Tools of the Trade

4

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Needles, Catheters, and Wires

In the early 1950s, Dr. Sven Seldinger revolutionized medicine when he described his percutaneous vascular access technique [1]. This technique has led to the development of highly specialized physicians in many fields including: radiology, cardiology, and vascular surgery. Utilizing this method, physicians are able to percutaneously treat pathologies that were previously only treated through open techniques. Though the percutaneous access has expanded through the past 60 plus years with the development of vascular and non-vascular procedures, the original concept has remained the same – needle, wire, and catheter. This chapter covers a selection of the most commonly used devices; however, there are numerous additional tools that are not mentioned as well as new devices being developed every day.

Vascular Access

Double Wall

Double-wall needles were designed for arterial access [1]. The needle consists of three parts: metal cannula, stylet, and hub (Fig. 4.1). The cannula is a blunt, stainless steel tube, with a plastic hub attached to one end. The stylet is a solid needle, beveled at the tip which slides through the cannula. On the opposite end of the stylet, a plastic adaptor is mounted connecting the stylet to the hub. The hub is designed with a groove to accept the plastic adaptor, locking the stylet's bevel in the correct level and orientation (Fig. 4.2). In addition, a double-wall needle is manufactured with plastic wings on either side of the hub to provide support for gripping the needle system.

Sizes: 18 gauge (G) or 19G

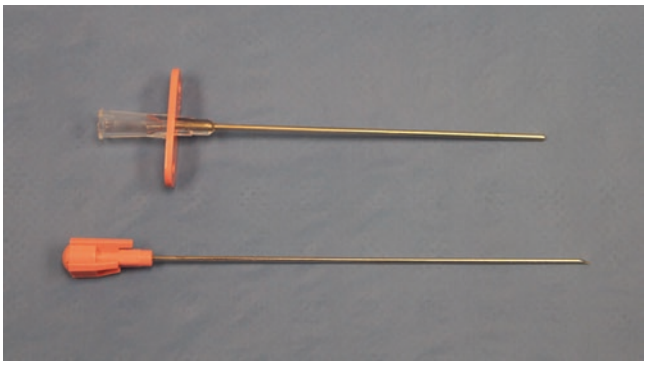

Fig. 4.1 Double-wall needle. Cannula is seen at the top of the image and the stylet at the bottom

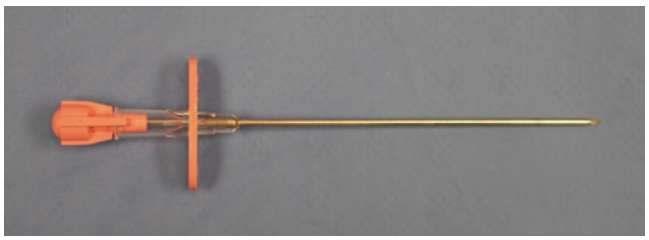

Fig. 4.2 Double-wall needle with stylet and hub attached

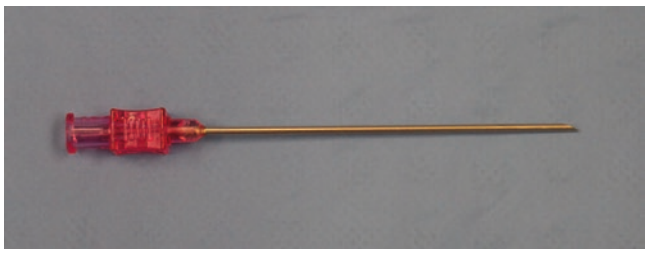

Fig. 4.3 Single-wall needle

Single Wall

Single-wall needles consist of a beveled cannula and hub (Fig. 4.3). The hub usually has a notch or indicator allowing the operator a quick visual reference of the bevel orientation.

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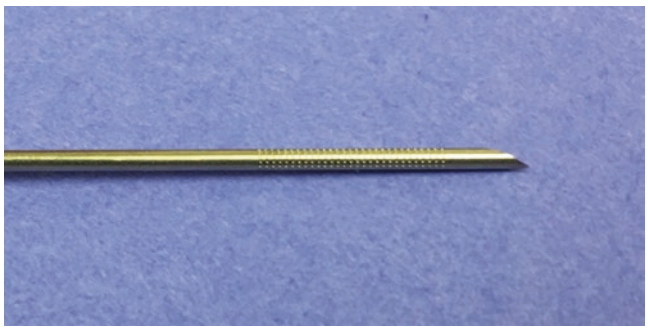


Fig. 4.4 Echogenic single-wall needle with scoring at the distal tip

They are either 18G or 21G, with the 21G being echogenic or non-echogenic. The echogenic needles are scored at the distal tip near the bevel to utilize ultrasound guidance more efficiently and accurately for vascular access (Fig. 4.4).

Sizes: 18G or 21G

Advantages/Disadvantages

There are always advantages and disadvantages with any device, and so it is with double-wall versus single-wall access technique. The advantage of the double-wall technique is the reduction in guidewire-associated intimal dissections compared to single-wall access [2]. On the other hand, the disadvantage is the severe discomfort associated with sticking the femoral head. Thus, 1% lidocaine is utilized in the posterior space between bone and artery prior to pulling the cannula back to gain access to the artery [2].

The advantage of an 18G single-wall needle versus a 21G needle is that an 18G allows the operator to utilize an assortment of 0.035″ guidewires immediately. This provides support for dilators, diagnostic catheters, or vascular sheaths tracking through the subcutaneous tissue into the vessel without making an exchange. This is invaluable, especially on previously operated common femoral arteries, because of the dense scar tissue. The disadvantage of an 18G single-wall needle versus the 21G needle is when the operator is unsuccessful with the initial stick, this requires a 5-min compression to obtain hemostasis before re-attempting another pass. In addition, there is a higher rate of subintimal dissections associated with this technique because the bevel may be only partly within the lumen of the vessel [2].

Key Point
The smaller the gauge number, the larger the diameter of the needle; an 18G needle is larger caliber than a 21G needle.

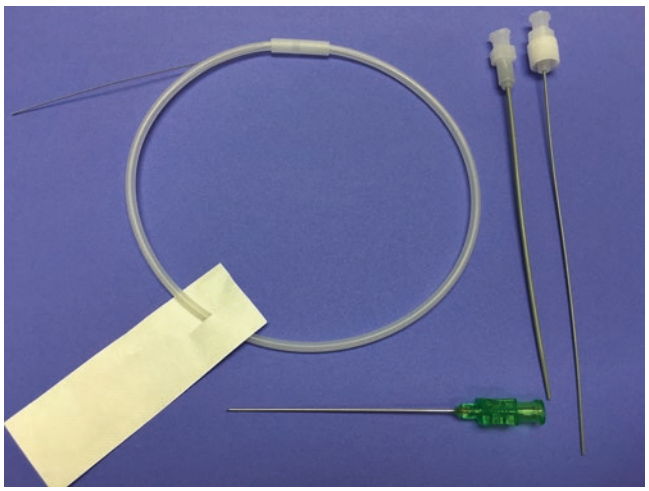


Fig. 4.5 Micropuncture kit (Cook Medical) with needle (bottom), wire (left), and transition dilator (right)

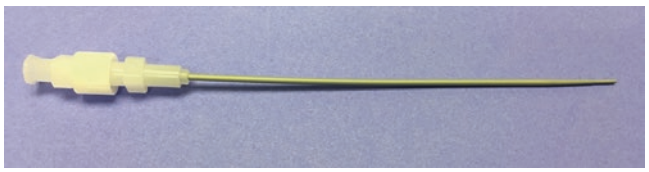


Fig. 4.6 Transition dilator with an inner 3F and an outer 4F or 5F dilator

While the 21G needles are less traumatic, they do require more exchanges to advance a 0.035″ guidewire into the vessel. An introducer set consisting of a 21G needle, a 0.018″ guidewire, and a transition dilator is utilized to gain access to the vessel, frequently termed a micropuncture kit (Fig. 4.5). The guidewire is constructed of either stainless steel or nitinol (nickel-titanium). The stainless steel 0.018″ guidewire has more body and provides better support for the transition dilator, but it can be kinked relatively easily. While the nitinol 0.018″ guidewire is very kink resistant, it can buckle subcutaneously due to the lack of support. The transition dilator is constructed with an inner 3 French (F) dilator tapered to the 0.018″ guidewire and an outer 4F or 5F dilator (Fig. 4.6). There is a "stiffened" transition dilator on the market that the inner 3F dilator is reenforced to provide more body. It is indicated for the scarred groin access.

Key Point
Always check the attachment of the transition dilator to confirm that it is threaded and secured appropriately.

Nonvascular Needles (Table 4.1)

The Chiba needle (Fig. 4.7) is designed with a bevel tip on both the stylet (Fig. 4.8) and cannula. The Chiba needle has the ability to be easily redirected within tissue to access vascular or nonvascular structures. It has become the primary "all around" access needle for nonvascular procedures, for example, percutaneous transhepatic cholangiogram and percutaneous nephrostomy. In addition, it is used for fine needle aspiration biopsy, hydro-dissection for ablation procedures, and deep medication delivery.

There are various gauge sizes and lengths, but most commonly a 20, 21, or 22G, 15-cm length needle is adequately suited for the majority of procedures. Today, echogenic tip Chiba needles (Fig. 4.9) are utilized with sonography to better visualize the needle tip.

The 22G Chiba needle, just like the 21G single-wall needle, will accept a 0.018″ guidewire. In addition, it will also require a transition introducer set to enable a more stable, stiff guidewire for catheter placement. There are a couple of different sets on the market, all with very similar designs including a metal cannula, inner dilator, and outer dilator with radiopaque marker (Fig. 4.10).

The trocar needle (Fig. 4.11), with the diamond-tip stylet (Fig. 4.12), is designed to penetrate through the tissue without much deviation. Thus, it is utilized as a second access point more peripherally in the organ, providing a straighter pathway to the target. The metal cannula comes in either 21G or 18G, depending on the specific need for each procedure.

Table 4.1 Select needle types, including size of needle and which guidewire can be used

Gauge	Type of needle	Guidewire
22G	Chiba	0.018"
21G	Chiba, trocar, single wall	0.018"
20G	Chiba	0.025"
19G	Seldinger, sheath needle	0.035"
18G	Seldinger, single wall, sheath needle	0.035/0.038"

Please note this is a selection of the most commonly used needles, and numerous additional types of needles exist on the market

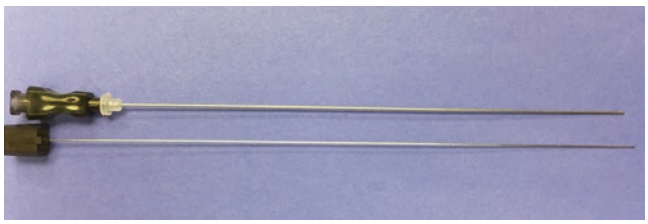


Fig. 4.7 Chiba needle (Cook Medical)

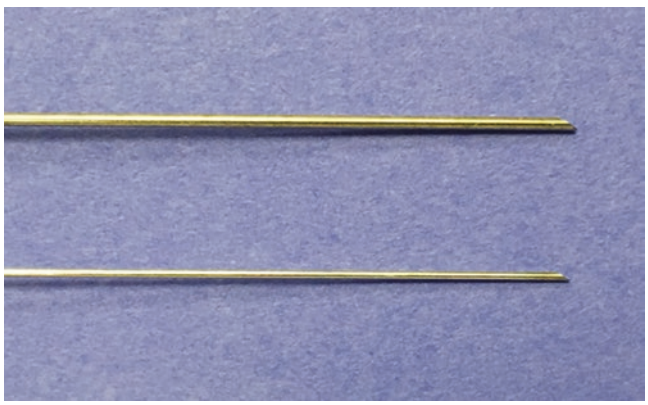


Fig. 4.8 Chiba needle (Inrad) with a bevel tip on the cannula (top) and bevel (bottom)

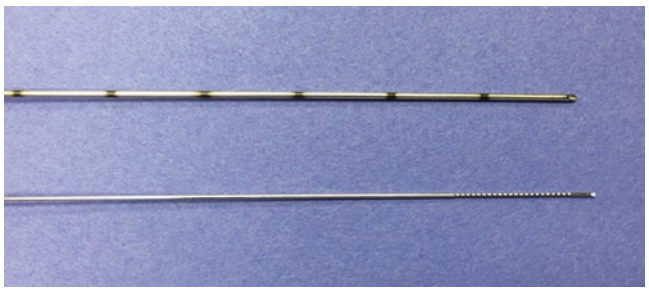


Fig. 4.9 Echogenic Chiba needle with scoring on the tip to allow for better visualization under US guidance

Fig. 4.10 Transition introducer used with a Chiba needle (Cook Medical). Metal cannula (top), inner dilator (middle), and outer dilator (bottom) with a radiopaque marker (arrow)

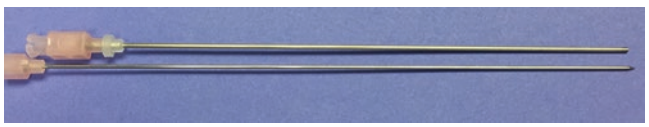


Fig. 4.11 Trocar needle (Cook Medical)

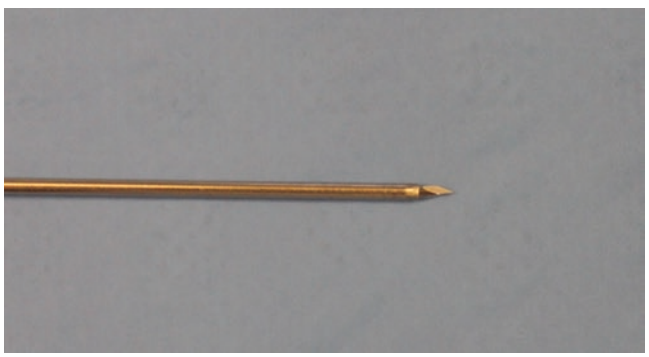


Fig. 4.12 Diamond-tip stylet of a trocar needle is designed to penetrate tissue

The trocar stylet is used for numerous applications. A sheath needle allows the needle to penetrate the structure while leaving a plastic catheter in place when the needle is retracted; this is ideal for abscess aspiration (Fig. 4.13).

Guidewires

A guidewire is a long, flexible, tightly coiled spring used to position a catheter. A guidewire is measured in fraction of inches. For most guidewires, they consist of three parts: coil spring, mandrel, and wire guide (Fig. 4.14). The coil spring is the outer portion of the guidewire, which is constructed of tightly wound wire, usually made of stainless steel. The mandrel is the core of the guidewire. It varies in stiffness or body and taper or flexibility to give the guidewire its characteristics. The wire guide is a thin, stainless steel wire which runs the length of the coil spring and attaches each end providing structure, so the coil spring does not unravel.

Key Point
The coil spring portion of a micro-access wire (mandrel wire) often catches the bevel edge of the needle as it is being removed. Be careful not to shear off the tip by pulling with too much pressure. The needle and wire may need to be removed together as a unit to prevent leaving part of the wire in the needle tract.

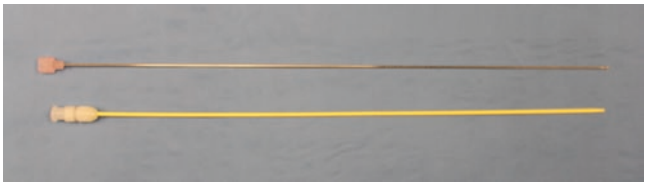


Fig. 4.13 Sheath needle (Cook Medical) with a metal needle and outer plastic sheath (top), which leaves the catheter in place after removal of the needle

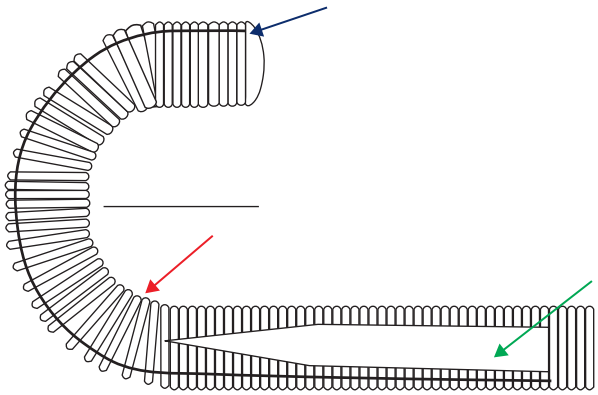


Fig. 4.14 Inner workings of a guidewire. Coil spring (red arrow), mandrel (green arrow), and wire guide (black arrow)

Curved

A curved guidewire decreases the risk of intimal dissection due to the blunted tip from the curve. Thus, in most procedures, it is the primary access guidewire. It comes with an introducer (Fig. 4.15) that straightens the curve (Fig. 4.16) and is inserted into the hub of a needle or catheter, ideally with the curve anteriorly (Fig. 4.17).

There are times when the introducer is unavailable to straighten the tip of a curved guidewire. In these cases, the operator has a couple of quick choices. First, the assistant can replace the introducer back on the wire by running it from the back end to the curved tip. Another technique requires the operator to use his fingers to pinch the wire with his thumb and index finger, applying forward pressure on the coil spring, while the other fingers pin the guidewire (Fig. 4.18).

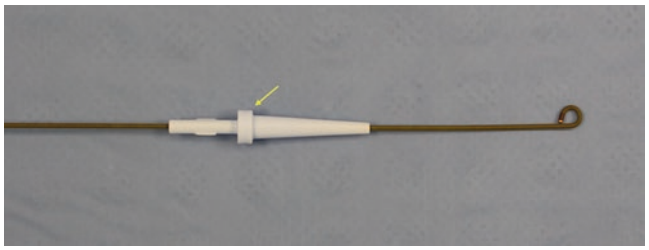


Fig. 4.15 Curved guidewire (Angiodynamics). This comes with an introducer (yellow arrow) which can be advanced over the tip to straighten it and allow easier access into the hub of a needle or catheter

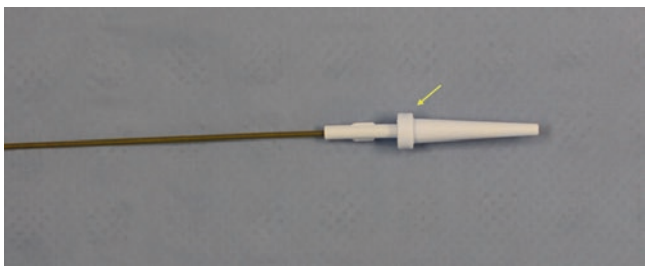


Fig. 4.16 Introducer (yellow arrow) advanced over the tip of a curved guidewire to straighten it

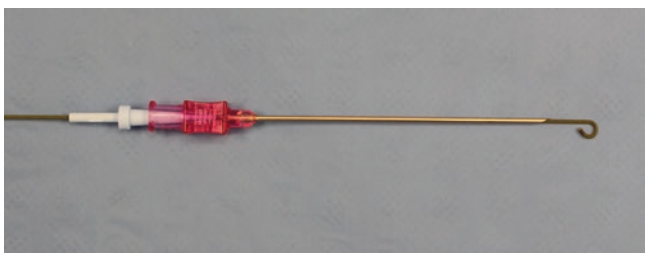


Fig. 4.17 Curved guidewire with an introducer straightening the tip which is inserted into the hub of a needle

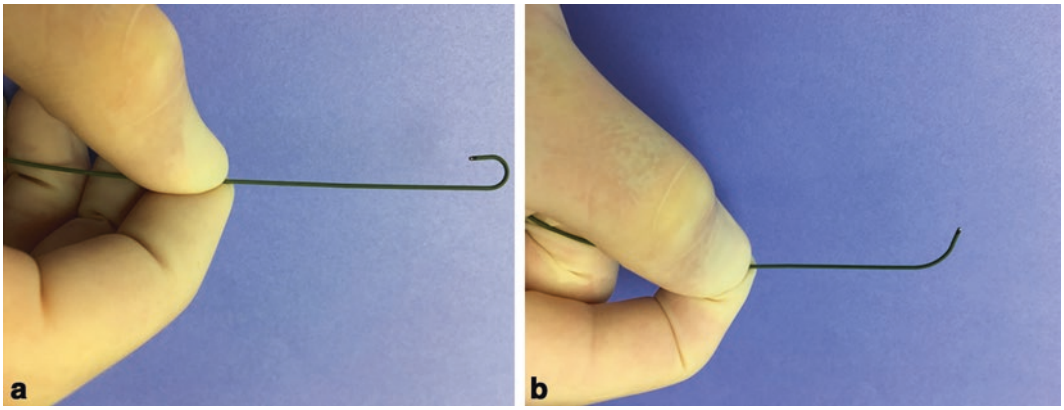


Fig. 4.18 A curved (J)-tipped wire (**a**) can be straightened to allow easier threading into a catheter by holding the front of the wire between your pointer finger and thumb and holding the back of the wire between the palm and fourth and fifth digits of the same hand. Apply forward pressure with the thumb and pointer finger (**b**) while holding the back of the wire taught to straighten the wire

Straight/Angled

Straight or angled guidewires are primarily used as a selective or crossing wire. For micro-access wires, the coil spring tip may be constructed of a more radiopaque material such as platinum or tungsten to provide better visibility under fluoroscopy.

Stiffness

The mandrel material determines the body of the wire. It is usually constructed of stainless steel. However, nitinol, a kink-resistant material, has successfully been used as the core for various wires. When the diameter of the core increases, it provides greater support for the insertion of catheters into the vessel or cavity. In addition, a stiffer guidewire will reduce the tortuosity of the anatomy allowing smoother placement of devices intravascularly.

Flexibility

The taper or "grind" of the mandrel determines the pliability of the wire. Thus, the long, tapered guidewires traverse tortuous vessels better than short tapered guidewires. This manufacturing technique is utilized with standard 0.035″ guidewires, but is essential in micro-guidewire technology.

Coating

Guidewires are often coated with Teflon (polytetrafluoroethylene, PTFE) to reduce the friction of the catheter or vessel. Other materials include hydrophilic polymers, silicone, and heparin that can be used to reduce wire thrombosis. Knowledge of these various wire coating allows the operator the ability to avoid complications associated with them. For example, a patient may have a heparin allergy or a contraindication to heparin. Thus, wire selection without the bonded heparin is utilized for the procedure. In addition, hydrophilic-coated guidewires become sticky and difficult to use if not wet [3]. A sloppy wet Telfa or 4x4 gauze applied to the wire will keep it slippery for proper functioning. Telfa is used predominently for neuroIR procedures as gauze may leave fuzz behind which can be catastrophic in the small intracranial vessels. Great care is needed when exchanging a catheter over a hydrophilic wire because it is very easy to lose vascular access, often requiring a Kelly clamp to secure the wire before the catheter is removed from it. Finally, hydrophilic guidewires are not recommended for gaining vascular access through a needle. There is risk of distal emboli with these materials due to the possible stripping of the coating on the metal cannula [1].

Table 4.2 Several companies have placed color identifiers for quick reference of the diameter of the wire on the plastic protective casing

Diameter	Color
0.018"	Green
0.021"	Black
0.025"	Blue
0.028"	White
0.032"	Orange
0.035"	Purple
0.038"	Red
0.045"	Yellow

Torqueability

Applying force to the guidewire to change the tip's direction is extremely advantageous for selective navigation of the wire and catheter. The ideal torque is 1:1 (i.e., turning the wire by hand 180° will result in a 180-degree rotation intravascularly), but due to distance, vessel tortuosity, or construction, it is not always achieved.

Opacity

Adding materials such as tungsten or platinum give the wire tip better visualization under fluoroscopy.

Wires come in various lengths and diameters (Tables 4.2 and 4.3). Ideally, the wire should be two times the length of

Table 4.3 Commonly used wires and their purposes

Common wire type	Example
Cook: 3-mm J/Bentson	Access wire
AngioDynamics: Rosen	Exchange wire, used in visceral angioplasty/stent
Hydrophilic wires (Terumo: Glidewire)	Navigate through tortuous or narrowed anatomy
Extra stiff (cook: Amplatz)	Provides support for dense tissue
Super stiff (cook: Lunderquist)	Supports large interventional devices: Endografts
Specialty wire (Covidien: Wholey)	All-purpose wire: Access, selective, or exchange wire

the catheter being utilized for purchase in order to maintain wire positioning during catheter exchange. In addition, the wire diameter should be less than or equal to the inner diameter of the catheter. If a 5F, 0.038″, 65-cm diagnostic visceral catheter is used for a renal arteriogram, a 0.035″ or 0.038″, 145- or 150-cm guidewire is acceptable for enough wire internally and externally to support the exchange.

Catheters

There is a vast selection of catheters available for interventional procedures. Each catheter has a specific curve to aid in its given purpose. Interventionalists employ knowledge of the materials and construction of these catheters to better serve their patient's condition.

The catheter materials include PTFE, polyethylene, nylon, and polyurethane. Each material has advantages and disadvantages. For example, polytetrafluoroethylene (Teflon) has the advantage of having the lowest coefficient of friction ($f = F/W$; f = coefficient of friction; F = force to move a 5 lb. weight over a non-lubricated polished metal table; and W = 5 lb. weight). In addition, Teflon is stiff making it an ideal material for traversing tight tissue planes or stenosis. In order to achieve that same performance of other plastic materials, hydrophilic polymers are bound to the surface of the catheter to decrease friction and increase the trackability of a catheter.

Traditionally, polyethylene was one of the primary diagnostic angiography catheter materials that had great trackability with minimal injury to the endothelium of the vessel [4]. Polyethylene catheters are not braided which can cause constraints on torqueability. Today, the high density of polyethylene catheters has a good columnar strength and a smooth catheter surface which allows for great pushability, ideal for subintimal recanalization.

One of the most common plastic materials used in interventional radiology is nylon. Diagnostic catheters, angioplasty balloons, and interventional material such as fibers on an embolic coil are all made of nylon. Nylon has a high tensile strength that allows thinner-walled diagnostic catheters to accept higher pressures without rupture [3]. In addition,

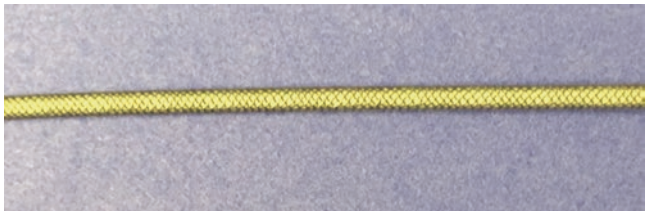


Fig. 4.19 Stainless steel braid of nylon selective catheters

nylon selective catheters contain additional stainless steel braid (Fig. 4.19) to reinforce the plastic material generating greater torque on the catheter. Thus, it creates the immediate desired response internally, which allows for quicker cannulation of the vessel.

The catheter's outer diameter (OD) is measured in French (F) scale which was developed by Charrière (French instrument maker) [4]. It is equivalent to mm (1F = 0.33 mm or 3F = 1 mm). The inner diameter (ID) is measured in fraction of inches for guidewire compatibility. Thus, 1 mm ÷ 25.4 = 0.039″.

Key Point
1F = 0.33 mm or 3F = 1 mm.

The "memory" of a catheter refers to how well it retains its shape. Polyurethane catheters demonstrate memory, which has led to their use in a wide variety of applications and designs (Fig. 4.20). They are flexible with high strength providing durability and patient comfort that is needed for the success of long-term care.

In the interventional department, diagnostic catheters are the interventionalists' second most valued tool. The most important being their hands, or more specifically, their tactile sensitivity to the catheter's movement. The wide variety of catheters can be broken down into two categories: tapered diagnostic catheters or non-tapered catheters. Each tapered catheter is designed for a specific purpose, which can be classified as flush, visceral, multipurpose, and neurointerventional radiology (INR) catheters.

Flush Catheters

The flush catheters (Fig. 4.21, Table 4.4) are nonselective catheters used to deliver a large bolus of contrast to opacify larger vessels in the body. They all are constructed with additional side holes [5–9], which increase the effectiveness by 10–20% compared to end-hole catheters [10]. The proximal side holes are smaller in diameter than the end hole to prevent the guidewire from protruding through the sidewall of the catheter [4]. The side holes spiral around the catheter preserving catheter integrity [4]. In addition, side holes reduce

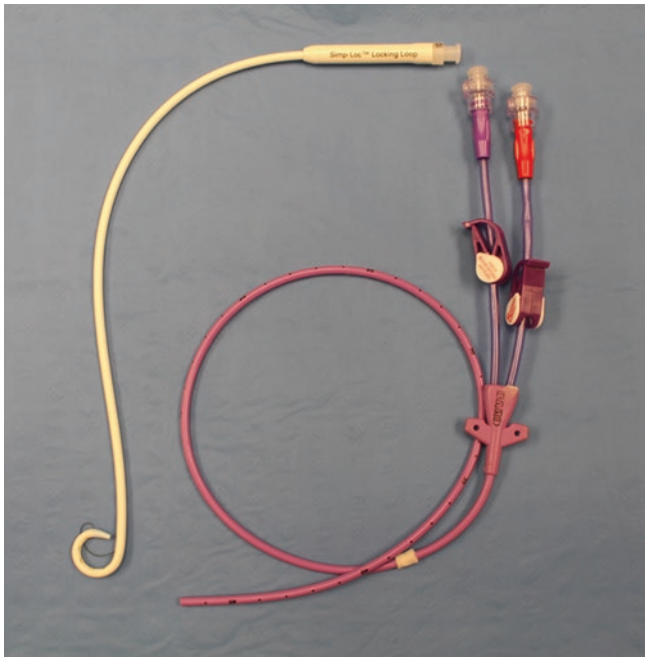


Fig. 4.20 Polyurethane catheters demonstrate memory. Locking pigtail catheter (left, Cook) and a tunneled Powerline (right, Bard)

Fig. 4.21 From left to right, pigtail catheter, Omni Flush catheter, and straight flush catheter (Angiodynamics)

Table 4.4 Based on catheter location, different rates, volumes, and pressures of contrast, injection should be performed so as not to injure the vessel

Angiogram anatomy	Injection rate (cc/s)	Injection volume (cc)	PSI
Thoracic aorta	20–30	40–60	1200
Abdominal aorta	15–20	30–40	1000
Aortic bifurcation	10–15	20–30	1000
Common iliac	8–10	16–20	1000
IVC	15–20	30–40	1000

the whipping action from the high velocity of contrast exiting the end hole of the catheter [10]. Finally, flush catheters are designed with different tip configurations (pigtail, omni, and strait flush), lengths, radiopaque sizing markers, and catheter material based on the intended purpose of the catheter. For example, the pigtail catheter, after it is formed, allows the operator to advance the catheter into position without a guidewire; this catheter delivers contrast in 360° during injection [1]. The Omni Flush is designed to access the contralateral iliac limb; it delivers contrast in a downward direction during injection.

Key Point
A saline flush bag should never be connected to flush catheter with multi-side holes because the fluid will exit the proximal side holes leaving the end hole to thrombosis and potentially cause an embolus.

Key Point
For catheters in the thoracic aorta, a double flush technique is used to prevent accidental injection or migration of blood clots into the cerebral circulation. This requires two syringes: one to aspirate the flush catheter and to discard the waste, while the other syringe is utilized to flush the catheter.

Pre-shaped selective catheters are designed for specific branches arising off the thoracic or abdominal aorta. The majority of selective catheters have a primary curve, which engages the artery, and a secondary curve that stabilizes the catheter against the aortic wall (Fig. 4.22). The vessel angle, pathology, and tortuosity dictates the decision on which selective catheter is ideally suited to access the target vessel.

Visceral Catheters

Visceral catheters are identified by the shape and/or named after the designer (Table 4.5). In general, as the secondary curve expands, the identifying number increases in size (e.g., Cobra 1, 2, 3) (Fig. 4.23). They are the first choice for selective catheterization of the mesenteric vessels because of the quick access and trackability. However, there are special situations when reverse curve catheters (Fig. 4.24) are more advantageous, for example, when crossing a high-grade visceral stenosis. As the operator pulls the catheter down over the guidewire, it generates downward force at the distal tip allowing it to penetrate through the stenosis (Fig. 4.25); primary visceral catheters tend to buckle in the aorta on branch vessel stenoses.

Key Point
Reforming a reverse curve catheter can be challenging. There are several safe methods: forming the curve in the thoracic aorta, over the aortic bifurcation, or using a tip-deflecting wire to reform the shape.

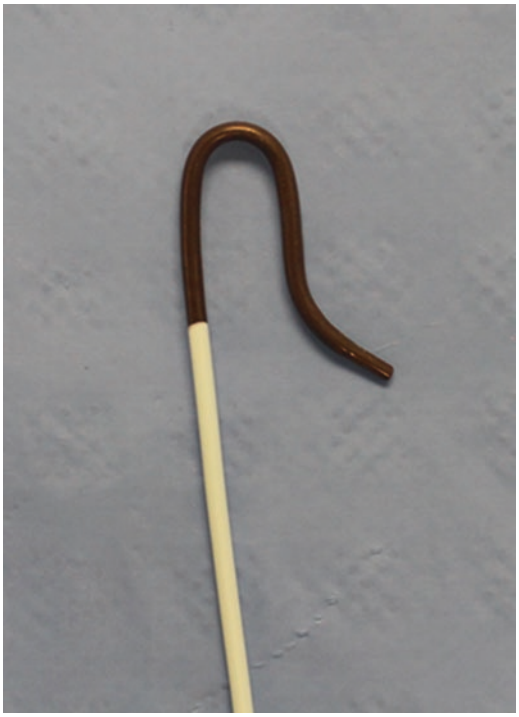


Fig. 4.22 Pre-shaped catheters (Angiodynamics) are designed to access specific branch vessels arising from the aorta. The primary curve engages the artery and the secondary curve stabilizes the catheter against the aortic wall

Table 4.5 A selection of commonly used visceral catheters

Artery	Catheters	Injection rate (cc/s)	Injection volume (cc)
Celiac	Rosch celiac (RC), cobra, Sos, Simmons	5–7	25–35
Superior mesenteric artery	RC, cobra, Sos	5–7	25–35
Renal	Renal double curve, RC, cobra, Sos	4–6	12–16
Lumbar	Cobra 2, Sos, Mickelson	Manual injection	
Inferior mesenteric artery	Rosch inferior mesenteric, Sos	3	15–18

Fig. 4.23 Visceral catheters from left to right: Rosch Interior mesenteric, Rosch celiac 2, Rosch celiac 1 (Cook), Cobra 1, 2, and 3 (Angiodynamics)

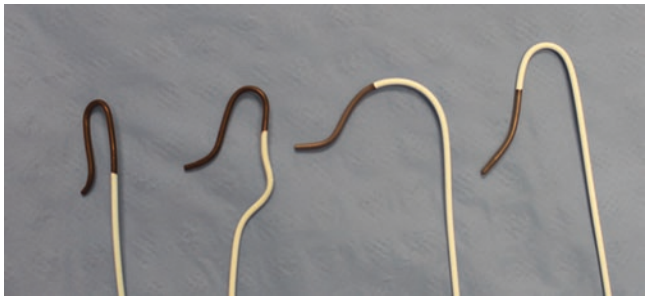


Fig. 4.24 Reverse curve catheters from left to right: Sos (Angiodynamics), Mickelson (Cook), Rosch left gastric (Cook), Simmons (Cook)

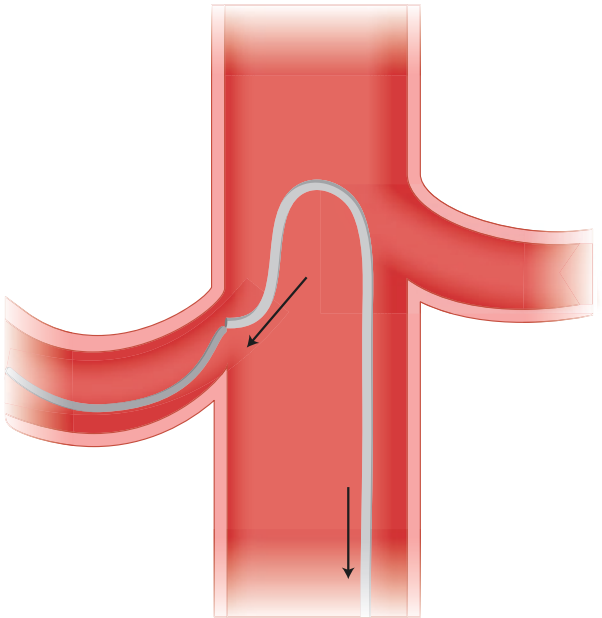


Fig. 4.25 Diagram demonstrating how to access a stenotic vessel with a reverse curve catheter

Multipurpose Catheters

Multipurpose catheters (Fig. 4.26) are desirable to navigate through tight stenosis or tortuous vessels. Variant angles allow the operator to change tip position while probing with the guidewire.

Cerebral Catheters

Cerebral catheters (Fig. 4.27) are selective catheters for the great vessels arising off the thoracic aorta. The most common shapes are the hockey stick and headhunter. However, catheter shapes increase in complexity as the vessels and aortic arch alter with age.

Guiding Catheters

Non-tapered or guiding catheters are constructed to have a larger inner diameter with soft, flexible atraumatic tips compared to tapered catheters (Fig. 4.28). They are designed

Fig. 4.26 Multipurpose catheters from left to right: Berenstein (Angiodynamics), Tegtmeyer (Cook), vertebral (Cook), multipurpose (Cook)

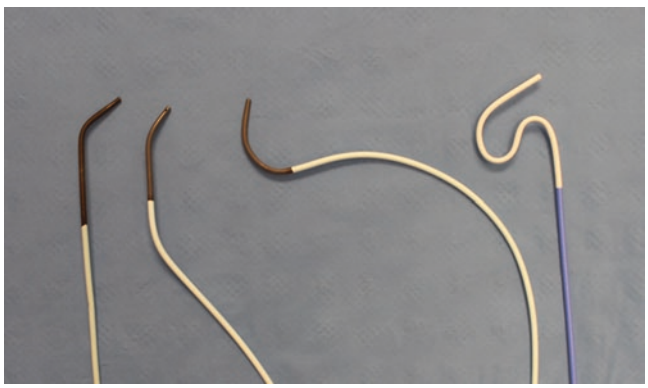


Fig. 4.27 Cerebral catheters from left to right: hockey stick (Angiodynamics), H1 (Cook), JB 2 (Cook), Newton (Merit)

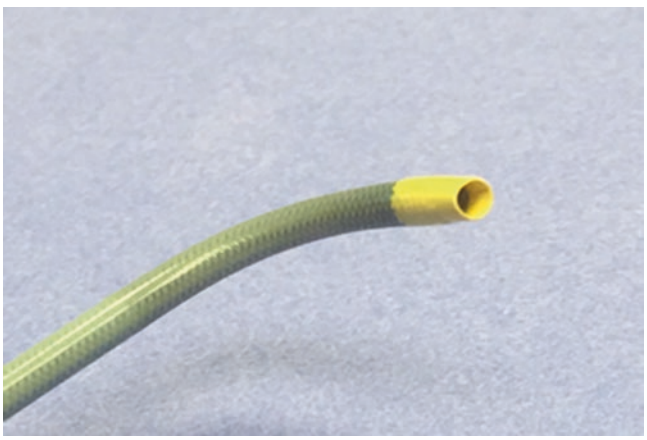


Fig. 4.28 Guiding catheter (Boston Scientific) with a flexible atraumatic non-tapered tip

to use their larger inner diameter to assist in delivering and stabilizing interventional devices such as stents (Fig. 4.29). The coaxial technique uses an outer guiding catheter with a smaller inner catheter and is used in numerous IR procedures. The coaxial catheter combination requires an extra flush system connected to it to avoid catheter thrombosis.

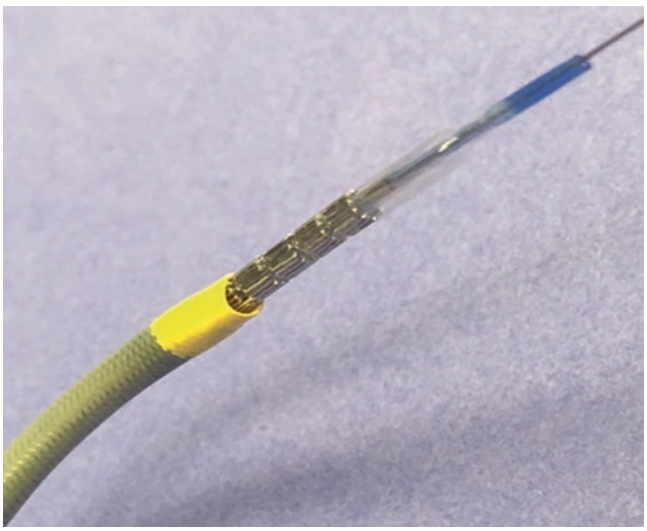


Fig. 4.29 Guiding catheter with a stent (Abbott) within the larger inner diameter

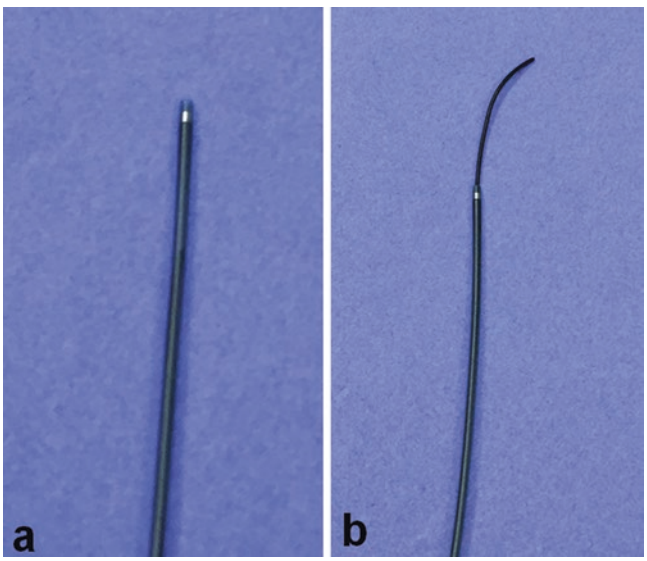


Fig. 4.30 Microcatheter (Terumo) with radiopaque tip (**a**). A microwire is seen advanced through the microcatheter (**b**)

Microcatheters

Microcatheters are small 1.5–3F catheters that are extremely pliable; they are used in the coaxial technique for super selective interventions. Microcatheter are a vital tool in an interventionalists armamentarium and can be categorized as either neurointerventional radiology (INR) or peripheral microcatheters. INR microcatheters usually have two radiopaque markers about 3-cm apart designed for cerebral aneurysm embolizations, while the peripheral microcatheters (Figs. 4.30 and 4.31) require only one radiopaque marker for visualization. Furthermore, peripheral microcatheters have a more robust construction for high-pressure power injections. There are several microcatheters that can accept 1200 psi, an

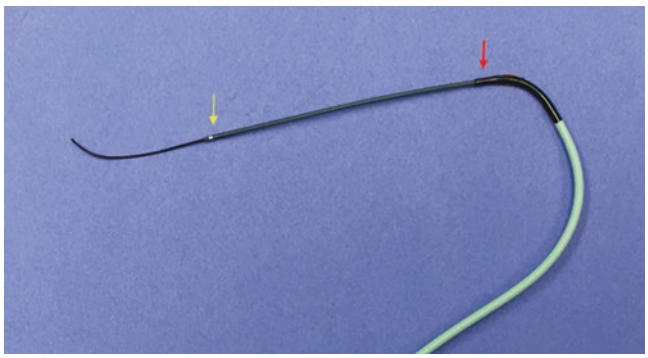


Fig. 4.31 Visceral catheter (Angiodynamics, red arrow) with a microcatheter (Terumo, yellow arrow) and wire advanced through the catheter

incredible pressure for a tiny 1 mm catheter. Thus, it is extremely important to understand the advantages and disadvantages of each microcatheter.

Key Point
The microcatheter's OD determines what ID is required of the diagnostic catheter for proper co-axial canalization.

Key Point
Smaller syringes (1, 3, 6 mL) are necessary for delivery of saline, contrast, and/or embolic materials through a microcatheter as they generate higher pressures and better control.

Vascular Sheaths

Vascular sheaths are conduits that improve the torqueability of diagnostic catheters, decrease bleeding complications from multiple catheter exchanges, and provide support for interventional devices. They come in a range from 4F to 28F. Sheaths are identified by their inner diameter, while their outer diameter is approximately 2F larger. A 5F sheath (Fig. 4.32) creates a 7F or 2.31-mm hole in the vessel. Sheaths are made of plastic material and designed with either a bicuspid or tricuspid valve to prevent excessive bleeding during the interventional procedure. A three-way side-arm adaptor is attached for continuous flushing during the procedure. A tapered, locking inner dilator is inserted through the valve of the sheath which is used during sheath placement but removed to accommodate other catheters. Finally, a braided material (Fig. 4.33) is woven within the sheaths to provide better support and to prevent the sheath from kinking when utilized around vascular curves.

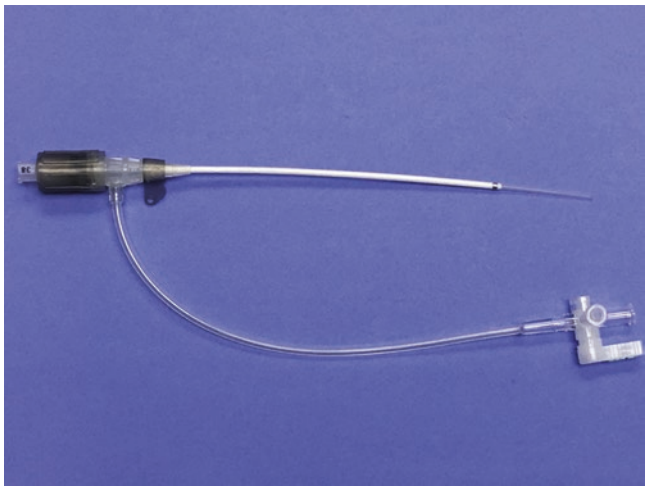


Fig. 4.32 A 5F vascular sheath with a three-way side-arm adaptor. For better visualization of the sheath, a radiopaque marker is incorporated at the distal tip of the sheath (Boston Scientific)

Fig. 4.33 A sheath is made of braided material for improved support (top, Cook; bottom, Arrow)

Key Point
Sheath color scheme. Quick visual reference of the sheath size:

4F = Red
5F = Gray
6F = Green
7F = Orange
8F = Blue
9F = Black

Vessel Dilators

Vessel dilators (Fig. 4.34) are 20-cm tapered, stiff catheters usually constructed of Teflon or nylon with a hydrophilic coating. They are designed to expand the tissue and arteriotomy site prior to sheath or catheter insertion [1]. They are ideal

Fig. 4.34 Vessel dilators gradually increase in size to expand or dilate the tissue prior to sheath insertion

for groin access on a previous surgical intervention (endarterectomy) because the scar tissue is problematic for sheath placement. In addition, serial dilation is used to reduce trauma to the vessel [1]. They have a diameter range of 4F to 16F with larger sizes for endografts sheaths. Serial dilation occurs with dilators in increments of 2F in order to dilate to the size of the sheath.

Accessories

Hemostatic valves (Fig. 4.35) are used to prevent back bleeding. They are attached to either a guide catheter or diagnostic catheter that fosters a smaller gauge wire or catheter during interventions.

Torque devices (Fig. 4.36) are used in conjunction with hydrophilic guidewires or microguidewires. They are locked onto the guidewire and are torqued to rotate the wire in the direction the operator is turning it. Most torque devices attach to 0.014″–0.038″ guidewires.

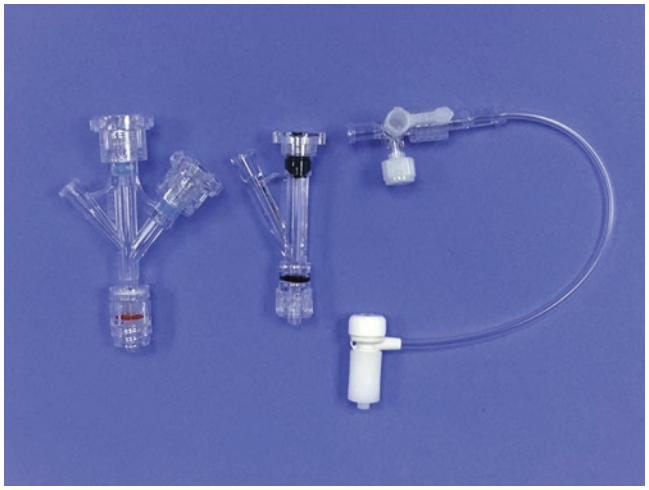


Fig. 4.35 Hemostatic valves (left, Cook; middle, Abbott; right, Merrit)

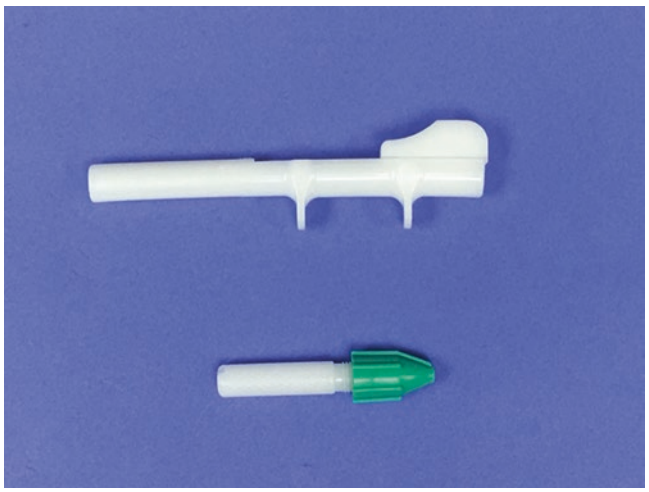


Fig. 4.36 Torque devices (top, Cook; bottom, Terumo)

Embolic Agents

For the past 50 years, there has been an evolution in the branch of radiology first called "special procedures" to interventional radiology (IR). The late 1960s and early 1970s experienced an explosion of innovation to surgical therapies. Coincidently, new, start-up surgical companies were attuned to these ideas and began to manufacture products utilized in this exciting field of medicine. Expansion in the endovascular treatment of hemorrhage and atherosclerosis led to the development of embolic material, angioplasty balloons, and stents.

Embolic materials can be separated into two classifications: temporary and permanent agents. Each embolic agent has pros and cons thus making each suitable for a different purpose. In this segment, the embolic materials and deployment method will be described for the different types of agents.

Temporary Agents

One of the first methods for managing gastrointestinal (GI) bleeding was the use of vasopressin. Pitressin, the trade name of vasopressin, is used for controlling either diverticular,

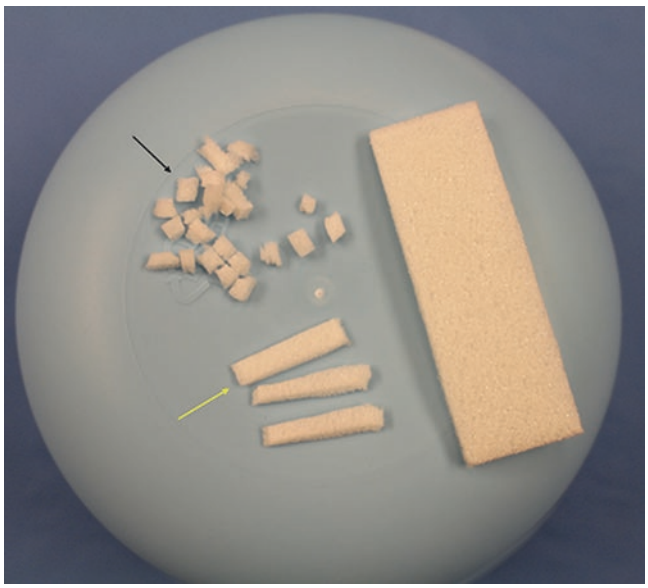


Fig. 4.37 Gelfoam temporary embolic agent (Upjohn Medical). This can be manufactured as a block that can be cut into particles (black arrow) or strips made into pledgets (yellow arrow)

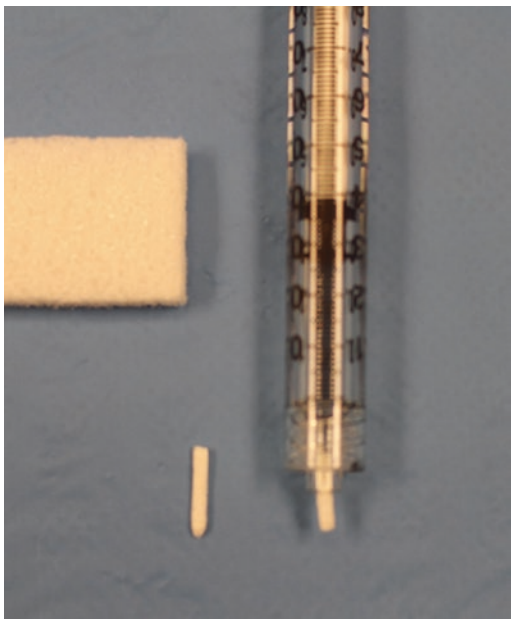


Fig. 4.38 Gelfoam pledgets

variceal, or mucosal bleeds by vasoconstricting the bleeding artery, arteriole, or capillary vessel [3, 5]. Eventually this leads to thrombosis in patients with normal circulating coagulates [6].

Autologous agents serve as temporary embolic material also. The most commonly used autologous agent is blood clot [7]. The injection of reconstituted thrombin or mixing of blood with aminocaproic acid can decrease the time it takes for the blood to congeal into a clot. Ultimately, the body's natural fibrolytic process will break down the thrombus [7]. With other options available for temporary agents, autologous agents are not utilized much today.

Gelfoam (The Upjohn Co.) is a temporary absorbable gelatin sponge that was introduced in 1945 to aid in surgical hemostasis [7]. It achieves hemostasis for days to weeks prior to dissolving. Gelfoam is either manufactured as a power (approximately 40–60 microns) or a block (Fig. 4.37). Due to the small size of the powder, care should be taken not to cause tissue ischemia or necrosis [3]. The versatility of the Gelfoam block has become the preferred material for IR departments.

To create a "torpedo" pledget, the Gelfoam is first compressed and then cut into a 2 mm × 5 mm length and rolled into a cylindrical shape (Fig. 4.38). The torpedo is inserted into the end of a 1-mL or 3-mL syringe of half-strength contrast and injected into the vessel being embolized [6]. The smaller syringes deliver a higher pressure in the catheter which decreases the probability of occluding the catheter with the Gelfoam material. However, if the catheter does become occluded, a floppy guidewire can be advanced through the catheter to push the material out.

There are two ways to create a Gelfoam slurry. The first is to shave the Gelfoam block into a small glass with a scalpel followed by half-strength contrast mixture. However, the quicker and most common method is to cut the Gelfoam block into sections (Fig. 4.39) and use a three-way stopcock and two 10-mL syringes to create a slurry. The process begins by removing one 10-mL syringe plunger, placing the desired amount of Gelfoam in the barrel, reassembling, and advancing the plunger completely forward compressing the Gelfoam. Attach the syringe to a three-way stopcock that has a second 10-mL syringe filled with half-strength contrast. Next, open the stopcock allowing the contrast mixture to fill the Gelfoam syringe. Continue to agitate the Gelfoam between the syringes fragmenting the Gelfoam into smaller particles by pushing each syringe plunger back and forth.

Permanent Agents

Pushable Coils

Metal coils are one of the most popular embolic materials in interventional radiology. Manufactures have developed coils of various sizes, shapes, lengths, and metals for specific embolization procedures. They are divided into two categories: pushable and detachable. In addition, coils are described by their diameter and any added material which increases the thrombogenicity of the coil.

Coils were first developed by Gianturco and Wallace in 1975 by removing the mandrel from a steel guidewire and adding wool fibers entwined in the steel coil [8]. The fibers increased the thrombogenicity of the coil but also caused

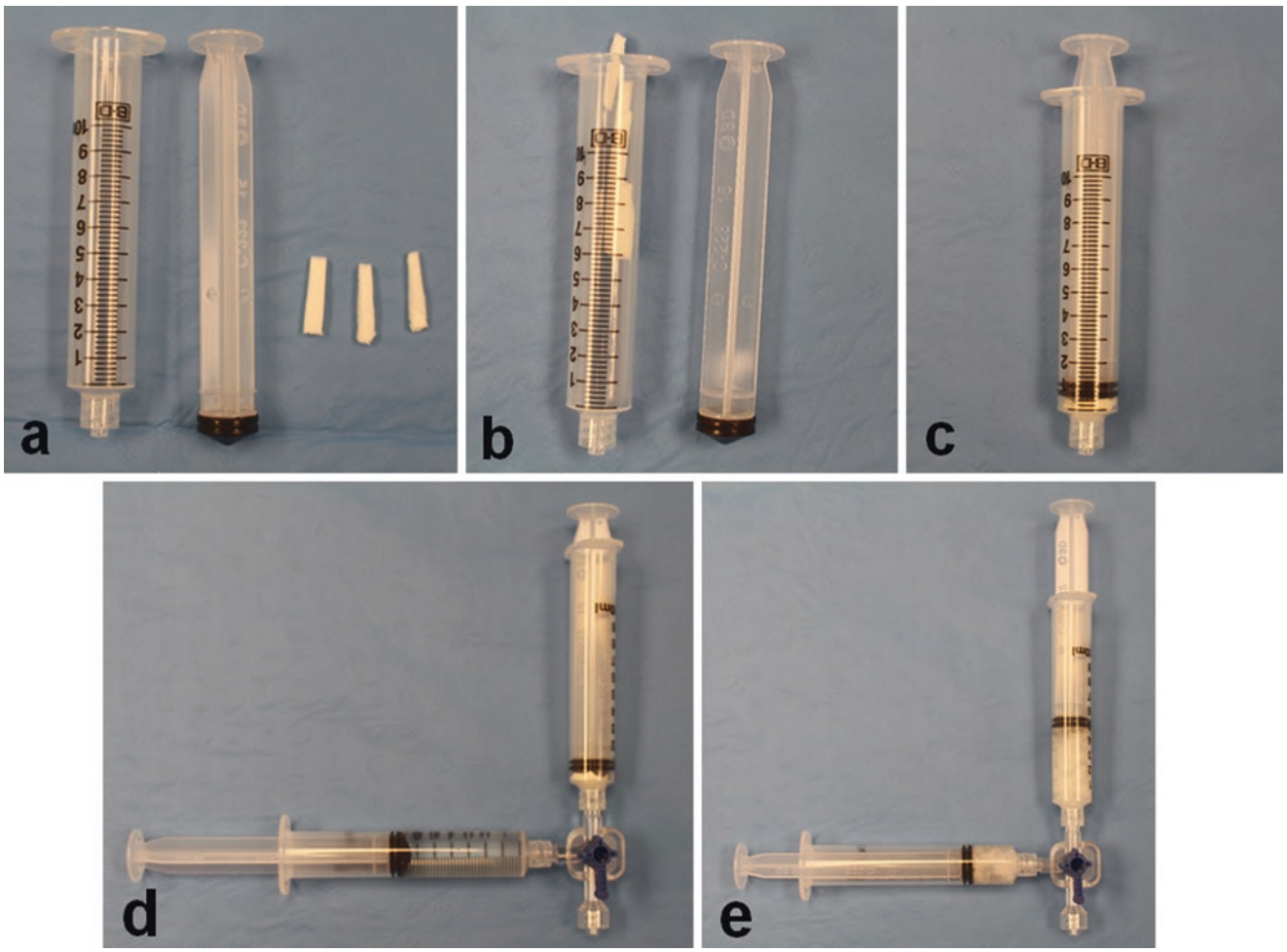


Fig. 4.39 Steps to create a Gelfoam slurry. (**a**) Cut the Gelfoam into blocks. (**b**) Insert the Gelfoam into a syringe. (**c**) Compress the Gelfoam with the plunger to remove excess air. (**d**) Attach to a three-way stop cock with contrast. (**e**) Mix the two syringes back and forth to make a slurry

severe granulomatous arteritis in the vessel's adventitia [7]. Eventually, the wool fibers were replaced by a synthetic polymer (Dacron) that provided the same thrombotic effect.

As technology progressed, the speed and resolution of CT and MRI have improved; the device industry adjusted to accommodate the artifacts created by stainless steel coils. Cook Medical (Bloomington, IN) created the MReye Coil (Fig. 4.40); it is made out of Inconel which is more visible than stainless steel and compatible up to a 3 Tesla MR magnet. The advantage of this coil is that it has better radial strength than platinum providing stability in high-flow vessels.

Key Point
A floppy Bentson guidewire is used to deploy the MReye coil.

Fig. 4.40 0.038" MReye Coil (Cook Medical)

The Bentson guidewire is typically used for coil deployment; the stiff back of the wire is used to insert the coil into the diagnostic catheter, while the floppy front end of the wire advances it into the target area. The Bentson's floppiness allows the diagnostic catheter to remain stable during deployment. When too much force is applied to the coil after deployment, the catheter may kick back. A Bentson guidewire is constructed of stainless steel which has a different density compared to Inconel which can be visualized under fluoroscopy, ideal for coil deployment.

The industries most versatile coil material today is platinum. Historically, platinum was harvested from coronary guidewires and delivered through a microcatheter to the target vessel [7]. Platinum coils are constructed in both pushable and detachable styles, and they may take on straight, helical, or complex shapes (Fig. 4.41). This non-ferrous material is MR compatible, extremely radiopaque, malleable, and deploys smoothly from the catheter. The addition of synthetic fibers naturally increases the thrombogenicity of the coil [7]. The more fibers on the coil, the more thrombogenic the coil becomes, so a 0.035″ coil is more thrombogenic than a 0.018″ coil due to the larger amount of fibers. Thus, the number of coils and thrombosis time is reduced with larger coils.

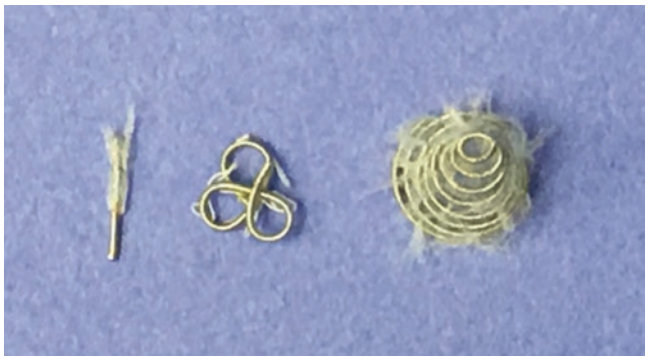


Fig. 4.41 Platinum coils from left to right: 0.018″ straight (Cook Medical), complex helical (Boston Scientific), and Tornado (Cook Medical)

Pushable style coil insertion (Fig. 4.42) begins by connecting the hemostatic valve to the hub of the catheter or microcatheter to prevent bleeding. With forward pressure on the metal cannula, an introducer wire is inserted through the hub of the cannula pushing the coil into the catheter. After the removal of the cannula, the introducer wire or stiff back of a Bentson wire is inserted into the catheter to advance the coil deeper within the lumen. The metal cannula is commonly kinked in half to easily denote used from new cannulas. Finally, a wire is used to push the coil from the catheter (Fig. 4.43).

Key Point
Forward pressure must be maintained between the metal cannula housing, the coil, and the catheter to prevent deployment of the coil into the hub of the catheter.

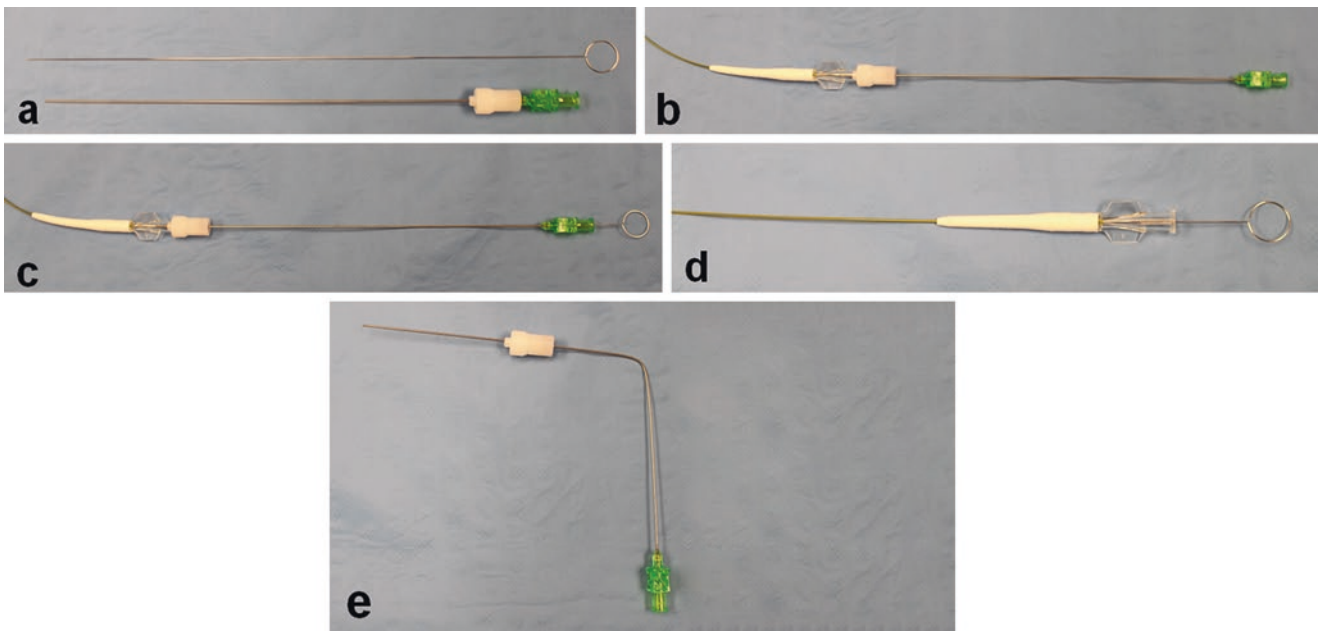


Fig. 4.42 Pushable coils (**a**) are inserted into the (**b**) hub of the catheter. (**c**) The introducer wire is inserted into the cannula to push the coil into the proximal catheter. (**d**) The cannula is removed and the introducer wire or back of a Bentson wire is used to advance the wire further into the catheter. (**e**) After use, the metal cannula is commonly kinked in half to denote a used coil (Cook Medical)

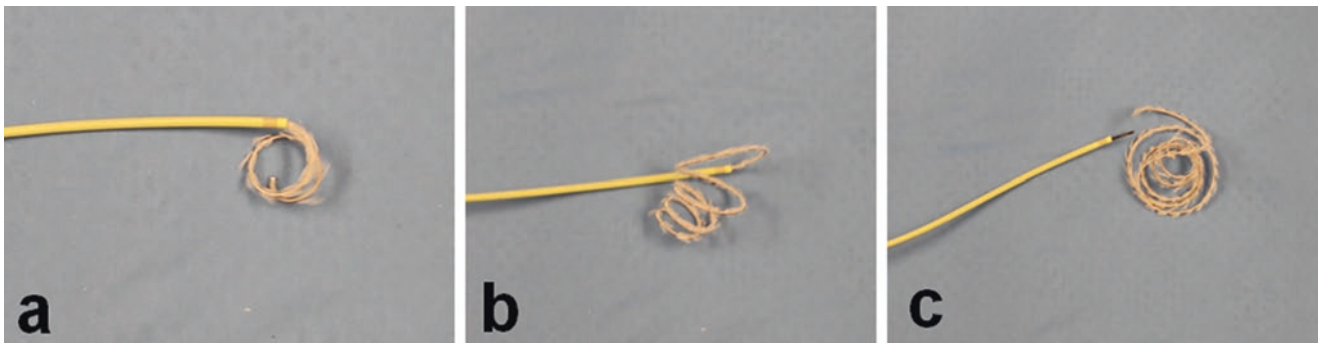


Fig. 4.43 (**a–c**) The coil (Cook Medical) is pushed out of the catheter slowly using a wire in order to advance it into the intravascular space of interest

Table 4.6 A selection of detachable coil shapes with given size specifications

Shape	Diameter (mm)	Length (cm)
Helical	2–22	4–60
Diamond	2/3–2/6	2.3–8
2D helical	3–18	4–40
Cube	4–20	6–40
Diamond	4–8	4.5–14

Detachable Coils

Detachable coils are specialized coils connected to a delivery cable by threads, a trigger wire, or soldering (Table 4.6). This design gives them the advantage over pushable coils being both precise in placement and minimizing the risk of coil migration. Traditionally, detachable coils were designed to treat cerebral aneurysms. The first generation coil (Guligalmi Detachable Coil) was a helical shape, non-fibered, non-coated, platinum coil that came in a variety of diameters and lengths. It utilized electrolysis to free the coil from the delivery wire. Today, due to increased technology, coil designs have taken on more complex three-dimensional shapes, with added materials (dehydrated polymers) or fibers. The dehydrated polymer (Hydrogel by Microvention Inc.) expands six times the size of a regular coil which reduces space within an aneurysm or vessel. In addition, it provides a matrix that enables neointimal growth. Industry innovation has led to mechanical release system where if a coil is not appropriately positioned it can be retracted into the catheter and repositioned. These detachable coils use a detachment handle to release the trigger wire from the coil in order to fully deploy the coil. Depending on the company, the point of no return (where the coil is committed to be released) varies on the construction of the coil and release design.

Detachable coils are unique because of the detachment zone, an area where the delivery wire and coil are attached. In addition, a long plastic introducer is used to protect and insert the coil into the hub of the catheter (Figs. 4.44 and 4.45).

Fig. 4.44 Detachable coils (Microvention) have an area where the delivery wire and coil are attached (arrow), allowing for coil placement and retraction as needed

Table 4.7 MReye Coil specifications

MReye coils	Diameter (mm)	Length (cm)
0.035”	2–20 mm	2–15
0.038”	3–45	2–16

One of the first non-cranial detachable coils was the Interlock coil by Boston Scientific Incorporated (BSI) (Fig. 4.46). It utilized a unique cable tip and coil-locking design that allows over 95% of the coil to be positioned in the vessel. As long as the lock remains connected, the coil can be withdrawn from the vessel.

Another unique coil is the Medusa coil (Endoshape). It is a 10-mm polymer coil with synthetic fibers and only two radiopaque markers (Fig. 4.47, Table 4.7). This reduces the amount of artifacts created by the metal on either CT or MR imaging. The Medusa coil can be repositioned if the coil does not form correctly or if the coil is too close to a bifurcation that the operator wants to preserve.

Coiling Techniques (Fig. 4.48)

Anchor

Utilizes a side branch to stabilize the coil as it is being deployed.

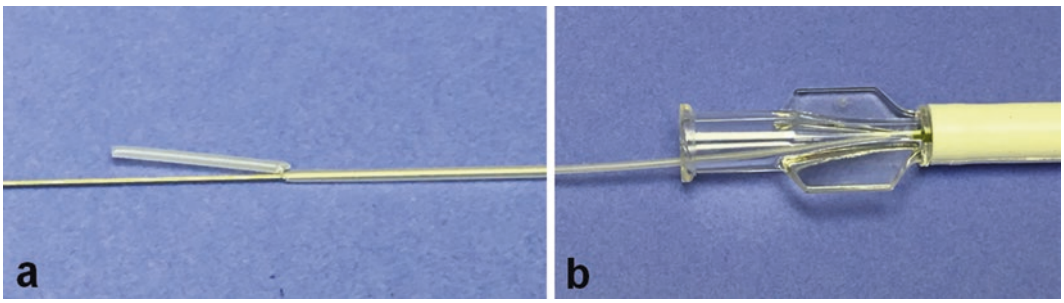


Fig. 4.45 Detachable coils (Microvention) use a long plastic introducer (**a**) in order to protect the coil when inserting it into the hub of a catheter (**b**)

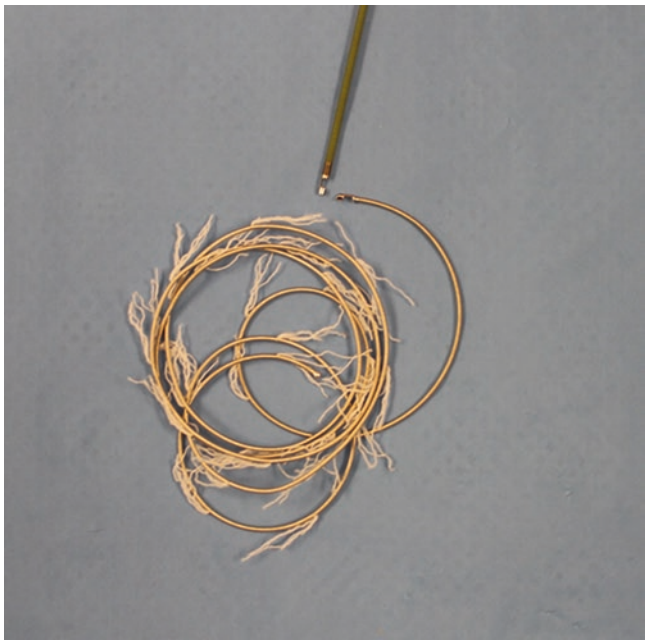


Fig. 4.46 Interlock Coil (Boston Scientific), one of the first non-cranial detachable coils

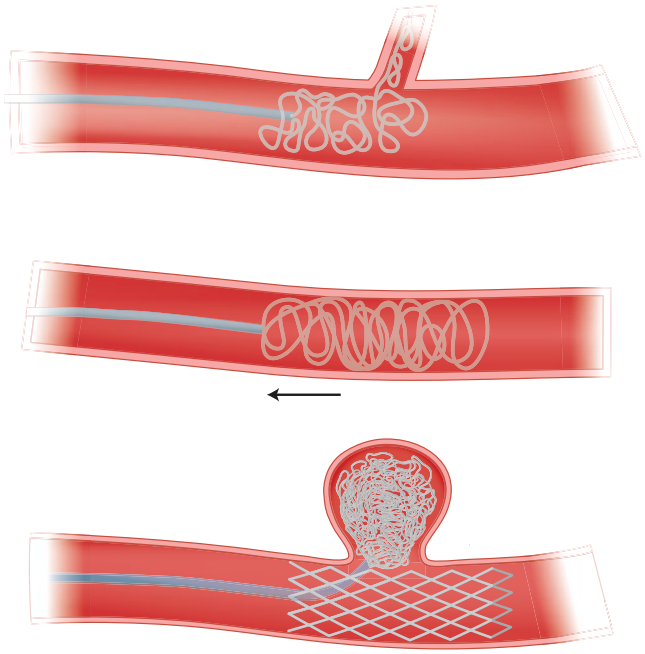


Fig. 4.48 (**a**) Anchor technique, (**b**) weave technique, and (**c**) scaffolding technique of coil deployment

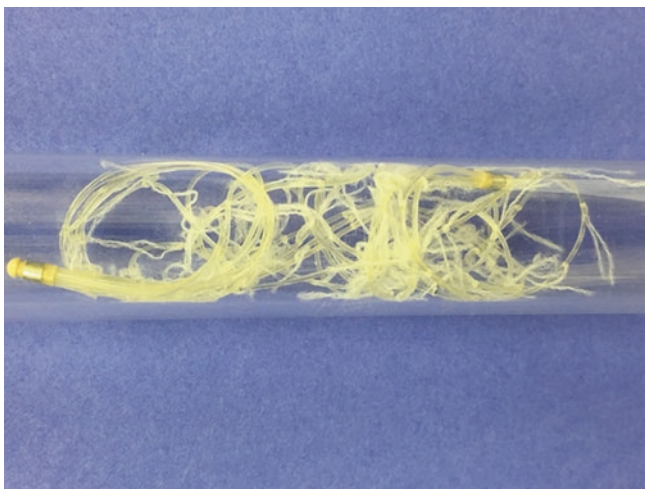


Fig. 4.47 Medusa Coil (Endoshape) which reduces metallic artifact on imaging

Weave
The catheter is allowed backward-forward movement during deployment.

Scaffolding
Used for wide-neck aneurysms. Can be either a vascular stent covering the neck or occlusion balloon.

Vascular Plugs

Through technological advancement, companies have developed larger detachable occlusion devices known as vascular plugs. These plugs are a nitinol mesh (Amplatzer Plug, St. Jude Medical) (Fig. 4.49) which if sized correctly collapses and decreases the blood flow causing thrombosis. Today, newer vascular plugs are made out of nitinol with expandable polytetrafluoroethylene (ePTFE, MVP plug EV3-Medtronic) (Fig. 4.50) or EOS (ArtVentive), which

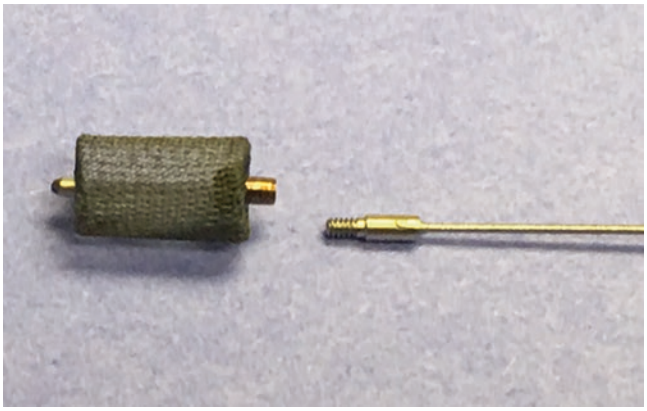


Fig. 4.49 Amplatzer I Plug (St. Jude Medical)

Fig. 4.50 MVP EV3 (Medtronic)

require a short landing zone but expand to the maximum vessel diameter to adequately occlude the vessel.

Key Point
An Amplatzer plug should be oversized by 20–50% of the area to be occluded.

Particulates

Permanent particulates are the most commonly utilized embolic agent used for distal arterial branch occlusion.

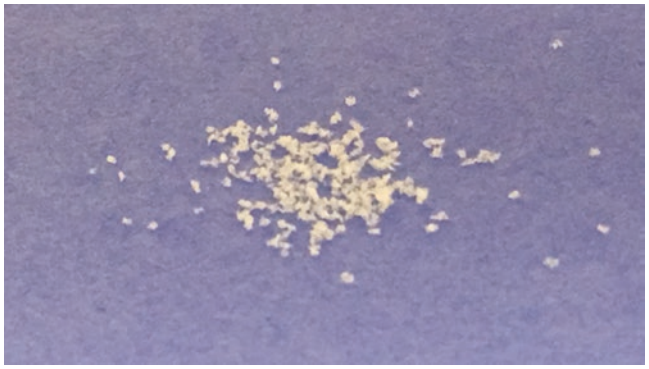


Fig. 4.51 PVA Contour (Boston Scientific)

Fig. 4.52 1:1 Contrast/saline suspension

Polyvinyl alcohol (PVA) is an inert injectable plastic material that is shaved and sieved into various sizes from 45 to 1200 μ [9]. Because they are ground down, they are irregular in shape which gives the appearance of popcorn (Fig. 4.51). They are packaged in a range of sizes such as 250–355 μ. The size selected for a particular procedure depends on the location and level of distal embolization. PVA produces a mild inflammatory response which leads to thrombosis and dense fibrous connective tissue response [6, 7].

PVA is suspended in either 1:1 contrast to saline (Fig. 4.52) or full strength contrast in order to visualize during fluoroscopy. Aggregation of the PVA particles within the catheter is prevented by suspending the PVA in the solution. A three-way stopcock is attached to the reservoir syringe (10 mL) which allows the operator to agitate the particles (Fig. 4.53) thoroughly prior to injection to prevent clumping of PVA. PVA is administered using a 1-mL or 3-mL syringe

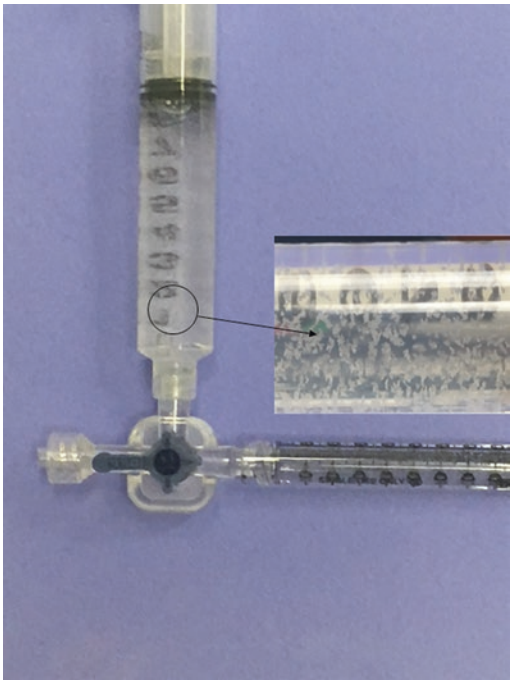


Fig. 4.53 PVA suspension using a three-way stopcock to agitate the solution

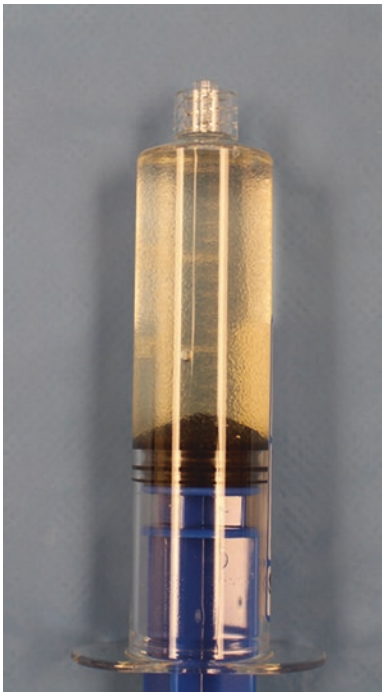


Fig. 4.54 Embospheres (Merit Medical)

with a slow pulsation under fluoroscopy to visualize a controlled delivery without refluxing the material into nontarget vessels.

To manage PVA's irregular shape and clumping, companies developed particulates in spherical form which have provided more accurate distal embolization. These PVA spheres have an acrylic coating or a hydrogel core which compresses to allow larger sized particles a smoother delivery through the microcatheter. In addition, a color coating is applied to the spheres for better visualization of the suspension prior to injection. They are manufactured in a solution within a sterile syringe, so the operator only has to add the desired volume of contrast (Fig. 4.54). Since contrast has different levels of concentration, viscosity, and osmolarity, companies recommend volume amounts based on these different levels. Particle size must be taken into account when deploying through a microcatheter so as not to clog the catheter (Table 4.8).

Table 4.8 Maximum particulate diameter based on catheter size

Catheter inner diameter	Maximum particulate (μ)
0.0165–0.017	300–500
0.021	500–710
0.027	700–1000
0.035	900–1200

Liquid Embolics

Thrombin is primarily used to treat superficial pseudoaneurysms percutaneously, but has been used as an additive for coil embolization (Fig. 4.55). The reconstituted thrombin is injected into the delivery cannula of the coil prior to delivery which may reduce the procedural time [6]. In addition, thrombin has been added to reduce autologous clot coagulation time for temporary embolizations.

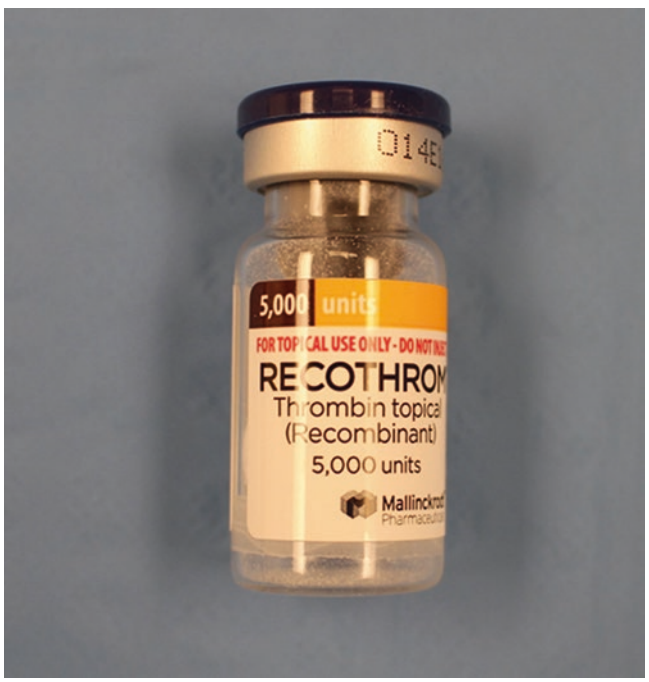


Fig. 4.55 Thrombin (Mallinckrodt Pharmaceuticals)

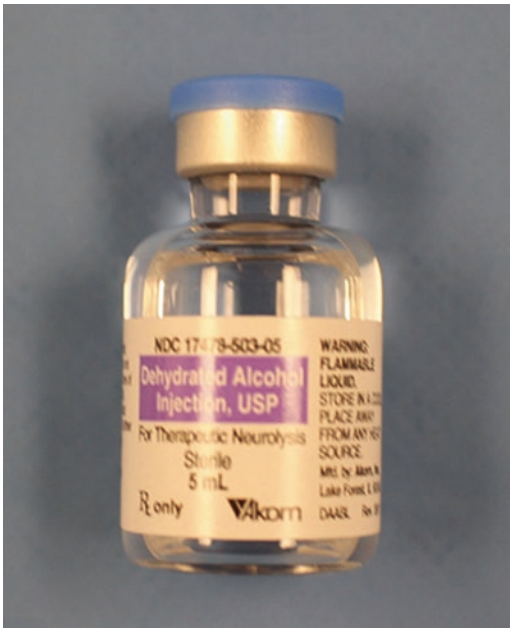


Fig. 4.56 Dehydrated alcohol

Fig. 4.57 Sodium tetradecol sulfate, Sotradecol, SDS (Angiodynamics Inc.)

Dehydrated alcohol is a sclerosant agent that produces a devastating effect in any tissue causing cell death (Fig. 4.56) [9]. Intravascularly, it causes an immediate denaturation of proteins and denudation of the endothelium leading to thrombosis [9]. Traditionally, occlusion balloons were used in conjunction with dehydrated alcohol to prevent reflux into nontargeted vessels. Today, it is emulsified with Lipiodol (Guerbet LLC), an oil based contrast, and injected through microcatheters distally to visualize and embolize tumor vessels.

Because of the risk for extravasation and the irreversible effects, highly skilled interventionalists will often use dehydrated alcohol for vascular malformations. Dehydrated alcohol is extremely painful and will require either deep sedation or general anesthesia.

Sodium tetradecol sulfate (Sotradecol (SDS), AngioDynamic Inc.) is a detergent that causes instantaneous injury to the endothelium leading to thrombosis and separation of the intima and media (Fig. 4.57) [11]. Traditionally, Sotradecol was used to treat varicose and spider veins. However, in today's IR departments, SDS is used intravascularly for varicoceles, gastric varices, and venous malformations.

The most common method of delivery is administering a foam mixture (Tessari method) [3]. This is performed by using a three-way stopcock, combining the desired air to Sotradecol ratio. The SDS/air mixture is under pressure, so before disconnecting from the stopcock, one must create negative pressure by aspirating to avoid spilling the contents on the sterile table. An advantage of the foam is that it tends to float allowing circumferential treatment of large vessels. It also travels further intravascularly than the pure liquid form [3].

Cyanoacrylates (i.e., medical grade super glue) are tissue adhesives that solidify when they come in contact chemically with ionic solutions (blood, saline). The adhesive properties were accidentally discovered in 1949 by Cooper through a number of experiments [12]. The first marketed cyanoacrylate was Eastman 910 monomer (Eastman Corporation Rochester, NY) [12]. Later materials include isobutyl 2-cyanoacrylate which was widely used until n-butyl 2-cyanoacrylate (Trufill; Cordis, Miami Lakes, FL) came to market, the only FDA approved cyanoacrylate [9]. Glue is indicated for the treatment of both cerebral and non-cranial arteriovenous malformations (AVMs), other aneurysms, pseudoaneurysms, varicoceles, and gastrointestinal embolizations [11].

Meticulous attention to detail during preparation is imperative. Cyanoacrylate (Fig. 4.58) is a clear liquid, and tantalum powder is used as an opacification agent. For superficial embolization with glue, white tantalum powder should be used for pale-skinned patients and black tantalum powder for dark-skinned patients to prevent skin discoloration [7]. The polymerization time can be adjusted with the addition of the oil-based contrast agent Ethiodol. The pathology, size of vessel, and location of the microcatheter to the target area of treatment are several considerations that dictate the amount of ethiodol used to increase the time of polymerization. The most important consideration is the experience and skill of the interventionalist.

Fig. 4.58 Trufill Cordis (Cardinal Health). Cyanoacrylate (center) is a clear liquid and tantalum powder (right) is used as an opacification agent. Ethiodol (left) is an oil-based contrast agent which can be used to adjust the polymerization time

Fig. 4.59 Ethylene vinyl alcohol, Onyx (Microtherapeutics) (left). Dimethyl sulfoxide (DMSO) is a solvent required to prevent precipitation of onyx within the lumen of the microcatheter (right)

Prior to glue administration, 5% dextrose solution is flushed through the microcatheter preventing the glue from solidifying when it contacts an ionic solution. After administration of glue, the microcatheter should be withdrawn quickly to prevent it from being stuck to the parent catheter.

Ethylene vinyl alcohol (EVOH, Onyx) (Microtherapeutics Inc. Irvine, CA) is a nonadhesive liquid embolic agent premixed with tantalum for visibility in a 1.5-mL vial (Fig. 4.59). The vial needs to be attached to a shaker for 20 min to properly mix the tantalum and EVOH liquid prior to injection [9]. Furthermore, it requires a solvent dimethyl sulfoxide (DMSO) to prevent precipitation of the material within the lumen of the microcatheter [11]. The microcatheter must be DMSO compatible due to the ability of DMSO to break down many plastic materials [11].

Onyx resembles the flow of lava. On contact with ionic solutions such as blood, Onyx develops a skin-like membrane, but the inner contents continue to flow. It solidifies from the "outside in" creating a sponge or foam-like substance [9]. This formation provides an advantage over that of the cyanoacrylates because the Onyx material allows improved control of delivery over time. Thus, Onyx has been highly effective in type II endoleaks.

Balloons and stents

As interventional radiology continues to expand to treat more disease etiologies and complex patient anatomy, devices continue to evolve to meet the needs of the patient. Treatment of peripheral artery disease has vastly expanded in the past 50 years from open surgical procedures to numerous endovascular options. While it was Charles Dotter in the 1960s who first described percutaneous transluminal angioplasty (PTA) via a series of dilators, it wasn't until a decade later, Andreas Gruntzig developed the first angioplasty balloon catheter [12].

The goal of angioplasty is to increase intraluminal vessel diameter without the removal of the organized plaque material. Since then, companies have invested in reengineering the performance of the balloon catheter. Balloon catheters can be categorized into compliant, semi-compliant, noncompliant, and specialty balloons. Compliant balloons are those that are atraumatic in nature and mold to the vessel; contrarily, noncompliant balloons are more rigid and are designed for angioplasty. Semi-compliant balloons are a version of noncompliant balloons that will expand beyond the nominal diameter.

Compliant balloons are balloon materials (latex, silicone, and expandable polyurethane) that cause little injury to the vessel's intima [12]. They are described by either balloon or catheter diameter, and they are based off of volume, not pres-

Fig. 4.60 Over-the-wire Fogarty Balloon (Edward Lifescience). These catheters are designed to have two lumens within the catheter wall, one lumen to inflate the balloon (red arrow), and the other lumen (orange arrow) to track over a 0.025″ or 0.035″ guidewire. Further, embolectomy catheters will have additional length markings (black arrow) that allow the operator to know the distance the balloon has advanced intravascularly. Finally, the OTW catheter usually has radiopaque markers (yellow arrows) to denote the balloon length

sure [12]. Catheters include occlusion balloons utilized for the delivery of embolic material, Fogarty balloons used for embolectomies, or molding balloons utilized for endograft wall apposition.

Fogarty Balloons

Embolectomy catheters come in two varieties: over the wire (OTW) and single lumen. The Fogarty balloon is a commonly used OTW embolectomy catheter (Fig. 4.60). The OTW system is used when vascular anatomy is challenging and requires a guidewire to navigate and maintain access through the area the balloon is being used. These catheters are designed to have two lumens within the catheter wall, one lumen to inflate the balloon, and the other lumen to track over a 0.025″ or 0.035″ guidewire. Further, embolectomy catheters will have additional length markings that allow the operator to know the distance the balloon has advanced intravascularly. Finally, the OTW catheter usually has radiopaque markers to denote the balloon length. The traditional single-lumen Fogarty balloon catheters directly connect the balloon to the inflation port. They are more commonly used in open embolectomy surgical procedures and are navigated through the vessel blindly. If fluoroscopy is available, they often can be redirected into an additional branch.

Key Point
All catheters, balloons, and drains that are advanced into a patient should be flushed with saline first for easier tracking over the wire but more importantly to prevent an air embolism.

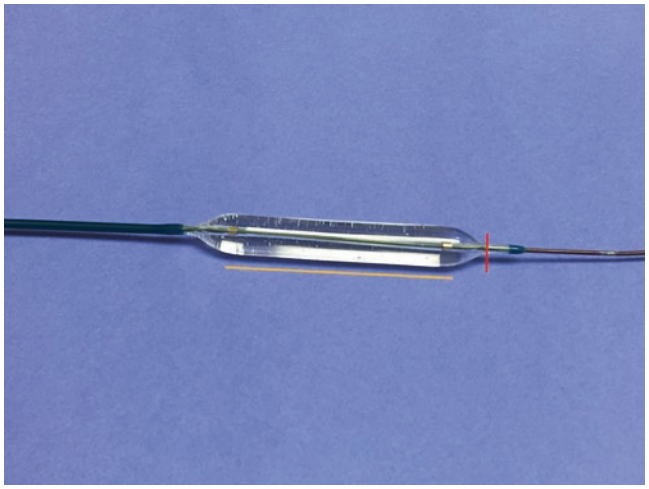


Fig. 4.61 Angioplasty balloon (Cortis Medical) is described by the length (orange line) and diameter (red line)

Angioplasty Balloons

Angioplasty balloon catheters are designed to treat a range of vascular pathology from fibromuscular dysplasia to atherosclerosis. When pressure is applied to the balloon, the balloon expands and fractures the plaque, pushing the material through fissures into the media. The adventitia is stretched causing nerve stimulation resulting in pain. Monitoring the pain is extremely important due to the increase risk of vessel rupture.

Angioplasty balloons (Fig. 4.61) are described by their diameter and length. The appropriate balloon diameter is determined by measuring the normal vessel diameter adjacent to the plaque from a digital subtracted acquisition (DSA). DSA images require calibrations to accurately measure the images. The most accurate calibrated source is the radiopaque marker catheter since the catheter is located at the same depth as the lesion; this prevents error due to magnification and reduces the risk of dissection or rupture. Balloon diameters range from 1.5 mm to >30 mm in diameter. Radiopaque markers on the balloon catheter shaft determine the usable length of the balloon. The balloon length is selected by the length of stenosis while aiming for minimal contact of normal vessel wall [6]. However, if it is too short, the balloon will slip out of the area of stenosis as it is inflated, termed watermelon seeding [11]. To compensate for this effect, a slightly longer balloon provides stability during inflation [3]. Additionally, the operator holds the catheter taught during inflation to control any unnecessary balloon movement. The most common balloon lengths are 2–10 cm. For lower extremity vessels, longer balloons ranging from 20 to 30 cm have been constructed to reduce the number of inflations along the length of the lesion.

There are several unique qualities regarding the construction of the balloon catheter. The catheter design is one constructed either OTW or monorail (aka: rapid exchange, RX). A monorail catheter is designed with a side hole midway through the catheter where the wire is thread proximally; distally there is no wire within the monorail catheter, but instead it lies adjacent to it. OTW catheters (Fig. 4.62) have two hubs, one for the balloon and the other for flushing the wire lumen, while the RX (Fig. 4.63) only has one hub for the balloon. OTW provides better pushability through a tight stenotic lesion. However, if the intervention is distally located and multiple exchanges are probable the monorail balloon *is ideally suited*; a monorail catheter's lumen for the wire is 30 cm in length allowing for quicker exchanges. In addition, the smaller diameter of RX balloon shafts allows the use of a smaller sheath, thereby reducing the risk of vascular bleeding complications.

The balloon lumen of the catheter is manufactured with either a coaxial, double-lumen, or triple-lumen design (Fig. 4.64). Each has advantages and disadvantages with inflation and deflation times of the balloon. Out of the three, the coaxial balloon lumen catheters have faster inflation and deflation times associated with their design [12]. This design is applied to longer length balloons (20–30 cm) required for peripheral interventions. While most traditional balloons catheters are double- or triple-lumen, they have a balloon lumen shape (semilunar or round, respectively), which affects the inflation/deflation performance [12].

Balloon materials are categorized as either semi-compliant or noncompliant. The compliancy of the balloon material is based off the percentage of balloon growth beyond its predetermined diameter. Noncompliant balloons do not expand beyond their given diameter when increased pressure is applied, while semi-compliant balloons enlarge in the areas of lower resistance with the additional pressure [12]. All balloons will burst if too much pressure is applied. Thus, angioplasty balloons are manufactured with a nominal pressure that equates to the diameter of the balloon, and a maximum burst pressure that is the pressure beyond which the balloon will rupture. If an angioplasty balloon does burst, it is designed to tear longitudinally (Fig. 4.65), allowing the balloon to be removed from the patient without complication. A transverse balloon tear becomes more problematic to remove as the plastic inverts inside-out and may shear off or occlude the vascular sheath.

Prior to use, a balloon must be adequately prepped. The balloon can be prepped with either one-half or one-third strength contrast in a 10-mL syringe (Fig. 4.66). The one-half strength contrast is more visible, but it requires more time to deflate the balloon because of the viscosity of the contrast agent; one-third strength contrast is less viscous and has better deflation rates, but it may become visually challenging under fluoroscopy in small-diameter balloons. The syringe is aspirated to create a negative vacuum. Upon release of the syringe plunger, a column of contrast mixture fills the balloon lumen, replacing the ambient air. The process is repeated

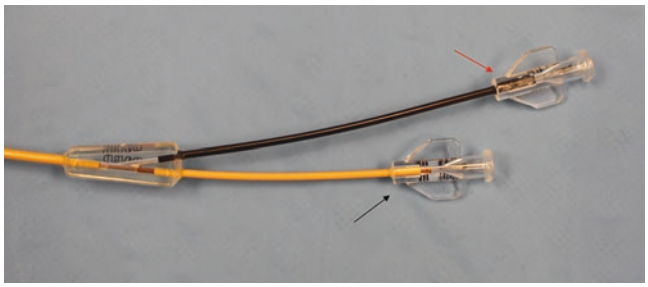


Fig. 4.62 Over-the-wire balloon catheter (Bard Peripheral) with the balloon hub (red arrow) and wire lumen (black arrow)

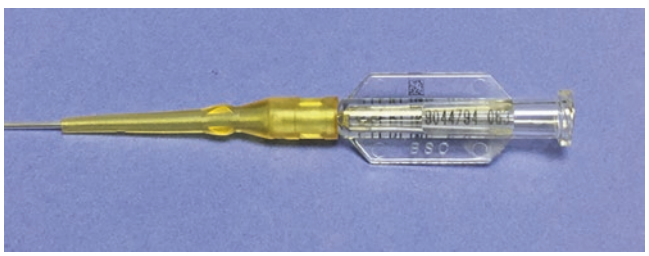
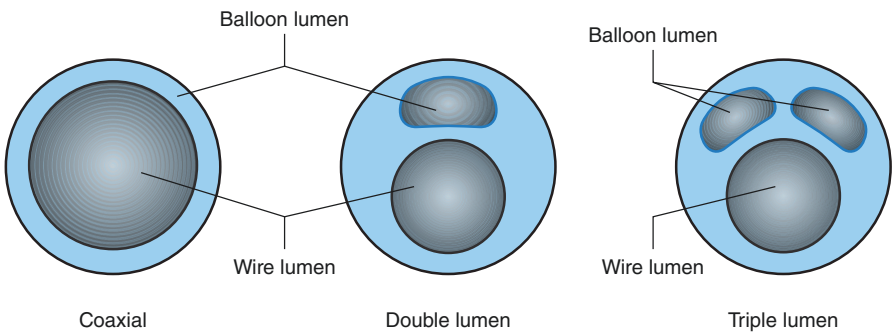


Fig. 4.63 Rapid exchange or monorail balloon catheter with a single hub for the balloon

Fig. 4.64 Coaxial, double-lumen, and triple-lumen balloon catheter designs



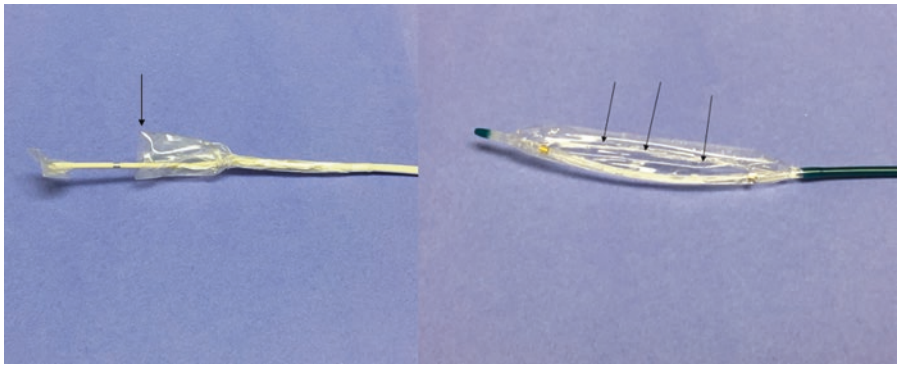


Fig. 4.65 Angioplasty balloons are designed to tear in the longitudinal direction (right). A transverse balloon tear inverts inside-out during removal and may shear off or occlude the sheath (left)

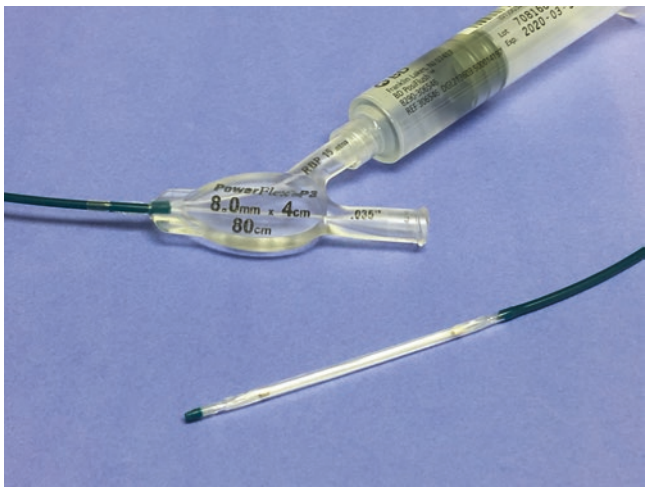


Fig. 4.66 A balloon should be prepped with a one-half or one-third strength contrast 10-mL syringe

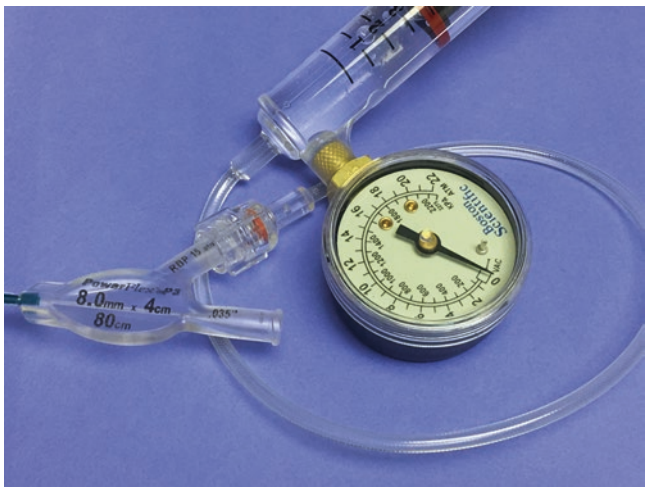


Fig. 4.67 A balloon hub is attached to an insufflation device (Namic) with a wet to wet connection

several times to maximize the reduction of air in the balloon, releasing any air from the syringe as needed. Next, an inflation device, with the same contrast mixture, is attached directly to the balloon lumen port (Fig. 4.67) with a wet to wet connection. The inflation device provides better control of the inflation of the balloon while generating greater pressures (measured in atmospheric pressure, or atm) than the 10-mL syringe. The pressure is measured by the inflation device gauge, while the balloon is monitored under fluoroscopy guidance.

Alternatively, the balloon can be prepped by connecting a three-way stopcock (Fig. 4.68) with/without a rotating Luer lock tip to the balloon port of the catheter. The inflation device, with a contrast mixture, is connected to the stopcock and opened to aspirate the balloon lumen. The vacuum created draws the contrast from the inflation device into the balloon lumen. The stopcock is rotated to the open port and the air from the inflation device is removed. This process is repeated several times to confirm complete air expulsion. Air is removed completely from the balloon prior to use to ensure that the entire lumen of the balloon is visualized; air bubbles can obscure the image or hide a stenosis.

When using a balloon, it is centered on the lesion under fluoroscopic guidance, and the inflation device is used to apply controlled pressure to insufflate the balloon. As the balloon is being inflated, the atm is verbalized to identify the pressure and to be documented, while a timer is started to regulate the inflation time. The pressure continues to be applied until the balloon is fully inflated, or the maximum balloon pressure limit has been reached. If the stenosis is resistant to the balloon, an alternative (high pressure) balloon or specialty (cutting or scoring) (Fig. 4.69) balloon can be utilized to either apply more pressure or to utilize metal bands to open the resistant lesion. Balloons used in the arterial system require inflation times between 30–45 s, while in the venous system the inflation time is prolonged to 1–2 min. If a vessel dissects from the balloon, the balloon is re-inflated at very low pressure (1–2 atm) for a longer inflation time of 3–5 min in order to tack down the dissected intimal flap and prevent propagation of the dissection flap [3].

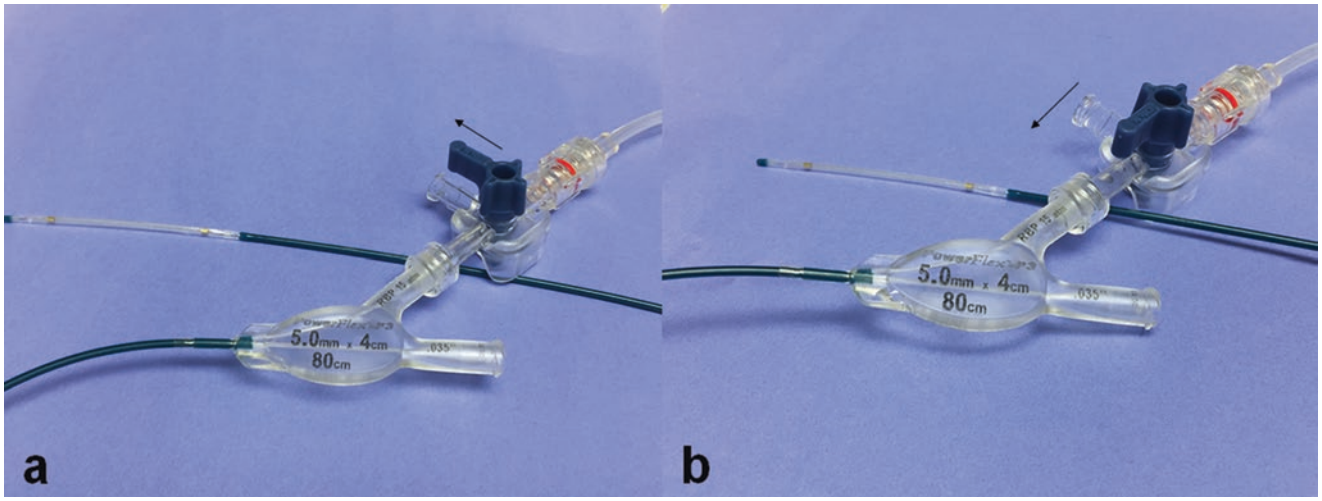


Fig. 4.68 A balloon can alternatively be prepped with a three-way stop cock. The stop cock is rotated to the "open to the balloon" port (**a**) to draw contrast from the inflation device into the balloon lumen. The stop cock is rotated to the "open to the air" port (**b**) to remove excess air

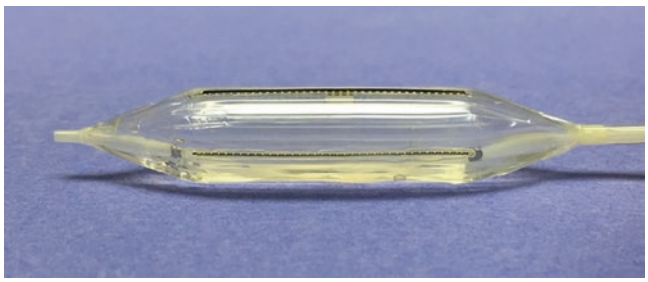


Fig. 4.69 Cutting balloon (Boston Scientific)

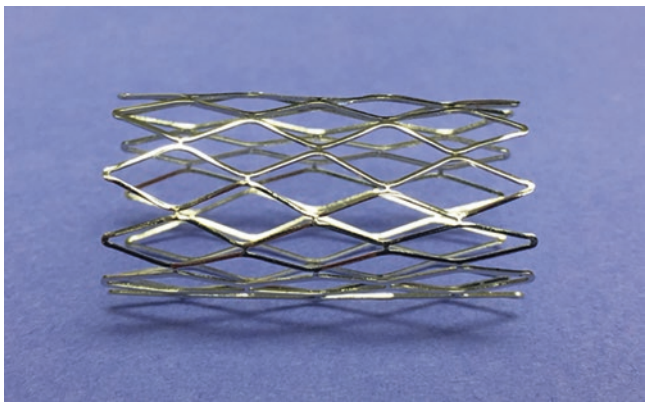


Fig. 4.70 Palmaz stent (Cordis, Cardinal Health)

Drug-Coated Balloons

Finally, drug-coated balloons (DCB) have been developed to increased long-term angioplasty patency rates. Once the balloon is inflated, the drug coating (paclitaxel) is released into the vessel wall, inhibiting smooth muscle proliferation and migration, and preventing intimal hyperplasia restenosis [13]. Primarily indicated for femoral and popliteal artery disease, DCB have increased 24-month patency rates from approximately 50% to 79% [14]. Unfortunately, post-angioplasty complications including flow limiting dissection and rupture or elastic recoil of the vessel.

Key Point
Each implantable device must be checked for size and expiration date on the manufacturing packaging prior to opening the package.

Vascular Stents

Balloon Expandable Stents

Vascular stents, first imagined in 1964 with Dotter's "endovascular splint," have gone through many transformations through the decades [15]. Stents are metal scaffolds that apply stress to the narrowed area and can be categorized as either balloon-expandable or self-expandable [3]. Furthermore, stents can be divided into bare or covered. Specialty stents such as endografts, drug-eluting stents, and transjugular intrahepatic portosystemic shunt (TIPS) stents are also available. Thus, within today's interventional departments, there are a variety of vascular and nonvascular stents designed to support an assortment of pathophysiologies.

The first-generation balloon-expandable Palmaz stent (Fig. 4.70) introduced in 1985 was constructed of stainless with a closed-cell diamond configuration [7]. An advantage

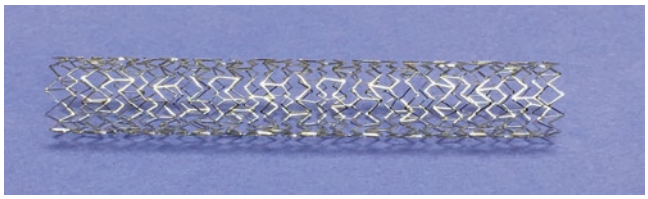


Fig. 4.71 Express LD (Boston Scientific)

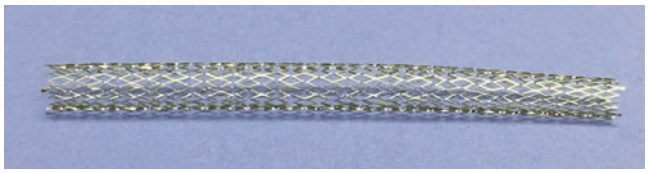


Fig. 4.73 Protégé, EV3 (Medtronic)

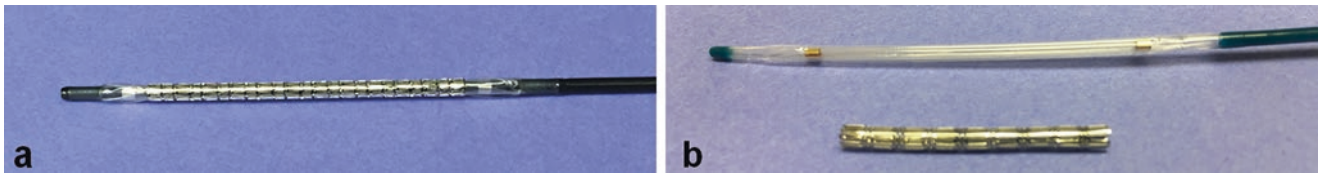


Fig. 4.72 Balloon expandable stent comes pre-mounted (**a**) on a delivery balloon (Boston Scientific) or comes separate (**b**) and must be hand mounted (Cordis)

of balloon-expandable stents is the ability to precisely place them with minimal foreshortening in length as the diameter increases in size [11]. Closed-cell balloon-expandable stents provide excellent hoop strength, but due to the rigidity of the stent, they can be permanently kinked or deformed by external pressure and thus should be avoided in vessels where there is a point of flexion or compression, for example, the popliteal artery [15]. Balloon-expandable stents are primarily deployed at the ostium of a vessel.

The need for flexibility in tortuous vessels required a design change to the open-cell stent (Fig. 4.71). Open-cell stents have hinges that provide increased flexibility of the stent [15]. The hinges connect the cell struts, which provide the support of the stent [15]. Balloon-expandable stents use the dilating force of the balloon to expand and compress the stent into the intima. Luminal gain is determined by the balloon's ability to remodel the vessel. Thus, pre-dilation of the vessel with a smaller diameter PTA balloon is often performed first to maximize the stent's luminal gain when inflated.

Balloon-expandable stents are manufactured either on a 0.014″ or 0.035″ guidewire platform. The balloon is inflated to expand the stent to an effective diameter. These stents are oversized to 1 mm larger than the vessel lumen to provide adequate wall apposition [3]. The lower profile of the 0.014″ stents allows them to be delivered through a smaller sheath size compared to the 0.035″ stents. However, the disadvantage of 0.014″ stents is the lack of visibility under fluoroscopy compared to 0.035″ stents. Thus, manufacturers have developed another alloy (cobalt-chromium) to increase the opacity of the stent. Balloon-expandable stents can come pre-mounted by the company on a delivery balloon or must be hand-mounted (Fig. 4.72).

Most institutions carry pre-mounted stents because hand-mounted stents have a greater probability of migration during either the insertion into the sheath or during deployment [3]. However, pre-mounted stents are designed only up to 10 mm in diameter with post-dilation up to 12 mm; for large vessel pathologies >12 mm in diameter, hand-mounted Palmez stents are essential. Proper technique for centering and crimping of the stent on a puncture-resistant balloon is necessary for successful delivery and deployment. The large vessel stents require a larger 7F delivery catheter shaft for adequate compression of the stent over the balloon.

Self-Expandable Stents

Self-expandable stents are constructed of either Elgiloy (stainless steel-cobalt alloy) or nitinol (nickel-titanium alloy) [11]. Nitinol (Fig. 4.73) is the most commonly used material because it has the ability to regain its original shape after deployment and minimal foreshortening (<7%) [15]. However, due to the radiolucency of nitinol, additional metals (platinum or tantalum) are added as visible markers to the ends of the stent [3].

The flexibility of self-expandable stents improves the trackability through tortuous vessels. Self-expandable stents conform to the vessel's contour, which provides better wall apposition and endothelialization [15]. They are ideally placed in vessels of external compression or areas of flexion because they exert a constant force against the wall. A slight oversizing of 1–2 mm anchors the stent to the vessel preventing migration [11].

The majority of self-expandable stents (Fig. 4.74) are constrained into a delivery catheter that consist of an outer sleeve that when retracted exposes the stent which naturally expands to its given diameter. If the treatment zone requires multiple stents, a 5- to 10-mm overlap is necessary because any space between the stents may lead to restenosis [11].

Each manufacturer has a unique deployment mechanism for stents (Fig. 4.75). Knowledge of safety features, locking pins/tabs, and skill of the operator allows for proper and

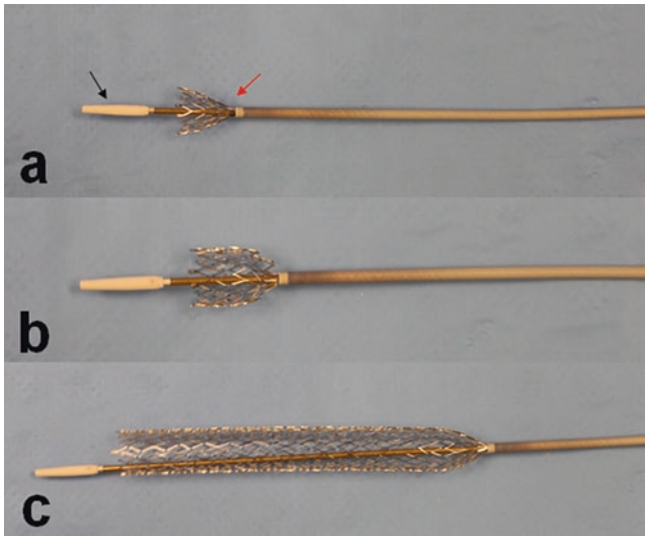


Fig. 4.74 (**a–c**) Protégé, EV3 (Medtronic). The delivery catheter (black arrow) consists of an outer sleeve (red arrow) that, when retracted, exposes the stent, which can be sequentially visualized being deployed

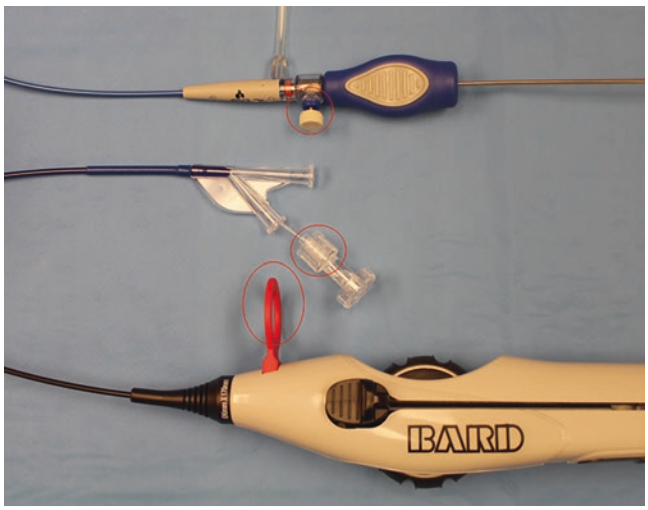


Fig. 4.75 Mechanism for stent deployment from top to bottom: Viabahn (Gore Medical), Protégé EV3 (Medtronic), LifeStent (Bard Medical).

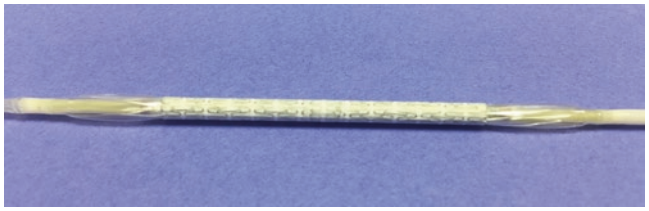


Fig. 4.76 Icast (Atrium-Medical) balloon expandable endograft.

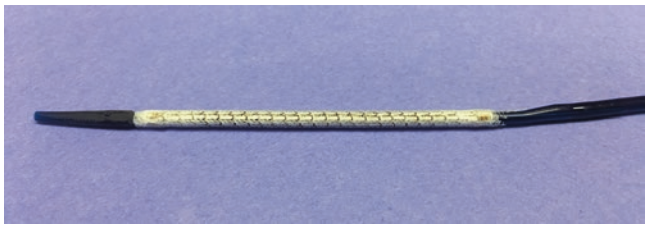


Fig. 4.77 Viabahn (Gore Medical) self-expandable endograft

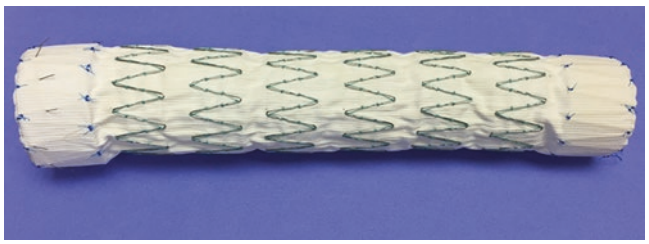


Fig. 4.78 Zenith (Cook Medical)

Fig. 4.79 Excluder (Gore Medical)

successful deployment within the treatment zone. Afterward, post-dilation by a PTA balloon is required to fully open the stent in areas of stenosis.

Specialty Stents

In the late 1990s, the interventional departments witnessed the fusion of stent technology with surgical grafts and thus the production of endografts. The combination of metal (316 L stainless steel, nitinol, and Elgiloy) with a surgical graft material (polyethylene terephthalate-PET, polytetrafluoroethylene-PTFE, and Polyester-Dacron) provides treatment options for vascular and nonvascular conditions [15]. Vascular indications include the exclusion of aneurysms, pseudoaneurysms, arteriovenous fistulae, traumatic injuries, areas of active extravasation, and the relining of in-stent occlusion [11]. Nonvascular grafts are utilized for treatment in the biliary, bronchial, and

Key Point
A covered stent is a generic term for a stent that can be used both in the vascular and nonvascular setting such as a biliary or esophageal stent. A stent graft or endograft is a term used specifically when referring to aortic or PAD stenting.

Key Point
A 3-mm J tip wire is used to re-access a bare metal stent to avoid going through the stent struts.

gastrointestinal systems for strictures and tumors. Endografts are also available as balloon-expandable (Fig. 4.76) or self-expandable (Fig. 4.77). They follow the same bare metal stent location limitations.

In addition, the intravascular repair of an aortic aneurysm or a dissection led companies to design large diameter grafts for the thoracic and abdominal regions. The thoracic endograft (Fig. 4.78) is a tubular graft material attached to large self-expandable stents. Abdominal endografts (Fig. 4.79) have modular components based off the vessel diameter and length required to exclude the aneurysm.

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