REVIEW ARTICLE

SPECTRUM OF CATHETERS IN NEUROINTERVENTION: A RADIOLOGIST'S PERSPECTIVE

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ABSTRACT

Catheters are an integral part of interventional neuroradiology and have their uses distributed from diagnostic to therapeutic neurointerventions. They are of several types according to shape (e.g Cobra, Headhunter, Simmons etc), size, purpose (Onyx and Glue compatiable), Structure (Balloon mounted, Detachable tip etc). Detailed knowledge about their properties is crucial for deep learning and successful neurointervention. Here we try to provide a comprehensive review of various catheters used in various sections of interventional neuroradiology.
Keywords: Catheters; Neurointervention; Distal Access Catheters; Microcatheters; Balloon guide catheters

ABBREVIATIONS: (OD) Outer Diameter, (ID) Internal Diameter, (PTFE) Polytetrafluoroethylene, (AVM) Arteriovenous Malformation, (PET) Polyethylene terephthalate

Introduction

The word catheter came from a latin word katheter that means to knock down. it's a flexible hollow tube that is inserted into a vessel, duct or body cavity, allowing drainage or injection of fluids, distending a passageway or providing access to endovascular procedures. Catheters are one of the most important materials in endovascular and sometimes nonvascular interventional radiological procedures. They are available in various shapes, sizes and material types according to their specific usage.

Descriptors of a catheter prototype

MATERIALS: The materials to make catheters are usually Teflon (polytetrafluoroethylene or PTFE), polyethylene, polyurethane or nylon. The selection of the fabric has effect on the torque, stiffness, flexibility, thrombogenicity, burst pressure and the friction. Stiffness allows the pushing of the catheter while flexibility allows bending of the catheter to follow the curve of the vessel. High burst pressure measures the strength of the fabric and its ability to resist the high injection rate without bursting.[1] The power of the catheter tip to rotate supported rotation of the catheter hub measures its torque ability. Mechanical braiding of the catheter wall by materials like nylon or chrome steel enhances the torque ability of the catheter and facilitates selective catheterization of vessels. Decreased friction of the catheter material on the luminal surface allows higher flow rates and on the outer surface enables easier advancement of the catheter with minimal buckling and wedging. Catheters is coated by hydrophilic polymers to permit easier trackability, e.g. slip catheter (Cook). Impregnation of the catheter wall with sulphate, tungsten or lead salts is commonly done to extend the fluoroscopic visibility because the catheters are generally faintly radiopaque. Generally, PTFE or nylon catheters are stiffer with high durability and burst pressure and hence are used for purpose of flush injections requiring high flow rates and pressures. In contrast polyethylene catheters are less stiff and more flexible and hence are used for purpose of selective catheterizations.[2]

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PARTS : A prototypical catheter consists of following parts:
(a)Tip the distal tapered part.
(b)Shaft the long tubing.
(c)Hub the proximal part with a plastic funnel for ease in guidewire insertions and attachment of syringes for injections of contrasts.

DIAMETERS AND LENGTHS: The catheters is of varying diameter and lengths. The diameter of the catheter is conventionally measured in French size (F). 3F = 1 mm = 0.038 inches. The catheter size in French refers to the outer diameter of the catheter. It's an element when making a decision the dimensions of the catheter to be used based upon the dimensions of the vessel to be catheterized. the overall use intravascular catheters are commonly of size 4F to 8F.[3] Catheters smaller than 4F don't seem to be used for flush purpose but are required for pediatric use and for selective catheterization of tortuous or smaller intracerebral vessels. They are referred to as microcatheters and are usually of less than or equal to 3F size. Larger catheters of size 7F to 9F are used as guiding catheters and are mainly accustomed guide smaller catheters or devices within them to be used as a co-axial system. The guiding catheters are usually stiffer and firmer to permit passage of balloon catheters, wires and stent delivery system through them. Mild stiffness comes from the wire braided design. For guiding catheters the scale in French refers to the inner diameter of the catheter (like the introducer sheaths). The length of the catheter is that the distance between the hub and therefore the tip. it's conventionally measured in centimeters and frequently varies between 60 to 110 cm for normal catheters. Longer lengths measuring up to 260 cm are required for upper limb, calf, intracranial vessels selective catheterization. The microcatheters are usually of long length as they're to be used co-axially within another catheter and their tips must embark an affordable distance out of the outer catheter.[4]

CLASSIFICATION CONSISTENT WITH SHAPE: Depending upon the form, the catheters are categorized as:

1. Simple straight/angled tip catheters: These have one curve or angle. The curve ranges from slightly curved (multipurpose), to more angled (hockeystick or picard) to completely circular (pigtail). These are either used as flush catheters (pigtail) or to catheterize arteries with angled origins to the direction of catheter like aorta branches (picard).

2. Complex curve catheters: These have quite one curve and are usually used for selective catheterization of branches of the aorta. The curve closest to the tip is the primary curve while the farther curves are called secondary or tertiary curves. The primary curve helps to hook a target vessel at an angle while the secondary curve supports the catheter by touching the opposite wall of the vessel and helps to push the catheter further into the target vessel. These catheters are also of two types:
(i) The primary and secondary curves are within the same direction, e.g. Cobra, head hunter, etc. They're best used for selective catheterization of vessels which have origins angled caudally just like the visceral arteries.
(ii) The primary and secondary curves in opposite direction - Reverse curve catheters, e.g. Simmons (1,2 and 3) catheters. These are best used for selective catheterization of vessels which have steep oblique angle just like the left gastric artery or steep acute angled vessels (sometimes visceral arteries, left-common carotid in bad aortic arch). These catheters are straightened over a guidewire before advancing and their curves must be reformed within the aorta after removal of guidewire. After hooking the target vessel by the tip of the catheter over a guidewire, these catheters are advanced into the vessel till the extent of apex of secondary curve by partial withdrawal of the catheter at the groin (instead of pushing as exhausted all standard forward curve catheters). Only after now the catheters may be further pushed into the vessel by advancing over a stiff guidewire. These catheters should be withdrawn after straightening over a guidewire under fluoroscopic monitoring.[5,6]

PER NUMBER OF HOLES: Depending upon the position and number of holes, the catheters are divided into two types:

1. End hole catheter: These are the quality diagnostic catheters which have one hole at the tip of the catheter. the dimensions of the outlet is tapered to permit the

most allowable sized guidewire to only undergo it snugly. These are used for selective catheterization. It can cause plaque dislodgement and dissection under pressure and so it is not used with pressure injectors.

2. Side hole catheters: The side holes are usually multiple with an end hole. These catheters are used as flush catheters to get angiograms of huge vessels. The side holes vary in number with typical pigtail flush catheter having 8 to 12 side holes. Though the scale of a side hole is smaller than the scale of the top hole (to prevent exiting of guidewire through this hole), the combined size of the side holes is larger than the tip hole allowing much larger volume of contrast dispersal through these holes than the top hole. They are also used for thrombolysis as they lead to uniform distribution of the thrombolytic within the thrombus. However, these catheters aren't used for embolization because the embolising agents may either diffuse out through these holes leading to nontarget embolization or may occlude the tip hole at the tip because of lesser pressure delivered at the tip. The embolising coils can also get struck within the side holes.[7]

CLASSIFICATION IN KEEPING WITH USE:

A.DIAGNOSTIC CATHETERS: (Fig.1)
The commonly used diagnostic catheters are:[8]

1. Vertebral Catheter: it's 45 degrees angulated tip. most typically used catheter in diagnostic neuro-angiography.

2. Multipurpose: it's straight tip. It can have end hole which is employed for selective catheterization of small vessels or in pediatric patients. The side holes multi-purpose catheter is employed for flush injections insmaller vessels which cannot accommodate the loop of pigtail catheter.

3. Picard: It's an end hole catheter with tip angled at obtuse shape (100 degree). it's commonly wont to selectively catheterize forward facing angled origin vessels just like the arch vessels.

4. Cobra: It's an end hole catheter with a double curve shape and is often used for selective catheterization of visceral vessels. it's available in three different curve shapes C1, C2 and C3 with C2 being the foremost commonly used.

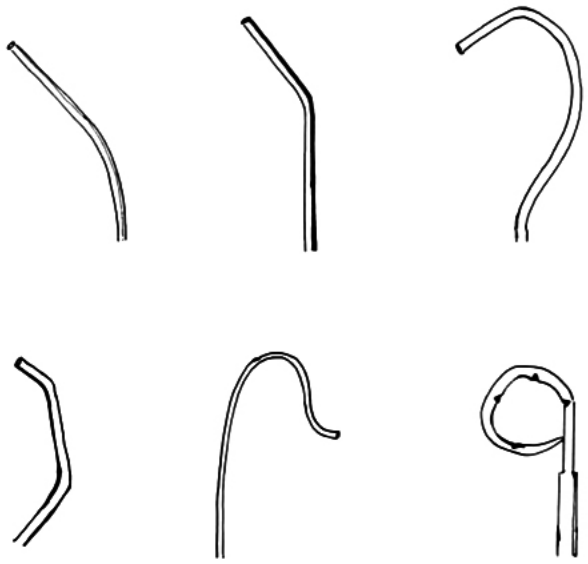


Figure 1: Schematic Diagram depicting tip Shapes of Various Diagnostic Catheters: Upper row from Left to Right- Multipurpose catheter,Vertebral Catheter, Cobra; Lower row from Left to Right- Headhunter, Simmon s, Pigtail catheter.

5. Head hunter: It's three curves. it's used for selective catheterization of the top and neck vessels.

6. Simmons: These are reverse curved catheters which are available in three curve shapes S1, S2 and S3 with increasing length of the curved segment. they're accustomed catheterize vessels with very acute or obtuse angled origin.

7. Pigtail: It's a multiple side hole and end hole catheter with a circular shape and is employed for flush injections in large lumen vessels like aorta. The pigtail shape prevents direct intimal injury and ensures much less recoil of catheter after forceful injection of contrast through a pressure injector. It's also commonly used for drainage of collections because it gets secured within the cavity.

Glidecath Terumo: These are catheters with a special hydrophilic coating to extend their pushability within the vessel. they'll be of varied tip shapes from straight to curved and might be single or double braided.

Imager II Angiographic Catheter (Boston Scientific): These are designed to provide a pathway for delivering contrast media to selected sites in the vascular system, including the carotid arteries.

B.CATHETERS EMPLOYED IN THERAPEUTIC NEUROINTERVENTIONS:

They can be broadly classified into distal access catheters, guiding catheters, micro catheters, and balloon catheters.[9]

1. DISTAL ACCESS CATHETERS:

(a) Phenom PLUS (Medtronic): It has been designed to aid in ease of accessing various tortuous anatomy in the neurovasculature. It has coiled distal, coiled and braided mid- and dual-braided composite shaft for superior pushability. Its 4.2F Distal OD is aimed for a low profile and highly trackable support system.

(b) The React 68 catheter and the React 71 catheter (Medtronic): They feature a coil and braid design along with end-to-end nitinol construction - easing navigation to the M1 and M2 segments. Combined with the Riptide aspiration system, these catheters are designed to revascularise patients experiencing acute ischemic stroke.

(c) RIST RADIAL ACCESS SYSTEM (Medtronic): It has atraumatic tip with 6cm nitinol round wire coil, gradual transition zone, stiffer support zone and flexible distal zone for optimum distal trackability.

(d) AXS Catalyst (Stryker): The AXS Catalyst 5 Distal Access Catheter (OD 5F; ID 0.058 in.: Length 132 cm)is a single lumen, variable stiffness catheter designed for use in facilitating the insertion and guidance of appropriately sized interventional devices into the peripheral and neurovascular system. The catheter shaft has a hydrophilic coating to reduce friction during use. The catheter includes a radiopaque marker on the distal end for angiographic visualization and a luer hub on the proximal end allowing attachments for flushing and aspiration. It is packaged with a Rotating Hemostasis Valve (RHV) and Tuohy Borst valve with sideport for flushing, insertion of catheters and aspiration. The peel away introducer sheaths are designed to protect the distal tip of the catheter during insertion into the RHV or Tuohy Borst. It is compatible with Excelsior microcatheter. The catheter is some what more trackable distally and less likely to kink or ovalize compared too ther distal access systems. However it has limited size and length options. The AXS Catalyst 6 (CAT 6) Distal Access Catheter (OD 6F; ID 0.060 in.: Length 132 cm) is fully compatible with FlowGate 8F Balloon Guide Catheter, and optimizes Trevo XP Pro Vue Retriever deliverability and clot retrieval capability.10 (Fig.2)

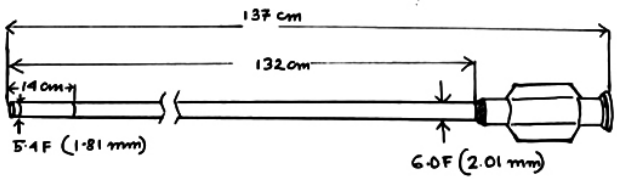


Figure 2: Schematic example of a distal access catheter- AXS catalyst.[10]

(e) SOFIA and SOFIA Plus Catheters (Microvention): The newly designed SOFIA (Soft torqueable catheter Optimized For Intracranial Access, Micro Vention, Tustin, California, USA) Plus catheter obtained CE mark approval in Europe in February 2015. It has a hybrid braid-coil design and is available in two different lengths (125 cm or 131 cm) with an outer diameter of 6F and an inner luminal diameter of 0.070 inch from distal to proximal zones. Braid overlay provides excellent torque response to bypass difficult bifurcations. Hybrid braid and coil reinforcement provides superior push response. The catheter tip has a straight configuration but is steam shapeable. Guiding Sheath or Balloon Guide Catheter needs at least 0.085" ID for SOFIA PLUS to fit through it. The SOFIA Plus Catheter is designed for aspiration thrombectomy and offers an ideal combination of excellent distal trackability and a large 0.070" lumen to help with rapid recanalization of the affected vessel. Its lubricious coating and smooth catheter transitions allow for easy access to MCA and beyond. It can track through tortuous distal bends without kinking. Compared with other aspiration catheters, it has the largest distal inner luminal diameter (0.070"), and, therefore, offers a higher aspiration flow rate and a greater force of aspiration at the tip of the catheter - thereby enabling faster recanalization.[11] (Fig.3)

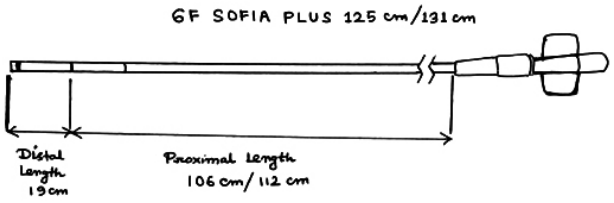


Figure 3: Schematic diagram of a Distal Access Catheter- SOFIA PLUS.[11]

(f) BENCHMARK BMX96 Access System (Penumbra): It has 6F OD, 0.071 in. (~5.4F) ID, it comes packaged with a curved Neuron Select catheter, desired for smooth access over a hydrophilic wire. Its advantages are: Large lumen, able to accommodate two microcatheters (e.g., ideal for balloon remodeling) and permits good angiograms with even larger microcatheters in position. With large lumen and reasonable stability, it is a good option for most interventional procedures. It has some disadvantages that it acts somewhat more stiff, navigable less distally than the smaller Neuron. Benchmark can be exchanged into position, but often using the inner Neuron Select it may be positioned primarily in the vessel of interest. It is available in two lengths: 95 and 105 cm in straight or multipurpose curve and corresponding Neuron Select is available in 120 or 130 cm lengths.

(g) The Neuronfi Intracranial Access System: These hybrid catheters have progressive suppleness with a 6 F OD supportive proximal catheter and a soft distal segment. They can often be used without additional support. Distal end is of 5F OD and 3.9F ID and it comes in straight and angled shapes. They are extremely soft and flexible and are able to be positioned within the very distal intracranial ICA or vertebral artery. However, they are less stable than other catheters and very slippery. They can be pushed out of the access vessel if the catheter is not in a distal-enough position. Only the distal tip is radiopaque; the radiolucent shaft can be difficult to see on fluoroscopy. Narrow lumen makes for limited-quality angiograms with a micro-catheter in position. Usually must be exchanged into position. Two lengths are available: 105 cm (for most patients) and 115 cm (for patients >6 ft. In height). Two distal flexible zone lengths are available: 6 cm (for most cases) and 12 cm (for cases in which a very tortuous ICA or vertebral artery must be traversed, e.g., a cervical ICA with a 360 loop). A standard hydrophilic wire is used for initial positioning of the Neuron . Coaxial microcatheter technique for final positioning of the Neuron 0.053 catheter is when one advances a micro-catheter over a microwire through the Neuron into the target vessel distal to the desired final position of the guide catheter. Then the Neuron over the microcatheter is advanced to its final position. A more substantial microcatheter such as a Velocity R(Penumbra, Inc., San Leandro, CA), Renegade R (Stryker Neurovascular, Fremont, CA), or ProwlerR Plus (Codman Neurovascular, Raynham, MA) with a substantial 0.016 in. Guidewire can provide good support to facilitate distal placement of the Neuron . The more distal the tip, the more stable the Neuron will be; for example, one should position the tip in the horizontal segment of the petrous ICA or the V4 segment of the vertebral artery for maximum stability. Optimal positioning is distal to at least two 90 turns in the vessel to provide sufficient support for the coaxial placement of a microcatheter. Guide catheter angiograms may be of marginal quality when a microcatheter is inside the guide catheter, because of the relatively narrow lumen. Injection of 100% contrast ina 3 mL syringe, rather than a 10 mL syringe, will produce better angiograms. The Neuron 053 will accept most microcatheters, but it may be difficult to inject contrast around 18-system or larger microcatheters like the Excelsior XT 27R or Prowler R Plus. However, when the Neuron is in its final intracranial position, use caution when flushing or injecting contrast. Use smaller volumes and lower pressures since the pressure is transmitted directly to the intracranial vessels. This can be particularly dangerous if there is an aneurysm near the catheter tip. Avoid using a power injector while a microcatheter is in the Neuron .

Neuron MAX 088 Large Lumen Catheter (Penumbra Inc): Large catheter, available either as a long sheath (for use like the Cook Shuttle R) or as a guide catheter. The 4 cm distal tip is softer and more flexible than the Cook; available in 80, 90, and 100 cm lengths. One has to obtain access to the target vessel (carotid or vertebral artery) with a diagnostic catheter first and then exchange the MAX 088 into position over an exchange-length hydrophilic wire. The MAX 088 comes with an inner dilator. A 6F

Neuron Select curved catheter can also be used within it.[12] (Fig.4)

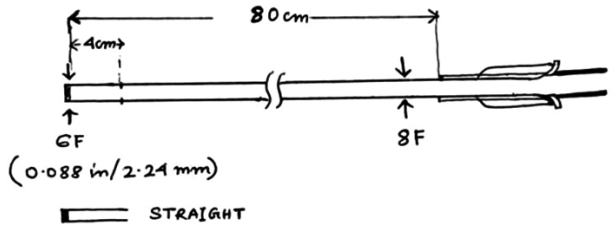


Figure 4: Schematic diagram of Neuron Maxx 088 long sheath.[12]

(h) The Penumbra 5MAX and 4MAX Distal Delivery Catheters (DDC) are designed to simplify therapy delivery to the most distal, tortuous anatomy. The tapered inner shaft maximizes the effective flow lumen to facilitate exceptional angiographic road mapping. These catheters are offered in three lengths, enabling a wide variety of device compatibility.

(i) Titan Catheter System (Balt): They are aspiration Catheter Systems, indicated for injection of intravascular fluids, the introduction of interventional devices into the peripheral & neuro vasculature, and/or aspiration of soft emboli and thrombi from the arterial system, includingthe peripheral and neuro vasculature. The TITAN 036 Catheter is indicated for general intravascular use, including the neuro and peripheral vasculature. It can be used to facilitate introduction of diagnostic and therapeutic agents. It is not intended for use in coronary arteries. The TITAN 070 Catheter is indicated for injection of intravascular fluids, the introduction of interventional devices into the peripheral and neuro vasculature, and removal/aspiration of soft emboli and thrombi from the arterial system, including the peripheral and neurovasculature. The TITAN Catheter System Kit is indicated for injection of intravascular fluids, the introduction of interventional devices into theperipheral and neuro vasculature, and removal/aspiration of soft emboli and thrombi from the arterial system, including the peripheral and neuro vasculature. The ballast 088 Long Sheath is indicated for the introduction of interventional devices into the peripheral, coronary and neuro vasculature. Catch+ and Catchview are designed for use in the flow restoration of patients with ischemic stroke due to large intracranial vessel occlusion. They are indicated to restore blood flow in the neurovasculature of patients who are ineligible for intravenous tissue plasminogen activator (IV t-PA), who fail IV t-PA therapy or as a supplement treatment of initiated IV t-PA therapy. They have unique design to optimize the balance between lumen diameter, proximal support & distal trackability; 12 transition zones to maximize the distal zone flexibility, Hydrophilic coating on 90 cm, available in kit together with .070 & .036 designed to ease navigation in the ophthalmic region and better track distally.

(k) DAC catheter (Stryker):

DAC™ 038	OD 3.9F, ID 0.038 in.: Lengths 125 and 136 cm;
DAC™ 044	OD 4.3F, ID 0.044 in.: Lengths 115, 130 and 136 cm;
DAC™ 057	OD 3.9F, ID 0.057 in.: Lengths 115 and 125 cm;
DAC™ 070	OD 3.9F, ID 0.070 in.: Lengths 105 and 120 cm

They are very soft and flexible, and can be advanced safely in tortuous vessels to a distal location to support the working microcatheter. Available in a variety of sizes and lengths. When used in procedures requiring use of multiple microcatheters such as AVM embolization, the distally placed DAC greatly facilitates and speeds repeated access of the distal vessels. Very floppy catheter is not supportive unless advanced quite distally around several turns and also requires proximal support from a guiding catheter or guiding sheath. Catheter may advance so distally in smaller vessels that it may be occlusive. If the chosen DAC is too long the microcatheter advanced through it may not be long enough to reach the desired location. Requires an additional pressurized saline infusion line. When the guide catheter is in position, one should advance a microcatheter over a microwire through the DAC and into the target vessel distal to the desired final position of the access catheter. Then one should advance the DAC over the microcatheter to its final position.[10] A more substantial microcatheter such as a Velocityfi (Penumbra, Inc., San Leandro, CA), Renegadefi (Stryker Neurovascular, Fremont, CA), or Prowlerfi Plus (Codman Neurovascular, Raynham, MA) with a beefier 0.016 in. guidewire can provide good support to facilitate distal placement of the DAC.

2.GUIDING CATHETERS:

(a) Chaperon (Microvention): Typical sizes used

are 5 and 6 F. (Respective internal diameters: 0.059 and 0.071 in; Available lengths: 95 cm.) Their advantages are that they have thin wall profile, so 6 F version has slightly larger inner lumen than some of the other 6 F competitors. Also they have good torque control. Thay comes with dedicated inner selective catheters for coaxial method. However, while they offer a relatively stable position, they are not as stable as some of their competitors.(Fig.5)

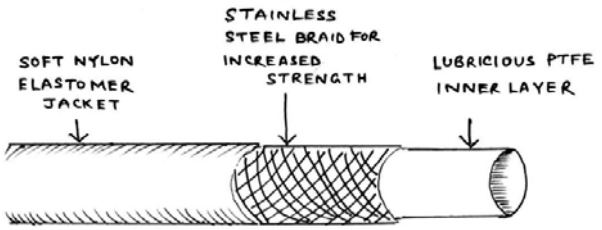


Figure 5: Layers of a Guide Catheter: A Schematic Diagram.

(b) Mach 1 Guide Catheter (Boston Scientific): They are Available in 6F (0.070"), 7F (0.081") and 8F (0.091") sizes. Its advantages are that they have unique polymer, softer shaft, enhances back-up support and curve retention, has large lumen design, offers the device compatibility needed for a multitude of treatment options and treatment scenarios, enables catheter downsizing, provides improved dye flow for better visualization.

(c) Rubicon Support Catheter (Boston Scientific): It has good visibility due to three radiopaque markers offer; Contrasting purple tip simplifies wire backloading and clear shaft provides visibility of bleedback.[13] (Fig.6)

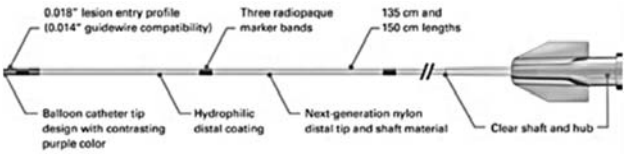
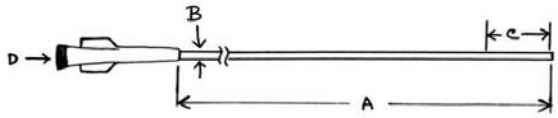


Figure 6: Schematic Diagram of Rubicon: A support catheter.[13]

(d) NAVIEN A+ Intracranial Support Catheters (Medtronic):

Navien™ 058	OD 5.2F; ID 0.058 in.: Available in 105, 115, 125, and 130 cm lengths.
Navien™ 072	OD 6.3F; ID 0.072 in.: Available in 95, 105, 115, 125, and 130 cm lengths.

It is also available with 25-degree angled tip. They are very soft and flexible, can be advanced quite distally, somewhat more supportive than DAC catheters. Multiple sizes are available. However, floppy proximal segment requires support with a guiding sheath. Fewer size options compared to DAC catheter. When the guide catheter is in position, one should advance a microcatheter over a microwire through the Navien and into the target vessel distal to the desired final position of the access catheter. Then they should advance the Navien over the microcatheter to its final position. A more substantial microcatheter such as a Marksman (Medtronic PLC, Minneapolis, MN) with a beefier 0.016 in. guidewire can provide good support to facilitate distal placement of the Navien. It has been designed for optimal support and minimal ovalisation in mechanical thrombectomy procedures or aneurysm treatment as well as arteriovenous malformation/arteriovenous fistulas (AVM/AVF) treatment. Its large ID for 5F or 6F allows device and microcatheter manipulation when using different combination for: Liquid embolic system, flow diversion device and coiling, contrast run, balloon-assisted coiling, removal/aspiration of fresh, soft emboli and thrombi, stent-assisted coiling etc.[14] (Fig.7)



A – 115cm (Usable length)	B – OD = 5F
C – 8 cm (Flexible distal length)	D – ID = 0.058"
Radioopaque Tip Marker at the tip	Straight tip type
0.038" (0.97mm)	

Figure 7: Schematic diagram of Navien Intracranial Support Catheter

(f) Penumbra JETfi 7 and Penumbra JET D, ACE, MAX Reperfusion Catheters: The Reperfusion Catheters and Separators are indicated for use in the revascularization of patients with acute ischemic stroke secondary to intracranial large vessel occlusive disease (within the internal carotid, middle cerebral - M1 and M2 segments, basilar, and vertebral arteries) within 8 hours of symptom onset.

(g) Penumbra Systemfi MAX Reperfusion Catheters: They are intended for use in the revascularization of patients with acute ischemic stroke secondary to large vessel occlusion disease. The 3MAX and 4MAX Reperfusion Catheters feature

advance tracking technology that allows access over a solo guidewire for ease of use. The 5MAX Reperfusion Catheter offers a combination of advanced tracking technology with a larger lumen. The MAX Reperfusion Catheters are part of the Penumbra System and intended for use with Penumbra ENGINE aspiration source and Hi-Flow Aspiration Tubing.

(h) Envoyfi DA Guiding Catheters (Codman Neuro, Raynham, MA): They have OD 6F, ID 0.071 in.: Available in 95 and 105 cm lengths. Available in straight and multipurpose tips. Also available in Envoy DA XB with a stiffer distal segment when added support is needed. They have large lumen, can accommodate multiple microcatheters and somewhat more supportive than other hybrid guiding/distal access catheter systems. However, stiffer distal segment may not allow safe access as distally as other catheter systems, they have limited size and length options. Radio-opaque distal marker is located proximal to the actual tip. The technique is similar to Neuron catheters.

(i) Cerebase DA Guide Sheath (Cerenovus): It is indicated for the introduction of interventional devices into the neurovasculature. It is designed for atraumatic vessel interaction with soft, compliant, and rounded distal edges and a highly flexible Dexterous tip that can minimize direct vessel wall contact.

(j) EMBOVAC Aspiration Catheter (Cerenovus):
It is a single lumen, variable stiffness catheter. The catheter has a hydrophilic coating to reduce friction during use.
The catheter includes a radiopaque marker on the distal end for angiographic visualization and a luer hub on the proximal end allowing attachments for flushing and aspiration. A hemostasis valve and two peelable introducers are included in the package. It is indicated for general intravascular use in the neuro vasculature. The catheter can be used to facilitate introduction of diagnostic or therapeutic agents and is also intended for use in removal/ aspiration of emboli and thrombi from selected blood vessels in the neuro vasculature.

(k) Fargo Mini, FARGO 058 and Fargo MAX (Balt Extrusion, Montmorency, France): These are CE mark approved, but not available in the United States.

Fargo	6F OD 6.0F, ID 4.2F; Available in 105, 115, 125, and 135 cm lengths and in straight or pre-shaped multipurpose curve.
Fargo MAX	OD 6.0F, ID 5.3F; Available in 105, 115, and 125 cm lengths and in straight or pre-shaped multipurpose curve.

Fargo Mini: Nitinol inner braiding struts; OD: 4,2F (140mm) proximal end; 3,9F (130mm) distal end suppleness with extra supple distal part; Used for Distal Navigation For Distal Stability: To control the microcatheter s tip For Distal High Flow road map inside a 6F guiding catheter (.070).

FARGO 058 [OD: 6F (2mm) proximal end; 4.9F (1.63mm) distal end]: It is used when the standard guiding catheter is not stable enough, together with a long introducer and the VASCO+21 for SILK+ casesto pass the carotid syphon or up to the basilar artery. With extra-supple distal part, they are made to pass through acute curves & has hydrophilic coating. They demonstrate good stability and support to tight braiding on distal part, and wide braiding on proximal part. They have good visibility due to its radiopaque shaft at the end of the distal part.

FARGOMAX (ID:1.78mm/.070 /5.3F):For remodeling balloon assisted coiling procedures with VASCO+10 and ECLIPSE or COPERNIC.
Also used together with a long introducer and the VASCO+21 for your SILK+ cases and for high flow road maps.

FARGOMAX 070: OD: 6F (2mm) proximal and distal ends, it provides support with extra-supple distal part.It has large ID 1.78mm (0.070) to fit both a balloon-tipped microcatheter (ECLIPSE or COPERNIC) and a coiling microcatheter (VASCO+10).

(l) Lumaxfi Guiding Catheter (Cook): The device comes packaged with inner dilator, which provides a smooth transition to the guidewire, minimizing trauma to vessel wall. Dilator also allows the catheter to be introduced without a groin sheath. Relatively rigid, providing stability. Disadvantages: Relatively stiff distal tip. Extremely lubricious catheter can slip out of tortuous vessels.

(m) Softip XF guide catheter (Stryker): It has soft atraumatic tip. Minimizes risk of vasospasm and dissection in small, tortuous vessels. Available angled tip allows it to be navigated into position primarily. Disadvantages: Relatively flimsy and prone to fall in the arch when the vasculature is tortuous.[11]

3. MICROCATHETERS:

(a) Phenom 17, 21, 27 microcatheters (Medtronic): It comes with Low coil delivery four different tip shapes: straight, J, 45 and 90 to enhance distal accessibility. Designed for low coil delivery force, large inner diameter and small proximal OD. It has OD 3F proximal, 2.7F distal, ID 0.027 in.It is a microcatheter with beveled and polished distal opening for more optimized delivery of Pipeline Flex and comes in 15 cm or more flexible 30 cm distal segment.

(b) Rebar reinforced micro catheter 18 & 27 (Medtronic): It is a single-lumen catheter introduced via a steerable guidewire into the vasculature. Its stainless-steel construction, high kink resistance, and hydrophilic coating help navigate tortuous anatomy and deploy therapeutic agents or contrast media with ease. It has a semi-rigid proximal shaft that transitions into a flexible distal shaft, standard luer adapter at the proximal end, distal radiopaque marker for fluoroscopic visualisation, lubricious hydrophilic outer coating to navigate tortuous vessels and reduce resistance and PTFE inner liner for the passage and deployment of embolic devices and agents. It is DMSO compatible. Its steam-shapeable catheter tip through the use of a mandrel enables treatment of super selective vessels.

(c) The Apollo Onyx delivery micro catheter (Medtronic): It is intended to access the neuro vasculature for the controlled selective infusion of the Onyx liquid embolic system. It has straight tip, usable length of 165 cm, and it has detachable tip length of 1.5 cm and 3 cm. The detachment force is about 33 grams and there will be no reflux proximal to the proximal marker. When in action, LDPE and proximal marker band retrieve with proximal portion of the catheter and the distal tip remains within Onyx liquid embolic system cast.15 (Fig.8)

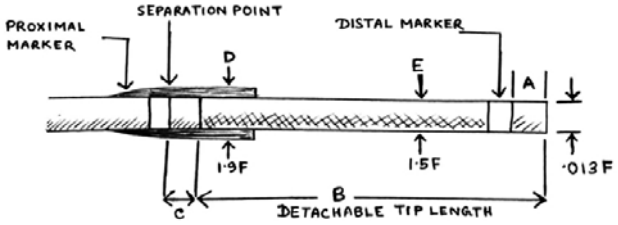
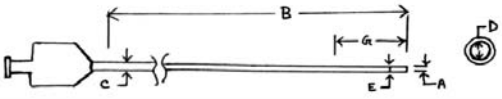


Figure 8: Schematic Diagram of The Apollo Onyx delivery microcatheter

(d) The Marathon flow directed microcatheter (Medtronic): It was designed for the infusion of therapeutic agents such as embolization materials and contrast media in tortuous, distal vessels. It has straight tip and usable length of 165 cm.[16] (Fig.9)



A – 1.5F, 0.51mm	B – 165 cm
C – 2.7F, 0.91mm	D – 0.013 in, 0.33mm
E = 1.5F, 0.51mm	F = 0.23ml (minimum dead space)
G – 25 cm (Distal Length)	H = 0.053 (1.35mm) compatiable Guiding catheter ID

Figure 9: Schematic diagram of the marathon flow directed microcatheter

(e) Marksman (Medtronic): Here microcatheter s coil and braid technologies combined produce a catheter that resists ovalisation in tortuous anatomy, to deliver optimised proximal support and distal flexibility for minimal friction during Solitaire Platinum stent delivery. It can be used during a tri-axial approach to deliver a stent retriever. It has OD 3.2F proximal, 2.8F distal, ID 0.027 in and comes in 105, 135, 150, and 160 cm lengths. It is a robust microcatheter which is resistant to ovalization. It is useful for NeuroformR EZ (Stryker, Fremont, CA) stent and Pipeline flow diverter(Medtronic, Minneapolis, MN) deployment.

(f) ECHELON Microcatheter (Medtronic): It is a DMSO compatibleend hole, single-lumen catheter designed to be introduced over a steerable guidewire into the vasculature. The proximal end of the catheter incorporates a standard luer adapter to facilitate the attachment of accessories. The catheter has a semi-rigid proximal shaft which transitions into the flexible distal shaft to facilitate the advancement of the catheter in the anatomy. Dual radiopaque markers at the distal end facilitate fluoroscopic visualization. The outer surface of the catheter is coated to increase lubricity.

It is intended to access peripheral and neuro vasculature for the controlled selective infusion of physician-specified therapeutic agents such as embolization materials and of diagnostic materials such as contrast media, especially during aneurysm coiling. It has OD 2.1F proximal, 1.7F distal, ID 0.017 in. The small proximal outer diameter of 2.1F (versus 2.4F for the ExcelsiorR SL-10) permits better guide catheter angiograms when a 5F guide catheter is used. Nitinol wire braiding produces a stable platform in spite of its small diameter.

(g) The Excelsior SL-10 Microcatheter (Stryker): It comes with thin-wall technology and lubricious Hydrolenefi outer surface is designed to provide versatility in performance. It has 7F (0.60mm) Low profile distal shaft, atraumatic distal tip and comes with six different clinically relevant shapes. It has OD 2.4F proximal, 1.7F distal, ID 0.0165 in, can be used for 10- and 14-system coils. It retains its shape better after steam-shaping than other microcatheters of the same size. Its polished tip less likely to hang up on side branches or if advancing through a stent compared with other microcatheters.[17]

Excelsiorfi XT-17 (Stryker Neurovascular, Fremont, CA): It has OD 2.4F proximal, 1.7F distal, ID 0.017 in. It is comparable to SL-10 but more support for greater stability.

Excelsiorfi 1018fi (Stryker, Fremont, CA): It has OD 2.6F proximal, 2.0F distal, ID 0.019 in. It is a versatile microcatheter can accommodate 10-, 14-, and 18-system coils. It is also good for particle embolization- the large inner diameter minimizes risk of clogging.

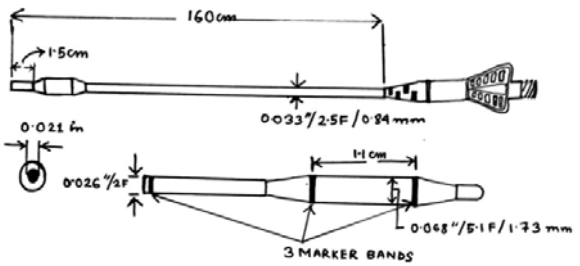
(f) Headway (Microvention):
It has hydrophilic Coating, round and shapable tip. Tapered PTFE Liner with Coil Reinforcement allow true 1:1 push/pull control, tight-pitch coil reinforcement resists ovalization while maintaining maximum flexibility. Tight pitch coil wind resists, kinking and ovalization, while maintaining maximum flexibility. PTFE Liner provides lubricious, yet durable inner, liner for smooth stent delivery. It has robust catheter body and offers enhanced resistance to stretching and elongation while delivering stents or other less flexible devices.

Headway DUO: Used for Balloon/Stent Assisted Coiling, Liquid Embolic/Coils Combined Therapy AVF.

(g) Ultraflow (Medtronic Neurovascular, Minneapolis, MN): It has OD 3.0F proximal, 1.5F distal, ID 0.012 in. It is Flow-directed, small-caliber, flexible microcatheter and compatible with DMSO for OnyxR embolization.

(h) VIA (Microvention): Used to deploy WEB intra-aneurysmal flow disruptor device.

(i) Wedge (Microvention): Improves SOFIAfi 6F Catheter Navigation Past Tortuous Anatomy. The Wedge Microcatheter was specifically designed for use with the SOFIA 6F 0.070 Catheters, is compatible with the Traxcess 14 Guidewire and guidewires with OD of 0.014 - 0.018". It is meant for easier passage through ophthalmic and MCA/ACA bifurcations; The bulb segment s enlarged outer diameter is designed to reduce ledge effect with the SOFIA 6F Catheter.[18] (Fig.10)



ID	Tip Shape	Catheter Length	Tip Length	OD Distal	OD Proximal	Bulb Working length	Bulb Max OD	Tip Markers
0.021"	Straight	160 cm	1.5cm	0.026" 2.0 F 0.67mm	0.033" 2.5F 0.84mm	1.1cm	5.1F 1.73mm	3

Figure 10: Schematic diagram of wedge microcatheter[18]

(j) Velocityfi Delivery Microcatheter (Penumbra): It is designed to deliver the 3D Revascularization Device which features advanced intraluminal chambers designed to lock and trap clot, and to facilitate the coaxial delivery of specific Penumbra Reperfusion Catheters.

(k) The PX SLIM Delivery Microcatheter: It is engineered for trackability and support when delivering Penumbra s large-volume coils (PC400 , POD400 & PAC400).

(l) Prowlerfi Select Plus (Codman, Raynham, MA) It has OD 2.8F proximal, 2.3F distal, ID 0.021 in. It is a large microcatheter, intended for use with the Enterprise Vascular Reconstruction System (Codman, Raynham, MA). It is available in 150 or 170 cm lengths.[19] (Fig.11)

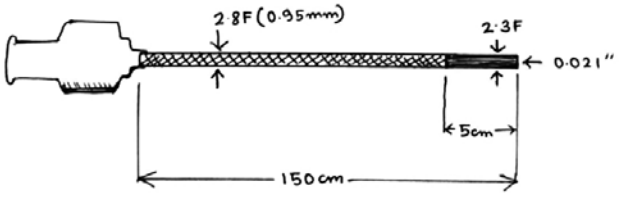


Figure 11: Schematic diagram of prowler select plus microcatheter[19]

(m) Vasco Microcatheter (Balt): It has double progressive step braiding on the entire microcatheter length, and gives maximized stability, high kink resistance and flexibility. Moreover, the VASCO+ s gradual suppleness associated with the hydrophilic coating increases its navigation performance.

VASCO+10MH: It has additional RX marker at 5 mm of the distal tip and assists the positioning of coils at the aneurysm s neck, helps choosing the best next coil, helps with the sizing of the coils, helps teaching coil delivery.

(n) Sonic Detachable Tip Microcatheter (Balt): Detachable tip braided microcatheter, compatible with DMSO. All SONIC are provided with a hybrid guide-wire.

(o) Gama Microcatheter (Balt): It has compatibility with devices frequently used during intravascular procedures: Flow diverter: silk vista baby, Stent: leo+ baby, Stentriever: catch+ mini & catch view mini, Coils: optima, it also has compatibility with DMSO and is supplied with a shaping mandrel and a pass valve.

(p) Magicfi infusion microcatheter (AIT-Balt, Miami, FL):

MagicR 1.8	OD 2.7F proximal, 1.8F distal, ID 0.012 in.
MagicR 1.5:	OD 2.7F proximal, 1.5F distal, ID 0.010 in.
MagicR 1.2	OD 2.7F proximal, 1.2F distal, ID 0.008 in

It is by far, the most flow-directed microcatheter of them all. The catheter is only compatible with nBCA. Both MagicR 1.8 and 1.5, available in 155 cm and 165 cm lengths. MagicR 1.2 available in 165 cm length only, but choice of 3 or 12 cm length of distal floppy segment. Magic, Ultraflow and Marathon are useful microcatheters for AVM cannulation.[15]

4. Balloon Catheters: These are catheters with a balloon mounted on them near their distal end. These are used for dilatation of a stenosed vessel, i.e. angioplasty or during blocking the flow of a vessel e.g: during mechanical thrombectomy or physiological stress tests or during coiling of wide neck or bifurcation aneurysms.[16,17] The balloons used in interventional neuroradiologicalcathlab are of two types:

(i) Noncompliant, high pressure balloons: They provide greater dilating force than analogous compliant balloons. These balloons aretypically fabricated from polyethylene terephthalate (PET). They mustn't be used on calcified plaques or metal stents due to high chances of rupture. They are mainly used for angio-plasty. These are used mainly in internal carotid arteries and the larger sized balloons are employed in aorta, veins or in valves.

(b) Compliant, low pressure balloons: Balloons that are made from nylon, latex, silicone or polyure-thane derivatives which are relative more compliant than PET. These are softer but more scratch resistant than a PET balloons and are commonly used for mounting balloon expandable stents and temporary vascular occlusion, embolectomy or molding of stent grafts, preventing reflux of embolic material proximally during embolization, or to attenuate antegrade blood flow during embolization.

Examples:

1. CELLO balloon guide catheter (Medtronic): It includes the balloon guide catheter range from 6F to 9F for radial to femoral approach. Typical sizes used: 8 F only. Respective internal diameters: 0.075 in (1.9 mm). Available lengths: 95 cm effective length. Its advantages are: soft atraumatic hydrophilic tip. Balloon inflation can achieve ICA flow arrest in mechanical thrombectomy cases and may allow for more effective aspiration during device/thrombus

retrieval. However, relatively small inner lumen when compared to outer diameter. A 125 cm 5.5 F SIM-2 Shuttle Select catheter inside this catheter provides a formidable access tool when used for mechanical thrombectomy in acute stroke patients who often have challenging aortic arch and neck vessel anatomy.

2. Scepter C & XC (Microvention): It focuses in four areas: Balloon remodeling, Stent delivery, Liquid embolic injection and Balloon Test Occlusion. It is an occlusion balloon catheter; its flexible coaxial lumen design provides separate inflation lumen. It has enhanced trackability, and it is. 014 guidewires. Its hydrophillic coated balloon diameter ranges from 2mm to 6mm, distal tip shapable by steam, Coil reinforced coaxial shaft provides column strength to stabilize the balloon during inflation/deflation.

Scepter XC - It has hyper-compliant balloon that conforms to extremely complex anatomies where neck coverage is more challenging.[28] (Fig.12)

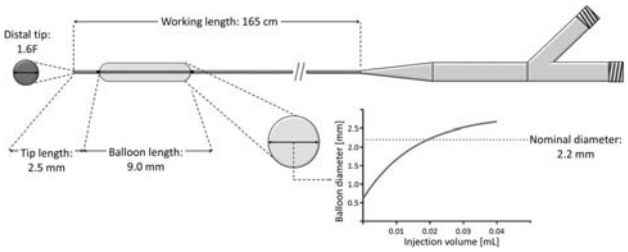


Figure 12: Scematic Diagram of Scepter Mini microballoon catheter. Specifications not shown in the figure: working lumen dead space of 0.44mL, proximal shaft outer diameter of 2.8 F, distal tip inner diameter of 0.010 in and maximum injection volume of 0.04mL.[28]

3. FlowGate2 Balloon Guide Catheters: They are of following two types:

ID	OD	Length
0.084 in (2.1mm/6.4F)	8F (2.7mm)	85cm
0.084 in (2.1mm/6.4F)	8F (2.7mm)	95cm

4. Merci Balloon Guide Catheters (Stryker): They are of folloewing types:

ID	OD	Length
0.078 in (1.9mm)	8F (2.7mm)	80cm/95cm
0.085 in (2.1mm)	9F (3.0mm)	80cm/95cm

5. Concentric Balloon Guide Catheter: They have ID of 0.059in (1.4mm), OD of 7F (2.3mm) and length of 95cm.

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