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INTERVENTIONAL RADIOLOGY

REVIEW

Catheters in vascular interventional radiology: an illustrated review

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ABSTRACT

The past five decades have seen significant developments in the knowledge and practice of interventional radiology. Advancements in angiographic equipment have made interventional radiology a safe, minimally invasive preferred option in the treatment of a variety of diseases. Today, a range of catheters are available in the armamentarium of the interventional radiologist to suit different needs when conducting diagnostic angiograms or performing interventions in various vascular territories. The hardware required for interventions includes needles, wires, catheters, balloons, and stents. Catheters, in particular, are an invaluable tool for interventionists. The purpose of this review is to describe the identification characteristics, properties, and uses of the common angiographic catheters used in interventional radiology, with a special focus on peripheral vascular interventions (excluding neurointerventions).

KEYWORDS

Angiocardiography, catheter, catheter angiography, interventional, vascular

The catheter is an invaluable tool for interventional radiologists. In 1929, Dr. Werner Forssmann demonstrated the catheterization of the pulmonary artery with a simple rubber catheter by performing an angiogram through the ante-cubital vein.[1] Today, a variety of catheters are available in the armamentarium of the interventional radiologist to suit different needs. However, the literature lacks a comprehensive compilation of the properties, types, and uses of catheters. In this review, we aim to describe the characteristics, properties, and uses of the common angiographic catheters used in vascular interventions.

Properties of catheters

A catheter is a flexible hollow tube that can be inserted into a duct, body cavity, or vessel. It consists of a hub at the rear end and a distal tubular shaft. The shaft can be straight or molded into different curved shapes (primary, secondary, or tertiary curves) and can have a tapered or non-tapered tip (Figure 1). Catheterization is the process of inserting a catheter. Angiographic catheters are the most important tool in any vascular intervention. They are introduced through a sheath placed at the vascular access site. Wires introduced via these catheters are navigated to enter the target vessels. Once the catheters are inside the vessel, they can be used to conduct diagnostic angiography of the intended vascular territory and as a conduit for the delivery of balloons and stents for endovascular intervention at the intended location.

An ideal catheter should have strength, good torque control, radiopacity, flexibility, an atraumatic tip, and low surface friction for good trackability over a guidewire.[2]

Construction

i) Surface coating: surface coatings can modify the catheter's friction coefficient, thrombogenicity, or antimicrobial properties. ii) Outer layer: angiographic catheters can be made of polyethylene, polyurethane, nylon, polytetrafluoroethylene, silicone, polyvinyl chloride, or a combination of these materials. Their respective properties, advantages, and disadvantages are discussed in Table 1.[3,4] The coefficient of friction on the luminal side is important for easy passage of the wire and achieving high flow rates of contrast during angiography. Conversely, a low coefficient of friction on the catheter's outer surface helps its trackability,

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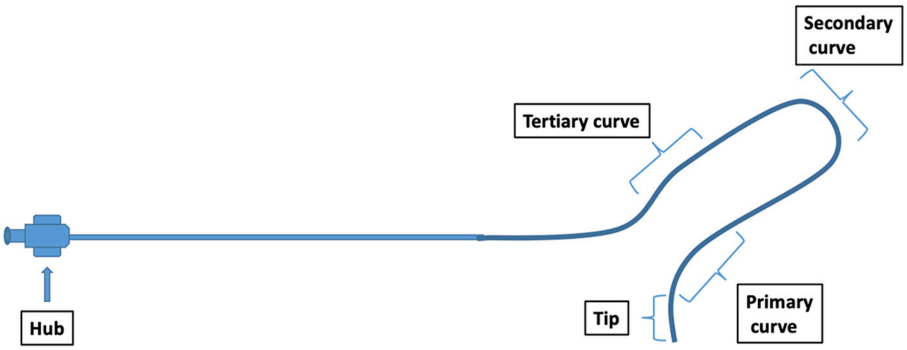

Figure 1. Basic construction of a catheter. Catheter consists of a hub at the rear end and a distal tubular shaft. The shaft can be straight and molded into different curves (primary, secondary or tertiary) and can have a tapered or non-tapered tip.

although this is at the expense of positional stability during injection.[5] The rigidity of the material allows the catheter to withstand the pressure sure exerted by the blood over an extended length of time. Selective catheters made of polyethylene are frequently braided with stiffer materials, such as nylon or stainless steel, to help maintain their torsional strength as well as increase torque control. The pushability of the catheter is also dependent on the bending stiffness of the material and the coefficient of friction at the external surface of the catheter. Catheters made with materials with less stiffness, like polyethylene, are more likely to negotiate the tortuosity of vessels, but they are more prone to bending or buckling. Buckling may also occur if the friction between the external surface of the catheter and the vessel wall is increased. Additionally, it can occur when the catheter is wedged on the wall of the vessel without perforating it.[6] iii) Tip: a rounded tip is less traumatic than square or bevel-ended tubing and is easier to insert. iv) Reinforcement: single or double wire braiding is utilized for extra torquability.[3]

Measurement

The size of the catheter is represented by its outer diameter, measured in French (Fr) units (1 Fr= 0.333 mm/0.013 in). A 3-F catheter means the outer diameter of the catheter is 1 mm. Mostly, a catheter is narrower at the advancing end and wider at the hub. For example, a Progreat™ (Terumo Interventional Systems) catheter specified as 2.4/3 F means the outer diameter of its tip is 2.4 Fr, and it measures 3 Fr at the hub end.[7] A disadvantage of this scale is that it does not specify the inner diameter of the catheter or tubing. The catheter diameter specified by the manufacturer corresponds to its outer diameter and to the inner diameter of a vascular sheath. Thus, a 4-F catheter can pass through a 4-F vascular sheath.

Most angiographies are performed with 4 or 5-F catheters over 0.035 or 0.038-in guidewires. The diameter of the catheter to be used is determined by the age of the patient, size of the vessel, rate of blood flow, and whether a selective or super-selective study is desired.

The inner diameter of a catheter is measured in inches (in). Knowledge of the inner diameter is necessary for introducing compatible guidewires inside the catheter. For example, the Progreat catheter (2.4/3 F) has an inner diameter of 0.022 in. Hence, it can admit guidewires with a diameter of less than 0.022 in. This information is usually stated on the packaging of the catheter.[8]

A guiding catheter is represented by its outer diameter in Fr.[9] The inner diameter of a guide catheter is larger than the correspond-

Main points

- The catheter is an invaluable tool for interventionists.
- The purpose of this review is to describe the identification characteristics, properties, and uses of common angiographic catheters used in interventional radiology, with a special focus on peripheral vascular interventions.
- The appropriate selection of catheters in various scenarios and vessels is of the utmost importance and is discussed.

Table 1. Properties of materials used for constructing catheters

Material	Coefficient of friction	Stiffness	Torsional strength	Advantages	Disadvantages	Used in
PTFE	Low	High	Low	Kink resistant, easier to track through scarred or obese groin tissue	Reduced flexibility, difficult negotiation across tortuous vessels	Sheaths and dilators Inner layer of guiding catheter
Polyethylene	Moderate	Low	Moderate	Good shape memory Pliable	Tends to become soft with repeated use with resultant loss of shape and torsional rigidity Often reinforced with braiding (nylon or stainless steel) to prevent loss of shape	Selective catheters
Nylon	High	High	High	Resists softening with repeated use Can withstand high pressure during flush injections	Reduced flexibility Difficult negotiation across tortuous vessels	Flush catheters Mechanical braiding of selective catheters and guide catheters
Polyurethane	High	Low	Moderate to high	Soft and pliable	Difficult passage over wire	Outer surface of guide catheters

PTFE, polytetrafluoroethylene.

ing diagnostic catheter with the same outer diameter. For example, the inner diameters of a 6-F Radifocus™ Optitorque™ (Terumo Corporation, Tokyo, Japan) angiographic catheter and a 6-F Heartrail™ III (Terumo Corporation, Tokyo, Japan) guiding catheter are 1.3 and 1.8 mm, respectively, with a 2-mm outer diameter (Figure 2).[10,11]

The length of the catheter used is determined by the access site and the desired application. Ideally, it should be of sufficient length to reach the target site and still have enough of its entire length remaining outside the patient. For example, to perform a cerebral angiogram from the femoral approach, a 100-cm catheter is used; however, a 65-cm catheter will suffice for a renal arteriogram (Table 2). Resistance is directly proportional to length, so excessive length should be avoided.

Torsional strength

This refers to the ability to steer the curve at the distal tip in a certain direction by rotating the proximal end of the catheter. This is considered a function of catheter diameter and is proportional to the difference between the fourth powers of the outer and inner diameters (Figure 3). The approximate torsional strength also varies according to the material of the catheter; for instance, the ratio of the torsional strength of Teflon–polyethylene–nylon is approximately 1:2:4. Wire reinforcement increases rotational stability by a factor of 3.[12]

The flow rate of contrast

The flow rate of contrast is specified by the manufacturer. It follows Poiseuille's law and depends upon the viscosity of the contrast, the pressure gradient across the tubing, and the diameter and length of the catheter (Table 3). Doubling the inner diameter increases the flow rate by 16 times, in concordance with Poiseuille's law.[13] Doubling the length of the catheter decreases the contrast flow rate by half, which is inversely proportional to the viscosity of the contrast (Figure 4). Increasing the pressure maximizes the flow. Because of this, the pressure-bearing capacity of the catheter wall is an important consideration.

Technical properties

Trackability is the ability of a catheter to follow a guidewire. *Pushability* is defined as the forward movement of the tip of the catheter due to the force applied by the operator at the hub of the catheter. *Crossability* is defined as the ability of a catheter to navigate across a tortuous or diseased arterial segment. *Steerability/torquability* refers to the rotational strength; i.e., the steering responsiveness of the catheter tip to handling maneuvers performed at the hub.[14]

Catheter shapes

Catheter shapes are derived from the presence or absence of curves, such as the primary curve, secondary curve, and occasionally, the tertiary curve. The various types are i) straight catheter (no curve), ii) pigtailed catheter (for flush aortograms), iii) simple curve or single curve catheters [(e.g., the multipurpose Head Hunter (H1) catheter)], and iv) complex curve catheters, which are usually a primary, secondary, and occasionally, a tertiary curve; these are subdivided into double curve [e.g., Cobra catheter, renal double-curve (RDC) catheter] and reverse-curve catheters (i.e., sidewinder catheters, e.g., Simmons and SOS Omni catheters). Both pigtailed and straight catheters have multiple side holes, which help in injecting a large volume of contrast at a high rate (velocity). They are also called *flush* catheters.[15]

Side holes

Catheters can also be classified depending on the number and type of side holes: i) single hole, ii) end hole with side holes (flush catheters for high-pressure and high-volume contrast injections), and iii) blocked end with side holes only. Side holes have multiple advantages, such as reducing resistance, reducing recoiling, allowing the effective distribution of contrast in large vessel lumens, and improving the opacification of proximal arterial side branches. However, at high injection pressures close to the catheter tolerance level, high-flow jets of contrast may escape from the side holes, which can cause the subintimal extravasation of contrast and vessel wall injury. This is known as the *jet effect*, which is a relatively uncommon but well-known complication of angiography.[16]

Types of catheters used in an interventional radiology suite

Vascular catheters can be broadly classified on the basis of the abovementioned properties:

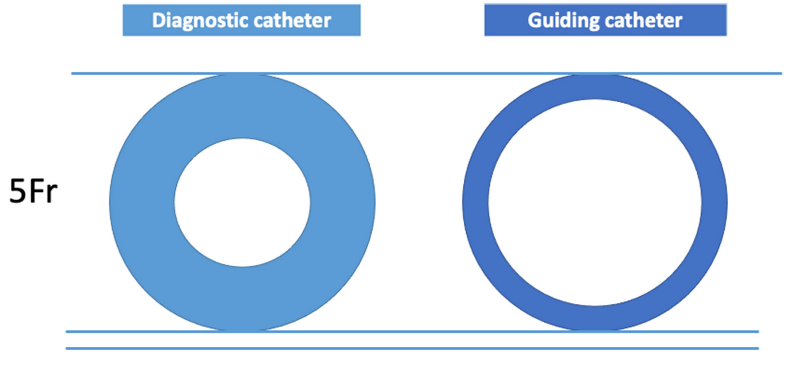

Figure 2. Diameter of the guiding catheter lumen is larger the diagnostic catheter for similar French sizes.

Table 2. Length of catheters used for the catheterization of various vessels	
Length (cm)	Purpose (from transfemoral approach)
15–20	Dilator
65	Abdominal aortography with lower extremity runoff, contralateral iliac artery injections
65–80	Selective renal and visceral catheterizations
90	Arch aortography, thoracic aortography
100	Selective cerebral catheters

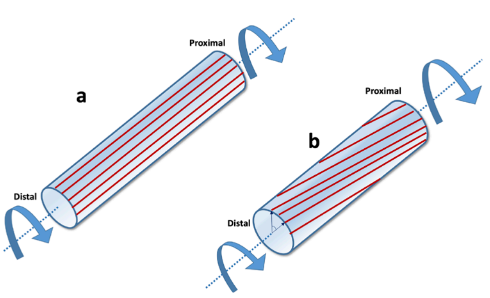

Figure 3. Schematic diagram showing the concept of torsion, i.e., the measure of the ability of a material to withstand a twisting load. Torsion is a moment that twists/deforms a member about its longitudinal axis. **(a)** Stiff catheter (e.g., nylon) with no deformation of longitudinal lines on applying torsion. **(b)** Non-stiff catheter (e.g., polytetrafluoroethylene) with deformation of longitudinal lines on applying torsion.

Table 3. Contrast-media flow rates[20]

Type of catheter	Caliber (in French)	Length (in cm)	Maximum flow rate (in mL/second) for 65- and 100-cm catheters, respectively (max pressure: 1.200 psi)
Flush (multiple side holes)	4	65, 100	19, 15
	5	65, 100	32, 27
Selective (end hole only)	5	65, 100	15, 11

Data from Cook Medical.

$$\text{Flow (Q)} = \frac{\Delta P \pi r^4}{8 \eta L}$$

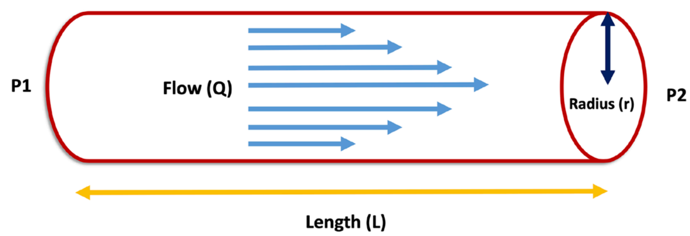

Figure 4. Schematic diagram showing Poiseuille's law. It states that the flow (Q) of fluid is related to a number of factors: the viscosity (n) of the fluid, the pressure gradient across the tubing (P), and the length (L) and radius (r) of the tubing.

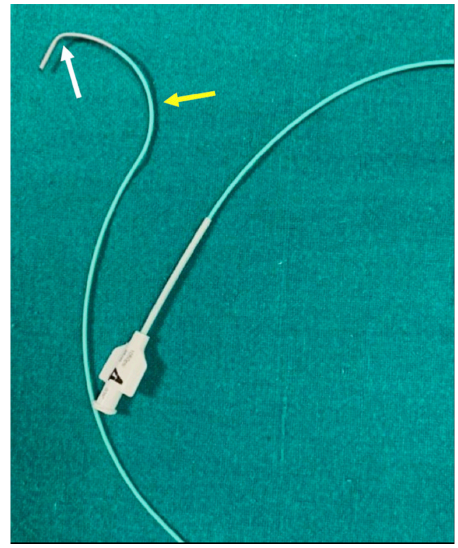

Figure 5. Cobra catheter with primary curve (white arrow) and secondary curve (yellow arrow).

A. Selective catheters,

B. Hemodynamic catheters,

C. Guide catheters,

D. Special catheters (e.g., microcatheters, flush catheters, drainage catheters, central venous catheters, sizing catheters, exchange catheters, and balloon catheters).

A) Selective catheters

Selective diagnostic catheter sizes range from 4 to 6 F, with lengths from 50 to 125 cm, respectively. Most of these catheters are braided and have soft tips. The following are examples of common selective catheters. The principles behind the selection of diagnostic catheters are described in a later section.

a) Catheters for arch vessel cannulation:

- **Cerebral catheters (for arch vessel cannulation):** Simple curve, Head Hunter (H1), Bentson Hanafee Wilson (JB1), Bernstein, multipurpose (MPA, MPB), vertebral, Picard, and internal mammary catheters.
- **Complex curve catheters:** Head Hunter (H2, H3), Bentson Hanafee Wilson (JB2, JB3), Simmons (SIM1, 2), Newton (HN3, HN4), Mani, and Judkin's right coronary catheters.

b) Catheters for visceral artery cannulation:

- **End-hole catheters:** Cobra (C1, C2, C3), Rosch Celiac (RCI, RC2, RC3), shepherd's hook, Mikaelsson, SOS Omni, sidewinder (SIM1, 2, 3), and RDC catheters.
- Superselective end-hole catheters: Rosch left gastric, Rosch hepatic, and Rosch dorsal pancreatic

The features of some common visceral catheters are described below:

- **Cobra catheter:** This type has a primary and secondary curve (double-curve catheter). The C1 and C2 types are progressively more curved (Figure 5). The Cobra catheter is relatively easy to direct, and its shape helps in the cannulation of visceral arteries, such as renal, bronchial, or celiac arteries. It is used extensively in renal arterial procedures, bronchial artery embolization, and aortopulmonary collateral embolization in patients with congenital heart disease.
- **Renal double-curve catheter:** This is a double-curve catheter with the tip pointing downwards. It is designed specifically to catheterize the acutely originating renal artery.
- **Sidewinder/Simmon's catheter:** This was first described in 1972. It is a reverse-curve catheter that is used for cannulating the arch vessels in tortuous anatomy, as it advances with a withdrawal motion. It has three curves, and the secondary curve is also known as the *knee.* The tertiary curve helps in the anchorage at the aorta. Simmon's catheter can be used in open or closed-loop configurations. There are various methods described for its formation, such as the left subclavian method, renal method, aortic bifurcation, or ascending aorta method. The left subclavian method of formation is considered the best and safest. Simmon's catheter is prone to becoming knotted, so care is required when it is being operated. A Beacon®-tipped Simmon's catheter can break; hence, it should be checked for length after use.[17]
- **Rosch celiac catheter:** The simple "C"-shaped curve of this catheter is the most appropriate for the celiac and superior mesenteric artery. If using the contralateral femoral approach, the common iliac artery is catheterized easily with an RC1. The RC3 is also known as the Rosch inferior mesenteric artery catheter and is used specifically for the catheterization of the inferior mesenteric artery.
- **Multipurpose catheter:** This is made of polyurethane. The MPA1 has a single-end hole, and the MPA2 has a single-end hole and two side holes (Figure 6). This type comes in 65, 80, 100, and 125-cm lengths and diameters of 4 to 7 F. Multipurpose catheters have a gentle 120° primary curve. They are the most commonly used catheter for selective angiograms. There is another MPA variant known as the Gensini MPA catheter. It comes in diameters of 4 to 7 F, with one end hole and six side

holes, and it is used for flush aortograms. The MPB catheter differs from the MPA in that it has a gentle 90° primary curve. Similar to MPA, MPB1 is an end-hole catheter, and MPB2 has an end hole and two side holes.

- **Robert's uterine artery catheter:** Anne Christine Roberts, an American interventional radiologist, designed this unique catheter. It has a long, sharp curve that facilitates access to both uterine arteries. This catheter tapers from 5-F (proximal end) to 4 F (distal end), and it has a soft radiopaque tip.[18]

B) Hemodynamic catheters

The Swan-Ganz, Berman, and reverse Berman catheters are commonly used for pulmonary catheterization and hemodynamic assessment. They are used primarily for the assessment of portal and pulmonary hypertension. Usually, a balloon is attached to the catheter tip, and it can be inflated for measuring, for example, the hepatic and pulmonary capillary wedge pressures. A transducer is placed in the catheter, with which the pressure waveform can be seen on a monitor during catheterization.

- **Swan-Ganz catheter:** This comes in sizes ranging from 60 to 110 cm in length and in calibers of 4 to 8 F. A balloon is proximal to the end hole. It is available with two to five lumens; each lumen has a different function, with the end hole utilized for pressure monitoring.
- **Berman and reverse Berman catheters:** These are available in sizes 4–8 F and in lengths from 50–110 cm. They do not have end holes but have multiple side holes. Since there is no end hole, wedge pressure cannot be measured. In the standard Berman catheter, the balloon is at the distal end and the side holes are proximal, so it can be used for balloon occlusion angiography of the proximal chamber or for measuring wedge pressure. In the reverse Berman catheter, the balloon is proximal (as in the Swan-Ganz catheter), and there are multiple side holes distal to the balloon.

C) Guide catheters

These are special types of catheters that do not taper towards the tip and have a reinforced construction. Table 4 summarizes the basic uses and differences of guide catheters vs. diagnostic catheters. Guide catheters are generally 6 to 8 F in diameter and range from 65 to 100 cm in length. The properties of a guide catheter are determined by its diameter. A narrower guide catheter (e.g., 6 F) requires a smaller puncture and can be engaged deep into the artery; however, it provides less support and torquability compared to a guide catheter with larger diameter. It also limits the size of the device/stent that can be used. A larger guide catheter (7 to 8 F) provides more support, torque, and visualization, and it also allows the use of larger devices. However, this type of catheter also results in an increased use of contrast. The selection of the guide catheter to be used is based on the size of the aorta and the location and ostium of the vessel to be hooked, e.g., renal, right coronary, and MP guide catheters (Figure 7).[15]

D) Special catheters

a) Microcatheters

These are 3 F or smaller in size and are designed for the catheterization of distal vessels. They are placed over a 0.010 to 0.025-in guidewire and are helpful in peripheral intervention for super selectively catheterizing smaller vessels for embolization. The 2.5-F Cantata microcatheter (Cook Medical, Bloomington, IN, USA) has a 0.021-in inner diameter and can deliver particles up to 500 µm in size. A 2.8-F Cantata microcatheter (Cook Medical, Bloomington, IN, USA) has an inner diameter of 0.025 in and can deliver particles up to 700 µm. They can be coaxially used only with catheters with an inner diameter of more than 0.035 in. They have

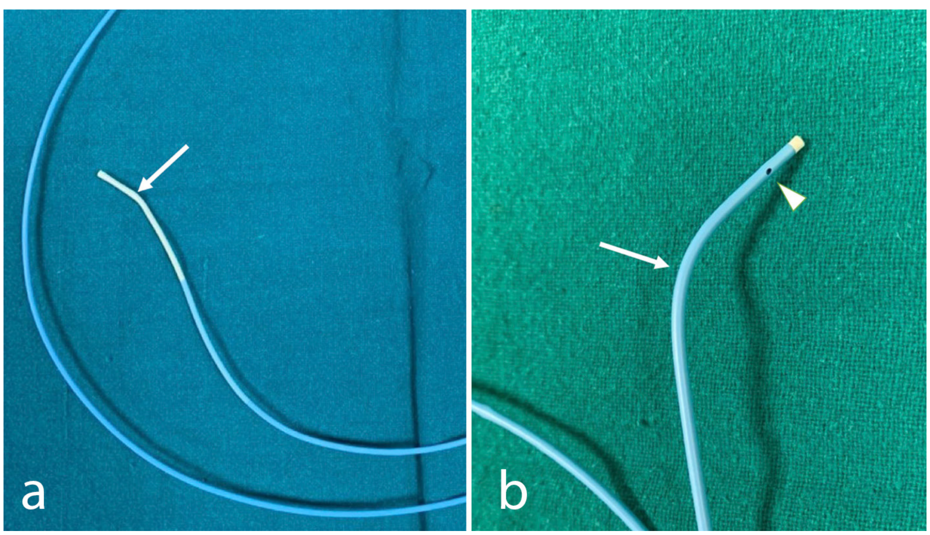

Figure 6. Multipurpose catheter (MPA 1) **(a)** with simple primary curve (arrow) and no side holes. Multipurpose catheter (MPA 2) **(b)** with simple primary curve (arrow) and side hole.

Table 4. Differences between diagnostic catheters and guide catheters

Diagnostic catheter	Guide catheter
Engage arteries	Conduit for device/balloon and wire
Inner diameter small	Larger inner diameter allows for better contrast opacification, better guide support, and enables pressure monitoring
Pressure assessment less accurate than guide catheter	Better pressure monitoring
Only angiographic assessment	Both angiography and supporting diagnostic catheters/balloons/stents
More flexible shaft	Stiffer shaft
Tapered ends (usually), which can cause trauma	Non-tapered ends: atraumatic

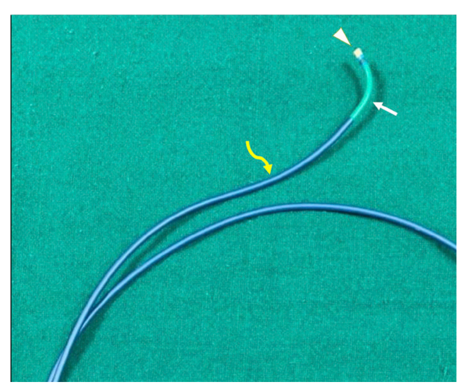

Figure 7. Renal double-curve guiding catheter with non-tapering tip (arrowhead) with primary (white arrow) and secondary curves (yellow curved arrow).

a braided construction for superior control, kink resistance, and trackability, with a radiopaque band for improved visibility. They are lipiodol/dimethyl sulfoxide compatible and have a hydrophilic coating for facilitating the introduction and reducing trauma.[19]

b) Flush catheters

These catheters have one end hole and multiple side holes, which help in minimizing a jet effect that might destabilize arterial plaque or thrombus. They are used for high-pressure injections (up to 1.200 psi), such as those used in aortography and some peripheral arteriography. The shape of the catheter head may be altered dramatically using a guidewire. The main purpose of flush catheters is to achieve an optimum contrast opacification in high-flow large vessels (aorta, IVC) with a minimum amount of contrast.[20]

A pigtail catheter is an example of a flush catheter which is made of polyurethane or polyethylene and has 4–12 non-laterally opposite side holes in the last 5 cm. It is available in sizes 5 to 8 F and in lengths of 65 to 110 cm (Figure 8). The major advantages of this type are that there is no catheter recoiling, it avoids subintimal injection of contrast, it reduces the risk of small-branch vessel catheterization, and its multiple side holes contribute to effective contrast distribution. The loop of the pigtail catheter is designed to prevent the end hole coming in direct contact with the endocardium. Pigtail catheters are atraumatic, with reduced recoil and risk of perforation. Various modified pigtail catheters are available, including Positrol, Nycone, Ducor high flow, Merit, Quanticor, Grollman, and Van Tassel.

c) Balloon (angioplasty) catheters

These are either soft and pliable for use as occlusion balloons or Fogarty balloons (to retract thrombus) or they can be rigid for use in dilatation (angioplasty). Balloons for dilatation can be divided into two main categories: the monorail type (Figure 9), which has a single lumen, with the wire extending proximally, and the over-the-wire type (Figure 10), which has a different lumen for balloon inflation and the wire. There are two properties of these catheters: the rated burst pressure, which is up to and including the pressure at which balloons will not burst upon single inflation, and nominal pressure, which refers to the pressure at which the balloon reaches its labelled diameter.

d) Sizing catheters

These are used to measure the lengths of vascular segments accurately, and they have metal markings on their body at regular intervals. For example, a marker pigtail catheter is used before the deployment of aortic stent grafts (Figure 11).

e) Infusion catheters

These are special catheters used for the infusion of therapeutic drugs during catheter-directed thrombolysis (CDT). These catheters usually have two radiopaque bands at the distal end, with multiple side holes in between for the infusion of drugs. The length is called the infusion length of the catheter. The Cragg-McNamar™ catheter (Medtronic, USA) is widely used for CDT. It is available in 4 and 5-F diameters, with an infusion length varying from 5 to 50 cm. Finally, the MicroMewi infusion catheter (Medtronic, USA) is a micro-infusion catheter available in a diameter of 2.9 F, with an infusion length of 5 or 10 cm.

Principles of selecting a suitable catheter

The principles of selecting a particular catheter depend upon the angle of origin of the target artery and the access site (femoral or brachial/radial). The presence of ostial narrowing precludes the use of high-pressure injection in the diseased part, as it can lead to distal embolization of the clot. A catheter is selected according to the desired direction of travel.

Tip length: Increased length gives more stability in the target vessel at the cost of maneuverability in the parent vessel.

Primary curve: Chosen by assessing the angle of the target vessel from its parent artery.

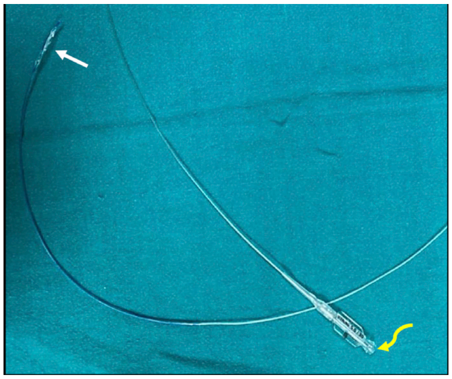

Figure 9. Monorail balloon catheter with the hub having only one inline lumen (curved yellow arrow) for the balloon inflation device with side port for the wire absent. The white arrow shows the tip of the catheter with a deflated balloon.

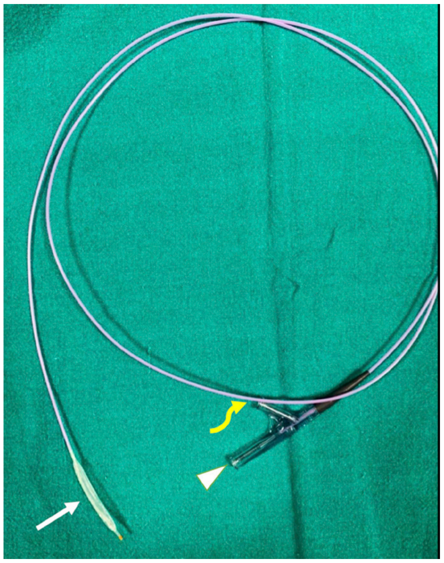

Figure 10. Over-the-wire balloon catheter with the hub having two lumens, the side port (yellow arrow) for the balloon inflation device, and the inline port (arrowhead) for the wire. The white arrow shows the tip of the catheter with a deflated balloon.

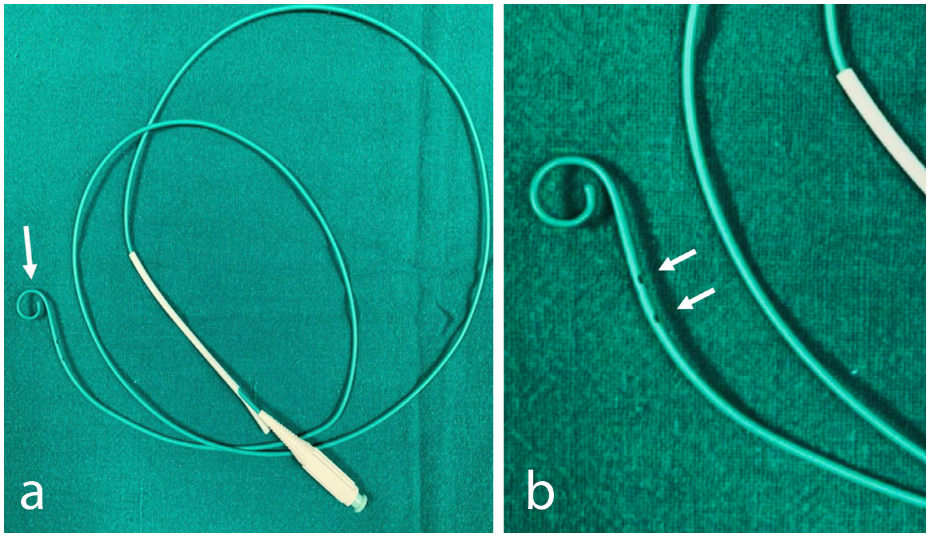

Figure 8. Pigtail catheter **(a)** with a pigtail loop (arrow). Sides are proximal to the pigtail loop **(b)** in the straight segment of the catheter (arrows).

Secondary curve: Chosen by assessing the width of the parent vessel.

Tertiary curve: Chosen by assessing the normal curvature of the parent vessel.

Catheter length: As described earlier (Table 1).

Arch vessel cannulation: The simple curve catheters are preferred in the type 1 aortic arch; however, a complex curve catheter will be required in type 2, type 3, or bovine aortic arches to catheterize a particular branch vessel. A simple curve catheter, such as the Picard catheter (90° primary curve) (Figure 12), or complex double catheters, such as Judkin's right coronary catheter or internal mammary catheter, can be used to cannulate the internal mammary artery depending upon the angle of origin.

The simple curve catheters may not suffice in the brachial/radial approach, and complex curve catheters will be required in most cases.

Visceral vessel cannulation: Chuang[21] proposed the 110 rule for selective visceral artery cannulation; it states that the length of the catheter tip distal to the primary curve and the curve width should be 110% of the native artery at the level of the target branch vessel (Figure 13). The use of specific catheters according to the angle of the origin of the renal artery is discussed in Figure 14. The celiac, superior, and inferior mesenteric arteries usually have <90° angle of origin with the aorta. These can be selectively cannulated with a Cobra or specialized catheter, such as the RC artery catheter.

Handling catheters

The catheter is prepared by flushing and wiping with a heparinized saline solution.[22] It is strongly advised that nothing is to be injected until there is an appropriate blood return. Contrast should be injected to verify the placement of the catheter and ensure that the catheter tip is in a safe position before high-pressure injection is performed. The catheter should be twirled using fluoroscopy to ensure its free movement. Contrast is injected to confirm that it rapidly enters the flow stream rather than staining the wall of the vessel or remaining stagnant. The catheter is removed over a guidewire to straighten its head. Initial catheter placement is performed using bony landmarks or other anatomical signs. After the catheter is in place, it is aspirated for the backflow of blood, flushed with heparin–saline, and connected to the injector (if indicated), meniscus to meniscus. The catheter shape may be changed by heating it with steam, bending it to the required shape, and quickly quenching it in a cold sterile saline solution.

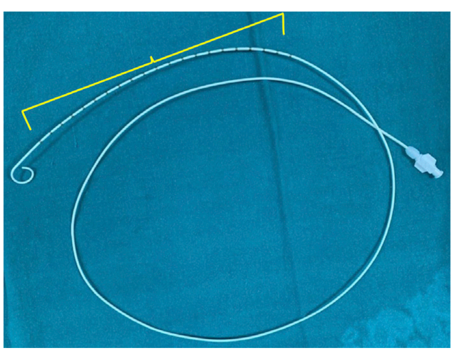

Figure 11. Marker pigtail catheter with platinum markers along the straight segment (bracket).

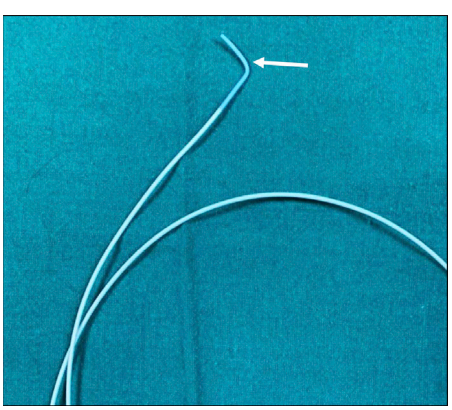

Figure 12. Picard catheter with 90° primary curve (arrow).

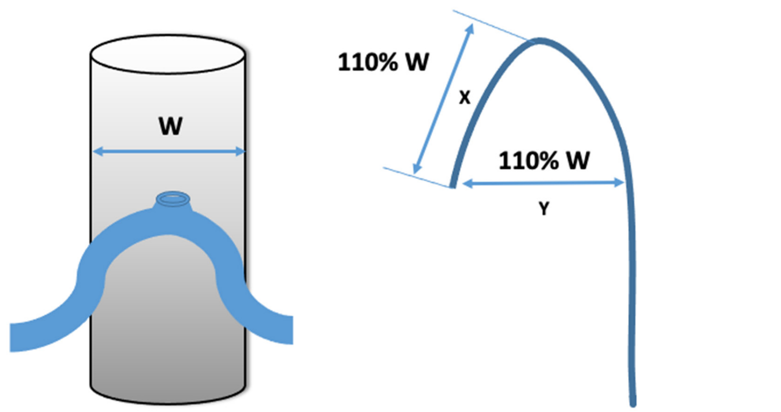

Figure 13. Length of the catheter tip distal to the primary curve (X) and the curve width (Y) should be 110% of the native artery width (W) at the level of the target branch vessel.

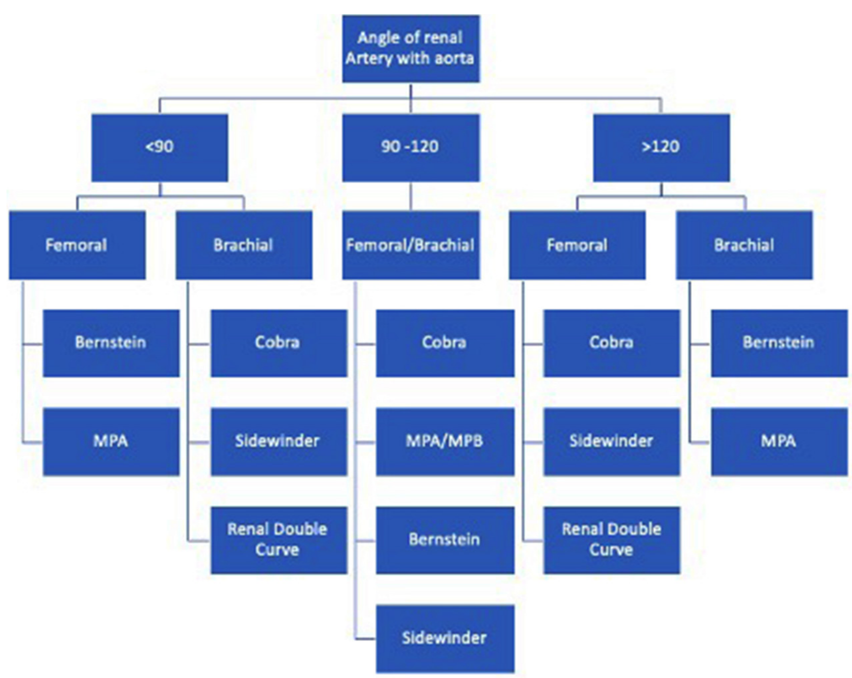

Figure 14. Algorithmic approach for renal artery cannulation.

The method of cleaning and sterilizing catheters is via liquid sterilant or gaseous/ plasma sterilization (or both) to ensure the complete and efficient decontamination of the catheter. The outer surfaces of the catheter and the guidewire lumen of the catheter are cleaned, decontaminated, and sterilized with the liquid sterilant. The filling and draining of the sterilant are conducted until the interior of the catheter's lumen is sterilized.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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