, MA 01760 800-225-3238	X	X	X	X	X	X
V. Braun Medical 824 12th Avenue Bethlehem, PA 18018 800-523-9676	X	X	X	X	X	
Cook, Inc. P.O. Box 489 Bloomington, IN 47402 800-457-4500	X	X	X	X	X	X
Cordis A Johnson & Johnson Co. 14300 NW 60th Avenue Miami, FL 33014 800-327-7714	X	X	X	X	X	X
Guidant Corporation Advanced Cardiovascular Systems Division 3200 Lakeside Drive Santa Clara, CA 95054 800-633-3375		X	X		X	X

(continued on next page)

Table 1 (continued)

Manufacturer	Needle	Guidewire	Catheter	Sheath	Balloon	Vascular stent
Mallinckrodt, Inc. 675 McDonnell Blvd. P.O. Box 5840 St. Louis, MO 63134 888-744-1414	X	X	X	X	X	
St. Jude Medical Company Daig Division 14901 Deveau Place Minnetonka, MN 55345 800-353-9073	X	X	X	X		

[a] This is a partial list of manufacturers of endovascular supplies.

Radiographic Equipment

Cathode/anode/x-ray tube. Within the x-ray tube, the cathode is a heated tungsten filament that emits electrons. The anode is the target. This process transforms energy into x-rays. Most of the energy becomes heat and a small amount is converted to x-rays. Fluoroscopic procedures that require high-energy settings risk overheating the equipment.

Generator. The generator serves as the electrical power source for the x-ray tube. One of the significant differences between portable and stationary angiographic systems is the size of the generator. Better image quality is to be expected with a more powerful generator.

Image intensifier. The x-rays travel through the patient and strike the image intensifier. Differential energy absorption is converted into light images and displayed on television monitors.

C-arm. The image intensifier and x-ray tube are usually mounted together in a C-shaped configuration, regardless of whether a portable or stationary fluoroscopic unit is used. This is referred to as the gantry.

Table 2 Tips for Inventory Management

Copy a colleague's inventory
Pick two or three companies: compare geography, price, service
Check catalogues
Know your reps
Read materials and methods
Use the case card approach
Put someone in charge of inventory
Review inventory every 6 months

Power injector. A power injector is a high-pressure contrast injector.

Digital console. The console commands the computer in which digital information is acquired and processed.

Radiographic Terms

kV. Kilovoltage is a measure of the penetrability of the x-ray beam and affects image contrast. It represents the electrical potential across the x-ray tube. The higher the voltage is across the x-ray tube, the greater the penetrating power of the beam and the better the contrast. Cerebral, thoracic, and abdominal arteriography usually require 65 to 75 kV. Extremity arteriography is performed with 55 to 65 kV.

mAs. The current (milliampere/second) required to generate the x-ray beam should be set at the highest milliamperage (to minimize image noise) for the shortest exposure time (to minimize motion artifact). The number of milliamperes determines the density of the image.

Frame rate. The frame rate is the number of image frames generated per second. Resolution increases with higher frame rates, but so does radiation. Images may be acquired anywhere from 1 to 30 per second. A standard DSA run usually includes frame rates of 3 or 4 images per second.

Matrix. The digital matrix is divided into pixels. When the matrix is divided into more but smaller pixels, the resolution is better. Modern DSA units acquire 1024 × 1024 pixels per frame.

Focal spot. The focal spot is the area on the anode that receives the electrons. The smaller the focal spot size, the better the resolution. Focal spot size ranges from 0.15 to 1.2 mm. Smaller focal spots, however, limit the frame rate and the amount of energy available for generating images because of heat production.

Mask. The digital mask image is obtained before contrast is injected. It is later subtracted from the images obtained during arteriography to eliminate overlying bone and other structures.

Radiation Exposure

Allowable limits. The maximum permissible dose for adults is 5 rems per year.

Dose calculation. The amount of radiation to the operator is equal to the exposure rate multiplied by the time. Radiation exposure decreases proportionally to the square of the distance from the beam.

X-ray tube position. Scatter radiation is decreased by turning the x-ray tube away from the operator and by placing it under the patient (rather than above).

Organ susceptibility. Skin and soft tissue are less susceptible to radiation damage than the eye, thyroid, gonads, and hematopoietic system.

Protective gear. A leaded apron, thyroid shield, gloves, and glasses reduce radiation exposure but are cumbersome. Aprons decrease radiation exposure by 75 to 90%.

Limiting exposure. A radiation dosimeter is worn to ensure that exposure remains below allowable limits. The image intensifier is placed close to the patient to reduce the scatter of x-ray beams. The image intensifier is turned away from the area in which the operator is working. Exposure time is shortened by using fluoroscopy intermittently rather than continuously. The frame rate is decreased. The beam is collimated to reduce scatter. Maximum distance from the beam is maintained. A ceiling- or floor-mounted shield may be used in addition to leaded apparel. See Chapter 5 for a discussion of radiation exposure.

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