CHAPTER 1

General principles of endovascular therapy

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Cardiovascular disease remains a major cause of mortality in the developed world since the beginning of the twenty-first century. Although surgical revascularization has played a predominant role in the management of patients with vascular disease, the modern treatment paradigms have evolved significantly with increased emphasis of catheter-based percutaneous interventions over the past two decades. The increasing role of this minimally invasive vascular intervention is fueled by various factors, including rapid advances in imaging technology, reduced morbidity, and mortality in endovascular interventions, as well as faster convalescence following percutaneous therapy when compared to traditional operations. There is little doubt that with continued device development and refined image-guided technology, endovascular intervention will provide improved clinical outcomes and play an even greater role in the treatment of vascular disease. In this chapter, a framework is provided for a brief history of endovascular therapy along with an overview of commonly used endovascular devices. The fundamental techniques of percutaneous access is also discussed.

Brief history of endovascular therapy

Evolution of diagnostic imaging

The discovery of the X-ray imaging system by Charles Röentgen in 1895, marked one of the most remarkable milestones in the history of medicine. Within months after its discovery, X-rays were used by battlefield surgeons to locate and remove bullet fragments.[1] This imaging modality quickly gained acceptance from physicians around the world in providing valuable diagnostic information in the care of their patients. As a natural evolution of this discovery, X-rays were soon adapted to evaluate the vascular system in conjunction with the use of a contrast material. In 1910, Frank performed the first venography in rabbits and dogs by injecting a solution of bismuth and oil intravenously and following its flow fluoroscopically.[2] Heuser is credited (in 1919) for performing the first contrast study in humans by injecting a solution of potassium iodide into the dorsal vein of a child and following the flow of the substance to the heart.[3] The use of such materials was initially quite toxic. This led to the

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development of safe contrast media, for example water soluble iodine-based organic contrast called Selectran-Neutral by Binz in 1929.[4] Concurrently, newer injection methods were also being developed. In 1927, Moniz was the first to perform direct arterial injections, and he used this technique to inject sodium iodide into the internal carotid arteries.[5] This direct approach was initially used to image the heart and thoracic aorta but was soon abandoned due to its hazards.

Castellanos used an indirect method of injection whereby a contrast agent was injected into a vein in the arm and, after a delay, the aorta was visualized.[6] Due to dilution of the agent in the heart and lungs, the aorta could be visualized only 75% of the time. For a better study of these vessels, Werner Forssmann, a resident surgeon in Berlin in 1929, ran a urethral catheter through his own basilic vein to visualize his right ventricle. This earned him the Nobel prize in 1956.[7] Also in 1929, dos Santos *et al*. described a technique of visualizing the aorta using a direct puncture technique by translumbar injection of a contrast medium directly into the abdominal aorta.[8] The modern aortogram via a femoral approach was first performed by Farinas in 1941,[9] a technique that was quickly adapted by physicians around the world. With the advent of guidewires in the early 1950s, selective angiography with catheter-directed injection was developed further. In 1962, Guzman and colleagues reported a large series of patients who underwent coronary angiography using selective coronary catheterizations.[10] Since then, the application of guidewires, catheters, and introducer sheaths has become a standard approach when performing diagnostic angiography.

Evolution of therapeutic interventions

Ivar Seldinger, a Swedish radiologist, was the first physician to describe a unique method of establishing arterial access using a guidewire technique in 1953, which heralded an evolution from diagnostic to therapeutic angiography.[11] A decade later, Fogarty detailed the use of a balloon-tipped catheter to extract thrombus.[12] Building on this, Dotter and Judkin in 1964 described a method of dilating an arterial occlusion using a rigid Teflon catheter to improve the arterial circulation.[13] In the field of venous intervention, catheter-based vena caval filters were introduced by Greenfield in 1973, and have revolutionized the current approach in the prevention of pulmonary embolism.[14] The technique of balloon angioplasty was introduced by Gruntzig, who performed the first coronary artery intervention in 1974.[15] To this day, this remains the most commonly performed endovascular procedure in clinical practice. The application of the balloon angioplasty catheter subsequently led to the development of the first intravascular balloon-expandable stent by Palmaz *et al*. in 1985.[16] Several years later, Parodi, an Argentinean vascular surgeon, combined both a Dacron graft and balloon-expandable stent technology to create a stent-graft, which was successfully used to exclude an abdominal aortic aneurysm from the systemic circulation.[17] Technology in this field is rapidly evolving and more complex modular stents with thermal memory are

in use today. There has also been an explosion in catheter-based technology, enabling access for the interventionalist to treat occlusive disease and increasingly, aneurysmal disease in nearly every vascular bed. Further development of this minimally invasive intervention is currently focused on combining a pharmacological agent with the current stent platform to create drug-eluting stents to improve the clinical outcome of endovascular therapy.

Basic vascular access

Percutaneous access can be achieved by a single- or double-wall puncture technique. In the former approach, a beveled needle is introduced, and a guidewire is passed after confirmation of arterial or venous access by visual inspection of back bleeding with or without the use of direct pressure measurement and inspection of arterial or venous waveforms. As a routine, we typically gain vascular access using a 21-gauge micropuncture needle and a 0.018-in. wire. The double-wall technique requires the use of a blunt needle with an inner cannula. The needle is inserted through the vessel, and then the inner cannula is removed, the introducer needle withdrawn until back bleeding is obtained, and a wire introduced. Although percutaneous access can be routinely achieved in nearly all patients, those with scarred access sites from prior interventions or patients with decreased pulses due to occlusive disease represent a specially challenging subset that may benefit from ultrasound guidance with Doppler insonation or B-mode visualization of the target vessel. Indeed, access site needles have been developed with integrated Doppler probes.

Retrograde femoral access

Percutaneous retrograde femoral puncture is the most commonly used arterial access technique. Both groins are prepped and draped in a sterile fashion. Visualization of the femoral head using fluoroscopy is recommended. In the majority of patients, the common femoral artery can be found over the medial third of the head of the femur (Figure 1.1). Another advantage of accessing the artery in this location is that the femoral head will serve as a hard surface to compress the artery against, after the completion of the procedure if manual compression is needed to achieve hemostasis. An 18-gauge angiographic needle is then advanced at a 45° angle through the skin until pulsatile back bleeding is encountered. As with all needle access, the bevel of the needle should point upward. Going through and through the artery should be avoided, as this can lead to problematic bleeding. Depending upon the body habitus, the artery may lie anywhere from 2–5 cm below the level of the skin. If venous entry is noted, it is useful to remember that the artery lies lateral to the vein. It is also important to remember that there is approximately 3 cm of common femoral artery that lies between the inferior ligament and the femoral bifurcation. Once brisk back bleeding is noted, a standard Bentson wire is passed through the needle into the artery for at least 20 cm. It is recommended

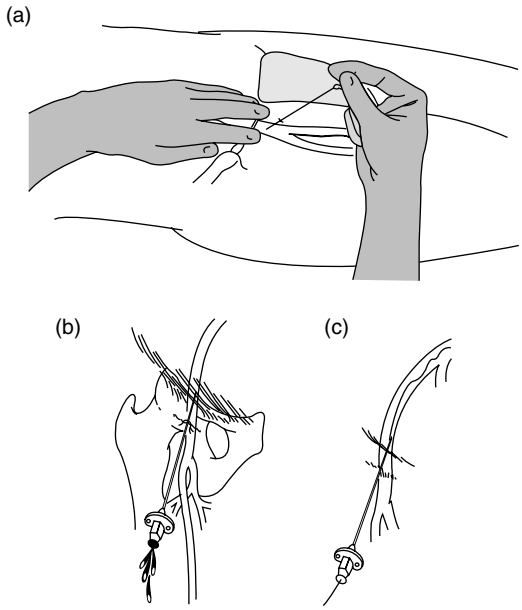

Figure 1.1 Retrograde femoral artery access. (a) The common femoral artery can usually be found medially 2–3 cm below the inguinal ligament. (b) Once the needle enters the common femoral artery, brisk back bleeding is seen. (c) The Bentson guidewire is next advanced through the needle under fluoroscopic guidance to establish the arterial access.

that this maneuver is performed under fluoroscopy to confirm that the wire is going into the aorta. Once the wire is in place, the introducer sheath with its dilator can be easily passed into the artery. If there is any doubt about the path of the wire, a small amount of contrast can be injected through the needle to delineate the needle location.

Arterial entry higher than the level of the femoral head can prove to be difficult in achieving hemostasis, and retroperitoneal hematoma often develops. Entry into the femoral artery far below the inguinal ligament can lead to entry into the superficial or profunda femoral arteries. Catheterization of either of these arteries can result in post-op hematoma and pseudoaneurysm development.

Antegrade femoral access

Antegrade femoral puncture is more challenging than retrograde but can be invaluable in problematic infrainguinal lesions. We recommend that the operator stand on the side that permits forehand approach of the needle (Figure 1.2). The needle is advanced at an angle of 45° to the skin until pulsatile back bleeding is noted. With this approach, it is even more important to avoid low punctures, as this would limit the working room to selectively catheterize the superficial femoral artery. With obese patients, it is often necessary to have

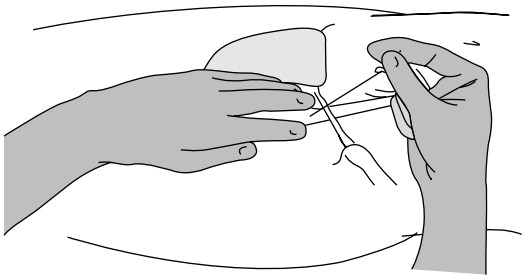

Figure 1.2 Antegrade femoral artery access. The needle is inserted just below the inguinal ligament in the common femoral artery whereby the guidewire is inserted in the ipsilateral superficial femoral artery.

an assistant retract the pannus cephalad out of the way. Once back bleeding is noted, the Bentson wire is placed, followed by a sheath. If there is little room between the site of entry of the wire and the femoral bifurcation, a sheathless technique may need to be employed. In order to selectively catheterize the superficial femoral artery, an angled catheter may help in directing the wire down the correct artery. If the guidewire begins to buckle, it should be withdrawn and retried using a different angle.

Difficult access

There are several techniques that can be employed to access the pulseless yet patent femoral artery. The common femoral artery almost always passes over the medial head of the femur, and attempts in this area will prove to be the most successful. Accessing the femoral artery via the contralateral side and placing a catheter over the bifurcation can be used to inject contrast and visualize the ipsilateral artery. Many patients have vessels that are calcified. Using magnification views, these calcifications can be used as a guide to determine the location of the femoral artery to which the needle can be inserted. Finally, a handheld ultrasound device can be used to determine the location of the noncompressible femoral artery with respect to the compressible femoral vein.

Crossing the aortic bifurcation

Crossing over the aortic bifurcation to gain access to the contralateral iliac artery is an indispensable technique in ileofemoral arterial interventions. This selective catheterization technique produces angiograms of significantly improved quality because of localized contrast injection. The first task is to determine the location of the aortic bifurcation. This can be done by either performing an aortogram for use as a road map or by using the L4 vertebrate and the iliac crest as a landmark. Calcifications in the arteries can help in establishing orientation. The catheter type can prove to be decisive in gaining access across the aortic bifurcation. We routinely use the Contra catheter, as this saves a step when an aortogram is also performed. The catheter is parked near where the bifurcation is suspected, and a glidewire is advanced. If initial attempts are

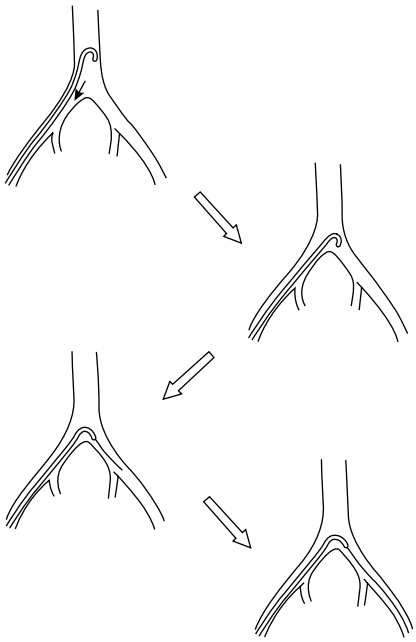

Figure 1.3 Gaining access across the aortic bifurcation. A curved catheter is inserted in a retrograde fashion from a femoral artery approach and is positioned across the aortic bifurcation. A guidewire is next advanced over the catheter to gain access in the contralateral common iliac artery.

unsuccessful, the catheter and wire can be rotated. Alternatively, the catheter can be advanced 1–2 cm up into the aorta, which helps the guidewire select the contralateral common iliac artery. Once the artery is selected, the catheter is pulled back down and securely positioned across the bifurcation (Figure 1.3). Alternative catheters for this approach may be the Cobra or C2 catheter. Once inside the contralateral iliac, the wire is advanced past the inguinal ligament in order to securely position the catheter in the iliofemoral arterial segment. Subsequently, catheters and sheaths can be advanced with ease. There are several specially shaped sheaths available that facilitate in crossing-over.

Brachial puncture

Occasionally when the distal aorta or bilateral ileofemoral axis are inaccessible, the brachial artery becomes a very useful access site. The left brachial artery is the preferred upper extremity access of choice, as this avoids the origin of the carotid artery and thus reduces the chance of a cerebrovascular accident due to catheter-related thrombus embolization. The arm is abducted and prepared on a radiolucent arm board. The most common location for puncture is just proximal to the antecubital crease, and this location reduces the incidence of nerve injuries (Figure 1.4). Once sterility has been established, a micropuncture kit is used to access the artery. The micropuncture sheath can then be exchanged for a 6 Fr sheath. Once at the aortic arch, an angled catheter can be used to deflect the wire down the aorta.

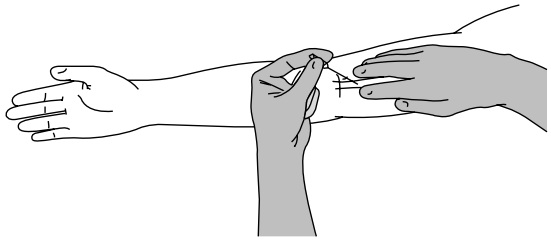

Figure 1.4 Brachial artery approach. A Seldinger needle is inserted in a retrograde fashion in the brachial artery just above the antecubital fossa, whereby the guidewire is next inserted in the brachial artery.

Table 1.1 Comparison of mobile C-arm and fixed angiosuite imaging system.

Imaging system	*Mobile C-arm unit*	*Fixed angiosuite unit*
Reliability	Adequate	Superior
Radiation exposure	More	Less
Availability	Can be moved to different locations because of its portability	Restricted to one location
Likelihood to overheat with prolonged usage	High	Low
Special construction	None	Needed
Cost	up to $20,000 US	up to $2 million US

Image-guided endovascular intervention

Choosing an imaging system

Excellent imaging is the key to endovascular therapies regardless of whether the intervention is performed in an imaging suite or an operating room. Fluoroscopy is the modality used for digital subtraction angiography. Fluoroscopy functions via an image intensifier that receives, concentrates, and brightens an X-ray image to produce an electronic image that can be displayed on a screen. The larger size of an image intensifier usually allows for better quality imaging. A standard imaging suite image intensifier is 15 in. in diameter, whereas a standard image intensifier on a portable C-arm is 12 in. in diameter. Both of these systems allow control of the irradiation by the use of a foot pedal. The advantages and disadvantages of each system are highlighted in Table 1.1. Although the versatility and durability of an angiosuite are better than a mobile C-arm unit, both are adequate for performing the majority

of endovascular procedures. For most surgeons, performing an endovascular intervention in the operating room using a mobile C-arm unit is a common strategy to build an endovascular practice. The portability of a C-arm unit enables surgeons to perform catheter-based interventions in any operating room, an environment that is intimately familiar to most surgeons in contrast to an angiosuite in the radiology or cardiology service. Moreover, the cost of a C-arm unit is only a fraction of the price of an angiosuite, which is easier to acquire in hospitals with budgetary constraints. There are however several limitations, however, associated with a C-arm fluoroscopic equipment. Despite the significant technical improvements in the current model of C-arm systems, the image quality remains slightly inferior to that obtained from the angiosuite. This is due to several factors including higher focal spot size, fixed distance between the X-ray tube, and the power output of a C-arm image intensifier.[18,19]. A common concern about the mobile C-arm unit is its propensity to overheat. When this happens, the unit must be shut down and allowed to cool, which can be severely limiting. In contrast to a mobile fluoroscopic unit, an angiosuite is typically more robust with less likelihood of overheating. In addition, all the necessary imaging equipments, such as image intensifier, fluoroscopic table, and power injector are typically electronically integrated in an angiosuite. Consequently, activating the image intensifier dims the room lights, initiates the imaging sequence, and times the injector activation. Another benefit of the angiosuite is that most are directly linked to a hospital picture archiving and communication system (PACS), which facilitates viewing. Lastly, images captured from an angiosuite can be used to create rotational angiography or three-dimensional reconstruction for further image analysis.

Both portable C-arm and an angiosuite imaging unit have specialized functions that are commonly used during interventions. Magnified views are obtained when focusing on a limited area such as the aortic bifurcation for kissing stent deployment. Another feature is the road map technique. This allows for a representation of the arterial tree by contrast angiography on one digital screen with real-time fluoroscopy on another. Fluoroscopic images can be adjusted in different oblique angles to enhance the accuracy of visualizing certain vascular anatomy, such as the internal iliac arteries or the aortic arch. The most commonly used fluoroscopic angle is anteroposterior (AP) projection. In contrast, examples of the oblique views include the right anterior oblique (RAO) and left anterior oblique (LAO) angles. When visualizing the internal iliac arteries, for example, an oblique angle allows the origin of this vessel to be visualized so that it does not overlap with the common iliac artery. This is especially important with iliac arterial interventions to prevent stenting across the origin of the internal iliac artery. Additional views such as craniocaudal correction can also be obtained. This is particularly useful for correcting angulation in difficult aortic necks during endovascular aneurysm repair. Commonly used orientations of the image intensifier in diagnostic angiography are listed in Table 1.2.

Table 1.2 Commonly used image intensifier orientations in arterial angiography and its contrast injection rates and volume.

Procedure	*Orientation*	*Injection rate (cc/s)*	*Injection volume (cc)*
Abdominal aortogram	AP	20	30
Arch aortogram	LAO 30–50° Chin up Shoulders down	30	50
Descending thoracic aortogram	LAO 15–30°	30	50
Selective carotid angiogram	AP and lateral Face rotated to opposite side	4	8
Cerebral angiogram	AP @10° craniocaudal, lateral	4	8
Mesenteric or renal angiogram	Full lateral, pig catheter in aorta	20	30
Renal selective angiogram	10–20° oblique to ipsilateral side	7	12
Selective run off via CIA	AP	8	40
Dual run off via aorta	AP	10	60
iliac bifurcation	Contralateral 20° AO	–	–
Common femoral angiogram	Ipsilateral 20° AO	–	–
Subclavian angiogram	AP	7	25
Inferior vena cavagram	AP	20	30
Common femoral venogram	AP	8	25
Superior vena cavagram	AP	10	30

Imaging table

The imaging table is an integral part of the endovascular suite. Although it is possible to perform an endovascular procedure in an operating room using a conventional operating room table, there are many drawbacks: variability in the cushioning and underlying metals provides for a nonuniform path for the radiation. For endovascular procedures, the primary requirement of the imaging table is that it must be radiolucent. In general, there are two types of radiolucent tables; fixed and movable. Fixed tables are constructed of a

nonmetallic carbon-fiber supported usually at only one end. This allows for unobstructed access for the C-arm because there are no structural elements underneath the table. These tables are relatively fragile and do not support patients in excess of 300 lbs. Movable tables allow for versatile positioning of the patient in the horizontal plane. They come with a set of bedside controls that also permit selection of the radiographic settings including gantry rotation, image intensifier location, collimation, and table height.

Power injector

There are two methods for delivering contrast: hand injection with a syringe and electronically calibrated precise power injection. For most small vessel and selective angiography, hand injection is adequate. However, for optimal opacification of high-flow blood vessels like the aorta, the use of a power injector is mandatory. Conversely, the power injector is also useful in small vessels when the contrast must be injected at a fixed slow rate. The power injector permits the operator to determine the rate of injection, total volume of injection, and pressure of the injection. Table 1.2 briefly outlines commonly used injection rates and contrast volume for diagnostic arteriographic studies.

Basics of radiation safety

Radiation exposure

Radiation safety is important in endovascular surgery not only because of regulations but also due to patient and personnel considerations. There are several federal, state, and local guidelines that are available for review. Significant levels of radiation exposure pose serious health hazards to medical personnel if standard safety guidelines are not followed. The general guiding philosophy is ALARA (as low as reasonably achievable).[20] This protective philosophy mandates that all interventionalists must compare the benefits to the risks of radiation exposure. With regards to exposure, there are three key principles: monitoring time, scatter, and distance of exposure.

With longer and more complex endovascular procedures, it becomes imperative to use the personal dosimeter device or badge. An external dosimeter badge must be placed over any radiation protective garments on the collar near the thyroid. A second badge is recommended to be worn underneath the protective garments at the waist level. This second badge becomes mandatory in pregnant women. The effective dose equivalent is then calculated from a weighted average of the two badges and is used to calculate exposure risk.

The duration of exposure is directly proportional to the received radiation dose. In this way, personnel exposure is linked to patient exposure. Reduction of personnel exposure can be effectively accomplished by reducing the "beam-on" time by judicious use of the exposure switch to ensure that radiation exposure is occurring only when the fluoroscopist is actively viewing the image and optimizing the number of images used in an exposure sequence.

Road mapping, pulse-mode fluoroscopy, and image hold and transfer can also help limit the time of exposure. Use of a control booth whenever possible (as in lower extremity run off) will also help to minimize radiation exposure time.

Another very important consideration is the scatter phenomenon. Although the majority of the radiation beam is absorbed by the patient, there is scatter radiation that is emitted from the patient in all directions. This scatter can be a major source of hazard for angiosuite personnel. Emission of radiation follows the inverse-square law whereby the radiation intensity decreases proportionately as the square of the distance from a point source.[20] Because increasing the distance decreases the radiation field intensity, it is always prudent to back away from the source when proximity is not required. Keeping the image intensifier as close to the patient as possible helps to maintain low fluoroscopic beam intensity and also allows the image intensifier to serve as a scatter barrier between the patient and the operator. One final point is that use of magnification modes further increases beam intensity, scatter, and heat production and should be used judiciously.

Radiation shielding

Shielding involves the use of protective barriers. The best type of shielding protects the whole body of an individual. Barriers may be fixed, moveable, or worn by the individual. The control room is an example of a structurally fixed barrier. Mobile barriers may be rolled into position inside angiosuites to protect nurses and anesthesia personnel who do not need to be near the patient for extended periods of time. Alternatively, ceiling-mounted transparent barriers may also be used to protect the upper body of the interventionalist. Flexible protective clothing such as aprons, skirts, and vests should always be used when working in an unprotected zone. The typical protective clothing consists of 0.50 mm lead impregnated rubber. Ninety-five percent of scatter is directed towards the head and neck, and the use of a thyroid shield is strongly recommended. In addition, leaded eyeglasses are available that can absorb 70% of scatter exposure to the lens. Personnel who have frequent back exposure should wear wrap-around protective garments (others may wish to wear them for comfort).

Every angiosuite should have a protocol in place to monitor the integrity of its protective garments. Folding and rolling of lead garments should be avoided, as this will lead to cracking. At the minimum, annual X-ray evaluation of the protective clothing should be practiced to evaluate for cracks. Drop off lead garments with shoulder and waist Velcro is available which allows for removal without breaking scrub.

Common devices used in endovascular interventions

Guidewires

Guidewires are used to introduce, position, and exchange catheters. A guidewire generally has a flexible and stiff end. In general, only the flexible

end of the guidewire is placed in the vessel. All guidewires are composed of a stiff inner core and an outer tightly coiled spring, which allows a catheter to track over the guidewire. There are five essential characteristics of guidewires: size, length, stiffness, coating, and tip configuration.

Guidewires come in different maximum transverse diameters ranging from 0.011 to 0.038 in. For most aortoilliac procedures, a 0.035 wire is most commonly used while the smaller diameter wires are reserved for selective small vessel angiography such as infrageniculate or carotid lesions. The 0.035 Bentson wire is often used as the initial guidewire to obtain access to the groin vessels for most interventions.

In addition to diameter size, guidewires come in varying lengths usually ranging from 180 to 260 cm in length. Increasing the length of the wire always makes it more difficult to handle and increases the risk of contamination. While performing a procedure, it is important to maintain the guidewire across the lesion until the arteriogram has been satisfactorily completed. A good rule of thumb to follow is that the guidewire should be twice the length of the longest catheter being used. This allows for easy catheter exchanges while maintaining the guidewire across the lesion.

The stiffness of the guidewire is also an important characteristic. Stiff wires allow for passage of large aortic stent-graft devices without kinking. They are also useful when trying to perform sheath or catheter exchanges around a tortuous artery. An example of a stiff guidewire is the Amplatz wire. For initial access, standard guidewires are coated with a nonhydrophilic coating composed of Teflon and heparin to lubricate the surface and reduce the thrombogenicity of the guidewire. The heparin coating lasts for about 10 min. Hydrophilic coated guidewires, such as the Glidewire, have become invaluable tools for assisting in difficult catheterizations. The coating is primed by bathing the guidewire in saline solution. The slippery nature of this guidewire along with its torque capability significantly facilitate difficult catheterizations. There are several disadvantages of hydrophilic coated guidewires that need to be remembered. These wires must be constantly rewetted in order to maintain their lubricated surface. Glidewires are often very slippery and difficult to handle with gloved hands, and one must be careful to monitor the tip of the wire while performing catheter exchanges.

Guidewires come in various tip configurations. Most tips of guidewires are soft. Many angiographers use the J-tip wire as the initial access guidewire, as it is associated with the lowest risk of dissection. We use the Bentson wire, which has a soft floppy tip that is straight in its packaged form but forms a functional large J-tip when being advanced through a vessel. Angled tip wires like the angled Glidewire can be steered to manipulate a catheter across a tight stenosis or to select a specific branch of a vessel. The Rosen wire has a soft curled end that makes it ideal for renal artery stenting. The soft curl of this wire prevents it from perforating small renal branch vessels.

Catheters

Catheters come in all different shapes and sizes and are sized according to their outer diameters. A plethora of catheters have been designed for specific arterial beds and designated by configuration, which are discussed in the last chapter of this book. Most catheters must be advanced over a wire to limit intimal injury. Catheters are generally differentiated based on whether they are nonselective or selective. An example of a nonselective catheter is the pigtail catheter. This type of catheter has multiple side and end holes that allow for a large cloud of contrast agent to be infused over a short period of time. They are most commonly used for viewing of high-flow vessels like the abdominal aorta. The other type of catheter is the selective catheter, which usually has only a single hole at the tip and is used to select certain vascular systems. Specific types of these selective catheters are described in the last chapter of this book. When using these catheters, care must be taken to avoid intimal injury by direct catheter tip advancement or by forceful injection of contrast material. The shape of catheters dictates their function. A commonly used selective catheter is the Bernstein catheter, which has a gentle angled tip and can be used to select many arterial branches.

Most other nonselective catheters have unique functions by design. In order to cannulate the contralateral iliac artery, we often use the Contra catheter. An alternate catheter for crossing over the aortic bifurcation is the C-2. For arch vessels, we recommend the use of Simmons-2 or JB-2. For bovine arches, a H-1 catheter is quite useful. These catheters must be reformed either in the ascending aorta or subclavian artery prior to using them to select a vessel. For renal and visceral vessels, we recommend the use of the renal double curve (RDC) catheter. This catheter can be advanced proximally and then slowly brought back down with a gentle rotation. It will generally land in a renal or visceral orifice. Once having been placed inside the ostia, a Glidewire can be slowly advanced across the lesion. A special category of catheters are the hydrophilic coated catheters like the Glidecath and Slip-Cath. They can be used for crossing tight lesions and can be advanced independent of a guidewire.

Introducer sheath, guiding sheaths, and guiding catheters

Vascular sheaths allow for easy exchange and introduction of catheters and guidewires. They have a hemostatic valve that prevents blood reflux and air embolism. Furthermore, they protect the vessel entry point from intimal injury and should be used whenever multiple guidewire exchanges are anticipated. Sizing of sheaths is based on their internal diameter: a 7 Fr sheath will accept up to a 7 Fr catheter. Sheaths come in multiple lengths. In addition, the side port of the sheath can be used to inject contrast or measure arterial pressure. All sheaths are packaged with dilators. Dilators serve as an obturator for entry of the sheath and also help to progressively enlarge the track once guidewire entry has been established. As with all sheaths, once placed they must be flushed with heparinized saline through the side port in order to prevent thrombosis.

Guiding catheters and sheaths can be used to facilitate passage of a smaller endovascular device through a tortuous curve. They are particularly useful in the renal and carotid system or contralateral iliac system. The distal portion of some guiding sheaths comes in a specialized shape like the renal curve sheath. Guiding sheaths are also particularly useful for intermittently assessing the results of angioplasty. The side port allows for puffing of contrast distally while the guidewire is still across the lesion.

Balloon catheters

Once the diseased arterial bed has been selected with the appropriate catheter and wire, the presence of the anticipated lesion needs to be confirmed, and where appropriate, its hemodynamic significance determined. An arteriogram is obtained by hand injection of contrast agent through the selective catheter, and a "road map" is acquired that creates a virtual image of the effected arterial segment through which repeated passes of catheters, wires, or stents can be visualized.

The contrast load is always minimized and tailored to the specific patient according to the intervention being performed. For patients with an elevated serum creatinine level ($\geq$1.4 mg/dL), preintervention hydration, minimization of contrast load, and/or use of fenoldopam have been advocated to limit the nephrotoxic effects of the contrast agent.[21] Fenoldopam is administered as a continuous infusion at a rate of 0.01–1.6 mg/kg/min. A steady-state concentration is usually reached within 20 min. Other options for lesion localization when the baseline serum creatinine exceeds 2 mg/dL include use of gadolinium, CO_2 contrast, or intravascular ultrasound. Of note, the total administered volume of gadolinium should not exceed 0.2–0.4 mmol/kg, which is equivalent to 30–60 mL in a 75-kg person.

There is no consensus as to whether an intervention should be based on a pressure gradient difference measured by an intraarterial catheter. We suggest that a mean pressure gradient greater than 10 mm Hg is sufficiently significant to require treatment. If no difference is detected in the resting state, then 100 mg of nitroglycerin can be infused intra-arterially to mimic the increased demand that occurs with walking. The gradient can be checked after the infusion is complete.

For a given lesion, a balloon catheter is selected on the basis of balloon diameter (millimeters) and length (centimeters), as well as the length of the catheter shaft, which is dictated by lesion location and the chosen access site. Characteristically, angioplasty balloons are produced from a noncompliant plastic, such as polyethylene, which facilitates high-pressure inflation to a predetermined maximum shape and size. Pressure required for inflation may vary widely from 4 to 16 atm and is dependent upon the compliance of the vascular lesion to be dilated. Higher pressures are typically required for relatively stiff venous stenoses. The ability to respond to an inflation pressure without balloon disruption is dictated by the material properties of a given balloon, and as a consequence, is also a factor in selection of an appropriate balloon

Table 1.3 Commonly used angioplasty balloon diameter size.

Arterial lesions	*Commonly used balloon diameter (mm)*
Abdominal aorta	8–16
Common illiac artery	6–10
External illiac 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

catheter. Balloons that are composed of a compliant plastic, such as Silastic, have a much greater range of potential final diameters, with continued balloon expansion dictated as a function of the inflated volume. Embolectomy balloons fall in this category, as well as occlusion balloons that may be used to seat an aortic stent graft or temporarily facilitate proximal aortic occlusion in the presence of a ruptured aneurysm. Both balloon types are capable of inadvertently perforating a vessel wall. Cutting balloon technology has been primarily utilized in the coronary circulation. A recent report from England demonstrated the short-term efficacy of a 6-mm cutting balloon in the periphery.[15] Further studies of cutting balloons for applications in peripheral arterial disease are underway.

Selection of the appropriate balloon size is primarily dictated by the diameter of the normal vessel in which a given lesion is located. Table 1.3 summarizes the typical diameter of angioplasty balloons used in peripheral arterial interventions. With experience, balloon selection can be made on the basis of the appearance of the arteriogram, but more accurate measurement techniques exist, including use of integrated image-based software programs referenced to a fluoroscopically visualized catheter of known French size. Alternatively, intravascular ultrasound[16] also provides a very accurate means for defining vessel size, and marker catheters that contain radiopaque marks at known intervals can also be used for a more accurate assessment of vessel diameter. Balloon shaft lengths are commonly 75 cm or 120 cm, and depending on the system, can be coaxial or monorail and designed to be inserted over 0.014-in., 0.018-in., or 0.035-in. wires.

The balloon inflating solution is usually a mixture of saline and contrast solution. Whereas most balloons are best imaged using a 50–50 mix, larger aortic balloons can be easily visualized using 20–30% (v/v) of contrast agent, which decreases the viscosity of the solution and allows the balloon to be more rapidly inflated or deflated. To accurately pre-position an angioplasty catheter

before inflation, balloons are designed with a radiopaque marker at each end of the cylindrical portion of the balloon. However, balloons may be designed with differing degrees of taper, and a significant "shoulder" may protrude past these marks. In this regard, when treating a lesion that lies near a branch point, it is important to account for balloon taper and limit inadvertent extension of the terminal portion of the balloon into a smaller branch vessel with attendant risk of vessel rupture or dissection.

Stents

Vascular stents are commonly used after an inadequate angioplasty with dissection or elastic recoil of an arterial stenosis. They serve to buttress collapsible vessels and help prevent atherosclerotic restenosis. Eventually, all intravascular stents have smooth muscle migration that leads to the formation of a neointima.[22] Appropriate indications for primary stenting of a lesion without an initial trial of angioplasty alone are evolving in manners that are dependent on the extent and site of the lesion. Stents are manufactured from a variety of metals including stainless steel, tantalum, cobalt-based alloy, and nitinol. Vascular stents are classified into two basic categories: balloon-expandable stents and self-expanding stents.

Self-expanding stents are deployed by retracting a restraining sheath and usually consist of Elgiloy (a cobalt, chromium, nickel alloy) or Nitinol (a shape memory alloy composed of nickel and titanium), the latter of which will contract and assume a heat-treated shape above a transition temperature that depends upon the composition of the alloy. Self-expanding stents will expand to a final diameter that is determined by stent geometry, hoop strength, and vessel size. In particular, if the vessel diameter is significantly less than that of the stent, final stent length may be longer than the anticipated unconstrained length. The self-expanding stent is mounted on a central shaft and is placed inside an outer sheath. It relies on a mechanical springlike action to achieve expansion. With deployment of these stents, there is some degree of foreshortening that has to be taken into account when choosing the area of deployment. In this way, self-expanding stents are more difficult to place with absolute precision. There are several advantages. Self-expanding stents generally comes in longer length than balloon-expandable stents and are therefore used to treat long and tortuous lesions. Their ability to continually expand after delivery allows them to accommodate adjacent vessels of different size. This makes these stents ideal for placement in the internal carotid artery. After the delivery system is inserted into the lesion, the stent is expanded to its predetermined diameter by withdrawing the sheath, while the end of the device is maintained in position. These stents are always oversized by 1–2 mm relative to the largest diameter of normal vessel adjacent to the lesion in order to prevent immediate migration.

Balloon-expandable stents are usually composed of stainless steel, mounted on an angioplasty balloon, and deployed by balloon inflation. They can be manually placed on a chosen balloon catheter or obtained premounted on a

balloon catheter. The capacity of a balloon expandable stent to shorten in length during deployment depends on both stent geometry and the final diameter to which the balloon is expanded. These stents are more rigid and are associated with a shorter time to complete endothelialization. They are often of limited flexibility and have a higher degree of crush resistance when compared to self-expanding ones. This makes them ideal for short-segment lesions, especially those that involve the ostia such as proximal common iliac or renal artery stenosis.

The most exciting area of development in stents is the evolution of drug-eluting stents. These stents are usually composed of nitinol and have various anti-inflammatory drugs bonded to them. Over time, the stents release the drug into the surrounding arterial wall and help prevent restenosis. Numerous randomized-controlled trials have proven their benefit in coronary arteries.[23,24] Examples and descriptions of various drug-eluting stents for endovascular intervention are discussed elsewhere in this book.

Stent grafts

The combination of a metal stent covered with fabric gave birth to the first stent grafts. Covered stents have been designed with either a surrounding polytetrafluoroethylene or polyester fabricand have been used predominantly for treatment of traumatic vascular lesions, including arterial disruption and arteriovenous fistulas. However, these devices may well find a growing role in the treatment of iliac or femoral arterial occlusive disease as well as popliteal aneurysms.

Endovascular aneurysm repair using the concept of stent grafts was initiated by Parodi *et al*. in 1991.[17] Since that time, a large number of endografts have been inserted under the auspice of clinical trials at first, and now as Food and Drug Administration-approved devices. The AneuRx (Medtronic AVE, Santa Rosa, CA), Ancure (Guidant Corp., Menlo Park, CA), Excluder (W.L.Gore & Associates, Flagstaff, AZ), PowerLink (Endologix Inc., Irvine, CA), and Zenith (Cook Inc., Bloomington, IN) devices have all been approved for clinical use in the United States as of 2005. All of these devices require that patients have an infrarenal aneurysm with at least a 1-cm neck and not greater than 60° of angulation. For those patients with associated common iliac artery aneurysmal disease, endovascular treatment can be achieved by initial coil embolization of the ipsilateral hypogastric artery with extension of the endovascular device into the external iliac artery. Clinical trials are underway with devices that will expand indications to aneurysms involving the visceral segment of the abdominal aorta. Aortic endografts for treatment of thoracic aortic disease are not yet available. However, experience with experimental devices is rapidly accumulating. Early studies have demonstrated short-term efficacy of thoracic aortic devices in the treatment of descending thoracic aneurysms, traumatic aortic transections, and aortic dissections.[25–27] A larger experience with these devices exists in both Europe and Asia, and trials are underway in the United States with several devices.

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