Original Paper

Utilization of a Novel, Multi-Durometer Intracranial Distal Access Catheter: Nuances and Experience in 110 Consecutive Cases of Aneurysm Flow Diversion

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Keywords

Cerebral aneurysm · Flow diversion · Distal access catheter · AXS Catalyst 5 · Pipeline embolization device

Abstract

Background: Coaxial catheter support systems provide a safe and stable foundation in endovascular treatment of intracranial aneurysms. Increasingly, robust distal intracranial support is sought during complex neurointerventions. The AXS Catalyst 5 distal access catheter (Cat5) is a new intracranial catheter designed for improved trackability and stability. We report the first experience using Cat5 for aneurysm treatment by flow diversion. **Methods:** A single-center aneurysm database was reviewed for cases of aneurysm treatment with the Pipeline embolization device (PED) that utilized Cat5. Data were collected for patient demographics, aneurysm characteristics, procedural details, catheter positions, vessel tortuosity, and catheter related complications. **Results:** One hundred and ten cases of aneurysm flow diversion were successfully performed using Cat5. Patient age ranged from 21 to 86 years (mean 57 ± 12.5 years) with 84% women. Aneurysm size ranged from 2 to 28 mm (mean 5.7 ± 5.0 mm), with 97% in the anterior circulation. Twenty-four aneurysms (22%) were located beyond the ICA termination. Significant cervical carotid tortuosity was present in 26% of cases, and moderate to severe cavernous tortuosity (cavernous grade ≥ 2) in 45% of cases. Cat5 was tracked to the intended distal position in all cases with 100% technical success of PED implantation. No iatrogenic catheter-related vessel injury occurred, and major neurological morbidity occurred in 1 patient (1%). **Summary:** The Cat5 is a novel, multi-durometer cranial distal access catheter designed for use in tri-axial systems. We have demonstrated the utility of Cat5 in 110 successful cases of flow diversion with a wide range of complexity. This catheter is a new tool in the neurointerventionalist's armamentarium to achieve robust and atraumatic distal access.

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Introduction

Successful endovascular treatment of intracranial aneurysms requires a coaxial catheter strategy to provide stable and reliable access to the cerebral vasculature. Historically, endovascular guide catheters were large in size and rigid in quality. These properties restricted the positioning of such catheters to the cervical vessels and, as a result, have limited their utility in modern neurointervention.

As the field of neurointerventional therapy expands, with novel treatments and devices of increasing sophistication, there has been a growing need for more robust and versatile catheter support systems. From this arose a newer generation of catheters, the distal intracranial catheters (DICs), which are designed with the flexibility to safely travel further into the cranial circulation. Initial versions of these catheters, including the traditional Outreach distal access catheter and Neuron, helped move support systems from the proximal cervical circulation to the distal cervical vessels and proximal intracranial vessels [1–4]. The Navien catheter, with additional advances in catheter technology, allowed for successful and reproducible placement of 5-Fr and 6-Fr support catheters distal into the intracranial anterior and posterior circulations [5, 6]. This robust support facilitated implantation of braided flow diverting devices, including the Pipeline embolization device (PED; Medtronic, Minneapolis, MN, USA).

Further improvements in catheter technology have focused on atraumatic distal tracking, stability in distal position, and resistance to catheter deformation (e.g., ovalization). The AXS Catalyst 5 distal access catheter (Cat5; Stryker, Fremont, CA, USA) is a novel multi-durometer intracranial support catheter for neurointervention. Here, we describe our experience using Cat5 in 110 cases of aneurysm treatment by PED flow diversion. To our knowledge, this represents the first description of this catheter and its technical nuances in the literature.

Methods

Patient Selection

A prospectively collected institutional cerebral aneurysm database was evaluated to identify all cases of endovascular aneurysm treatment with the PED utilizing Cat5 from January 2016 (first availability of Cat5 at our institution) to September 2016. All cases were performed at either the Johns Hopkins Hospital or the Johns Hopkins Bayview Medical Center (both in Baltimore, MD).

Endovascular Procedure

Endovascular procedures were performed as previously described [7, 8]. Briefly, cases were performed through femoral access and using a tri-axial system that consisted of a long guide sheath, a distal access catheter, and a microcatheter. The guide sheaths utilized included an AXS Infinity 0.088-inch ID (Stryker, Fremont, CA, USA), Neuron MAX 0.088-inch ID (Penumbra, Alameda CA, USA), and Flexor Shuttle Sheath (Cook Medical, Bloomington, IA, USA). The 0.027-inch ID microcatheters utilized included the VIA (Sequent/MicroVention, Tustin, CA, USA), Marksman (Medtronic), and Phenom (Medtronic). In each case, the Cat5 catheter (115-cm length) was used as the DIC. The Cat5 catheter is shown in Figure 1.

Data Collection and Statistical Analysis

Data were collected for patient demographics, aneurysm characteristics, procedural details, catheter positions, vessel tortuosity, and complications. For neurological complications, major stroke was defined as stroke symptoms present after 7 days that increased the NIH Stroke Scale by ≥ 4 points, and minor stroke was defined as stroke symptoms that resolved within 7 days or increased the NIH Stroke Scale by ≤ 3 points. Data are presented as counts, percentages, means, and standard error of the mean. Student's test was used calculate *p* values when comparing 2 groups.

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Fig. 1. AXS Catalyst 5 distal access catheter. **a** Image of the Cat5 115-cm, 0.058-inch ID catheter. The catheter has a 5.6-Fr proximal OD and 5.3-Fr distal OD. **b** Magnified image of the distal tip. The black arrows mark the 5 cm distal flex zone. The black arrowheads mark a portion of the hydrophilic-coated catheter.

Results

Patient and Aneurysm Characteristics

From January 2016 to September 2016, 110 patients with cerebral aneurysms were treated with the PED using the Cat5 catheter at our institution. Patient demographics are presented in Table 1. Patient age ranged between 21 and 86 years old, with an average of 57 ± 12.5 years. Ninety-two (84%) patients were women, and 18 (16%) were men. Sixteen (15%) patients had a history of prior subarachnoid hemorrhage (SAH). Patients with prior SAH returned to care for either definitive treatment of a partially coiled previously ruptured aneurysm or for aneurysm multiplicity. No patient was treated with the PED in the setting of acute SAH. Additionally, none of the aneurysms treated had a preexisting indwelling endoluminal stent/device at the target site.

Aneurysm sizes are presented in Table 1. Aneurysm size ranged from 2 to 28 mm, with a mean aneurysm size of 5.7 ± 5.0 mm. Ninety-eight (89%) aneurysms were categorized as small (2–10 mm), 10 (9%) were large (11–24 mm), and 2 (2%) were giant (≥ 25). Aneurysm locations are presented in Table 2. Most aneurysms (107/110, 97%) were located in the anterior circulation, with only 3/110 (3%) in the posterior circulation. The most common

Table 1. Patient demographics

Total cases	110
Total patients	110
Age, years	57±12.5
Sex	
Female	92 (84)
Male	18 (16)
Prior SAH	16 (15)
Aneurysm	
Size, mm	5.7±5.0
Small	98 (89)
Large	10 (9)
Giant	2 (2)

Data are presented as *n* (%) or mean ± SEM.

Table 2. Aneurysm location

Anterior circulation	107 (97)
ICA	83 (75)
Cavernous	11 (10)
Paraophthalmic/clinoidal	67 (61)
Supraclinoid	3 (3)
Termination	1 (1)
ACA	20 (18)
MCA	4 (4)
Posterior circulation	3 (3)
PCA	1 (1)
V3/V4	1 (1)
PICA	1 (1)

Data are presented as *n* (%). ACA, anterior cerebral artery; ICA, internal carotid artery; MCA, middle cerebral artery; PICA, posterior cerebral artery; PCA, posterior cerebral artery; V, vertebral artery.

aneurysm location in the carotid anterior circulation was paraophthalmic/clinoidal (67, 61%), followed by cavernous segment (11, 10%), supraclinoid (3, 3%), and an internal carotid artery (ICA) termination (1, 1%). In addition to ICA aneurysms, 20 (18%) anterior cerebral artery (ACA) and 4 (4%) middle cerebral artery (MCA) aneurysms were treated. All ACA aneurysms in the series were treated with PED deployment from ipsilateral A1 to ipsilateral A2. Three MCA aneurysms involved M1 to M2 PED deployments, and in 1 case the PED remained entirely within the M1. Three posterior circulation aneurysms were treated, including a P1 segment aneurysm, a branch point PICA origin aneurysm, and a fusiform aneurysm originating at the V3–4 junction.

Equipment Utilized

The Cat5 catheter, 115-cm length, was used as part of a tri-axial support system in all 110 cases. In each case, a 6-Fr guide sheath was passed through an 8-Fr short femoral sheath. Guide sheaths utilized included AXS Infinity 0.088 in 27 cases and NeuronMax 0.088 or Flexor Cook Shuttle 0.087 (Cook Medical) in 83 cases. In each case, the Cat5 was tracked over a 0.027 microcatheter. The microcatheter most frequently used was the VIA 0.027 (105/110, 95%). A Marksman microcatheter was used in 3 cases (3%), and a Phenom microcatheter (Medtronic) was used in 2 cases (2%). The Fathom-16 microwire (Boston Scientific, Natick, MA, USA) was the most common wire used to track the 0.027 microcatheter and Cat5 into position.

Table 3. Vessel characteristics and Cat5 distal access catheter positions

Cervical carotid tortuosity ^a	28 (26)
Cavernous grade ^a	
1a	22 (21)
1b	37 (35)
2	21 (20)
3	16 (15)
4	11 (10)
Cat5 distal position	
Proximal cavernous	57 (52)
Distal cavernous	29 (26)
Supraclinoid	20 (18)
A1	1 (1)
V3/V4	3 (3)

Data are presented as *n* (%). A, anterior cerebral artery; V, vertebral artery. ^a Data for carotid catheter position calculated from 107 anterior circulation procedures.

Vessel Tortuosity and Distal Access Catheter Positions

Tortuosity of the parent vessels and Cat5 catheter positions are presented in Table 3. Significant cervical tortuosity was present in 28 patients (26%). Cervical tortuosity was defined as the presence of a hairpin loop, a corkscrew loop or a vessel turn of 90° or more in the cervical ICA. Figure 2 demonstrates selected examples of cervical tortuosity successfully navigated by the Cat5. In all cases, cavernous carotid tortuosity was also recorded according to a previously published classification system [9]. This anatomical grading system serves as a surrogate marker and predictor of PED case complexity in the anterior circulation. Fifty-nine patients (56%) had minimal tortuosity of the cavernous ICA (grade 1a and 1b). Moderate cavernous tortuosity (grade 2) was present in 21 patients (20%), and severe tortuosity (grade 3 and 4) present in 27 patients (25%). Figure 3 demonstrates an example of intracranial cavernous tortuosity easily navigated by Cat5 without vessel distortion.

In all 107 anterior circulation cases, Cat5 was positioned distal to the petrous segment. In 57 (52%) cases, Cat5 was positioned within the posterior genu or horizontal segments of the cavernous ICA. In 29 (26%) cases, Cat5 was positioned within the anterior genu of the cavernous ICA. In 21 (19%) cases, Cat5 was tracked to the supraclinoid ICA or beyond. In 1 case, Cat5 was tracked into the proximal A1 for treatment of a distal ACA aneurysm (Fig. 3). For posterior circulation aneurysms, Cat5 was tracked to the V4 segment in 2 cases and positioned in V3 for a V3–4 junction aneurysm. An example of vertebral artery tortuosity that was easily navigated by Cat5 is demonstrated in Figure 2.

Procedural Details and Complications

Procedural details and guide catheter complications are presented in Table 4. Total procedure fluoroscopic times ranged between 11.2 and 151.7 min, with a mean time of 32.1 ± 23.5 min. This demonstrates the varied complexity of cases in the series. Advanced PED deployment techniques that were enhanced by Cat5 are demonstrated in Figures 4 and 5. In all 110 cases (100%), the Cat5 catheter was tracked to the operator's intended position. Likewise, in all cases (100%), a PED Flex was successfully deployed and implanted. One PED was deployed in 98 cases (89%). Two PEDs were deployed in 10 cases (9%), and 3 PEDs were deployed in 2 cases (2%). Balloon angioplasty was utilized in 8 cases (7%) to improve vessel wall apposition of the PED. In addition, adjuvant coiling was performed in 5 cases at the time of PED implantation. This was accomplished through a jailed microcatheter that originated from a separate guide catheter using contralateral femoral access. Vasospasm prophylaxis

Fig. 2. Enhanced trackability and stability of Cat5 in cervical tortuosity of the anterior and posterior circulations. **a–c** Road-map fluoroscopy demonstrating sequential images of Cat5 (black arrow) tracking through tight proximal cervical ICA tortuosity with little to no retrograde displacement of the AXS Infinity guide sheath (black arrowhead). This is attributed to the trackability of Cat5 in combination with the stability of AXS Infinity. **d, e** Road-map fluoroscopy demonstrating sequential images of Cat5 (black arrow) stability while advancing the VIA 0.027 catheter (white arrow) and Fathom 0.016 wire through vertebral artery tortuosity. **e, f** Cat5 is then tracked easily over the VIA through this tortuosity.

and treatment was accomplished with intraarterial verapamil infusion delivered through the guide sheath and/or Cat5 in 15 cases (16%). Most commonly, verapamil was administered for vasospasm prophylaxis prior to advancing catheters in cases of ACA/Acom aneurysm treatment. No iatrogenic arterial dissections or other complications resulted from positioning the Cat5 in any of the 110 cases.

Neurological complications that were also evaluated in this case series included mortality, major and minor stroke, intracerebral hemorrhage (ICH), and SAH. In this series of 110 cases, there were zero periprocedure mortality (0%), 1 major stroke (1%), 1 minor stroke (1%), 1 ICH (1%), and zero SAH (0%). Major neurological morbidity and mortality, defined as major stroke or death, occurred in 1 patient (1%).

Fig. 3. Cat5 trackability through the intracranial anterior circulation. **a–c** Road-map fluoroscopy demonstrating sequential images of Cat5 (black arrow) tracking through a tortuous cavernous ICA over a VIA 0.027 microcatheter and Fathom 0.016 wire. Note that the vessel geometry is not distorted during this maneuver, and the Cat5 tracks easily past the shelf created by the ophthalmic artery origin (black arrowhead). **d, e** Road-map fluoroscopy demonstrating sequential images of Cat5 (black arrow) tracking from the supraclinoid ICA to the A1 segment over a VIA 0.027 catheter and Fathom 0.016 wire with little to no retrograde displacement of the VIA catheter (white arrow).

Discussion

In this report, we describe our experience with a new, multi-durometer 0.058 distal access catheter in 110 cases of aneurysm flow diversion with the PED. To our knowledge, this represents the first description of the Cat5 for cerebral neurointervention. As part of a tri-axial system, the Cat5 was successfully tracked and positioned in all areas of the intracranial

ICA and vertebral arteries for PED deployment (Fig. 2, 3). The intended distal position was achieved in 100% of cases without iatrogenic vessel injury or dissection. This was performed despite significant cervical carotid tortuosity in 26% of the cases and moderate to severe cavernous tortuosity (cavernous ICA grade ≥ 2) in 45% of cases. All cases resulted in successful deployment and implantation of a PED across the aneurysm neck, including complex cases with advanced PED techniques (Fig. 4, 5).

Successful utilization of Cat5 is attributed to both catheter construction and to techniques employed to track and position it. Intended for distal intracranial access, Cat5 is available in 115- and 132-cm working lengths, although 115 cm is preferred in our center. This is ideally suited for use in a tri-axial system with the primary guide sheath (e.g., AXS Infinity) measuring 90 cm for anterior circulation cases and 80 cm for posterior circulation cases. The ID of Cat5 is 0.058 inch throughout the length of the catheter. This allows for easy

Table 4. Procedural details

Total procedure fluoroscopy time, min	32.1 $\pm$ 23.5
Technical success tracking Cat5 catheter	110 (100)
Cases with successful PED implantation	110 (100)
PED of devices deployed per case	
1	98 (89)
2	10 (9)
3	2 (2)
Balloon angioplasty	8 (7)
Adjuvant coiling at time of PED implantation	5 (5)
Intra-arterial verapamil administered	15 (14)
Vessel injury/dissection	0 (0)

Data are presented as *n* (%) or mean $\pm$ SEM. PED, pipeline embolization device.

Fig. 4. Cat5 facilitates intra-DIC deployment and balloon “push-through” techniques during PED-coiling of a 28-mm ophthalmic aneurysm in a septuagenarian. AP (a) and lateral DSA (b) demonstrating a right-sided 28-mm ophthalmic ICA aneurysm with a near-type III cavernous genu system. c The Cat5 catheter (tip = black arrow) is positioned at the anterior genu for PED deployment (back arrowhead) through a VIA 0.027-inch ID catheter (white arrow). An AXS Infinity 90-cm guide sheath (not visualized) is positioned in the midcervical ICA. An SL-10 coiling catheter (white arrowhead) is looped within the aneurysm dome. The SL-10 is coaxial with a 5-Fr Envoy guide positioned in the distal common carotid using contralateral groin access. This setup of 2 independent catheter systems was chosen (as opposed to dual catheter technique through a 0.072-inch ID Navien), so that the Cat5 could be used independently to facilitate PED deployment as described below. d The PED was deployed around the anterior genu, jailing the SL-10. To reduce the risk of PED herniation into the aneurysm during deployment, an intra-DIC technique was utilized for the proximal PED. For this maneuver, the proximal PED is fully unsheathed within the Cat5 and then (e) “pushed” out of the Cat5 using the VIA. As the VIA pushes the proximal PED (black arrowhead), the device foreshortens and improves wall apposition. The VIA is then tracked over the PED delivery wire, and the Cat5 is advanced to establish robust endoluminal access. f The VIA is removed, and a Transform balloon (asterisk) is introduced through the Cat5. g With the balloon in position, the Cat5 is withdrawn more proximally, and coiling is performed. The coil mass will help prevent herniation of the PED during subsequent device manipulation. h After coiling, the SL-10 is removed, and the Cat5 provides support for a balloon “push-through” technique. This involves advancing a partially inflated balloon (asterisk) to bump the proximal PED (black arrowhead) and facilitate foreshortening. i Similarly, Cat5 is easily tracked over the deflated balloon catheter on the vessel outer curvature to further bump and foreshorten the proximal PED. j Final control angiography demonstrates excellent wall apposition of the PED without vasospasm or dissection. k Six-month follow-up DSA demonstrates complete aneurysm occlusion with normal appearance of the parent vessel. l Illustration demonstrating key highlights of this case and Cat5 attributes.

(For figure see next pages.)

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Fig. 5. Utilizing Cat5 for restoring neutral catheter position and recapture of a twisted PED during embolization of a 25-mm petrocavernous aneurysm in a quinquagenarian. Preembolization 3D rotational (**a**, **b**) and conventional (**c**) DSA angiography of a right-sided 25-mm petrocavernous aneurysm in a patient with multiple intracranial aneurysms and prior PED treatment of a left-sided ICA aneurysm. **c** Note the proximal cervical ICA tortuosity. **d** Native fluoroscopy (lateral view) demonstrating the Cat5 catheter (black arrow = catheter tip) and VIA 0.027-inch ID microcatheter catheter (white arrow = catheter tip) looped within the aneurysm. This was necessary to provide support for deployment and opening of the distal PED (black arrowhead). A PED in the contralateral ICA is also visualized (white arrowhead). **e** Native fluoroscopy (oblique view) demonstrating a twist in the PED (asterisk) during deployment of the midportion of the device. The white arrow marks the tip of the VIA catheter. **f**, **g** Native fluoroscopy (oblique view) demonstrating resheathing of the midportion of the PED with VIA (white arrow = catheter tip) and subsequent advancement of the Cat5 over the VIA. Black arrowhead = distal PED. As seen in **g**, the Cat5 is advanced past the VIA tip and over the distal PED (black arrowhead) to fully recapture the PED while maintaining complete distal access across the aneurysm. Following this, a neutral microcatheter was positioned across the aneurysm for PED deployment. **h** Native fluoroscopy (lateral view) demonstrating proper deployment of the PED without twisting (black arrowheads). The white arrow marks the tip of the VIA, and the black arrow marks the tip of the Cat5. The white arrowhead marks the contralateral PED.

passage of a standard 0.027 microcatheter with additional space for continuous flush and contrast injections through the Cat5 lumen. The OD of Cat5 is 5.6 Fr proximally and tapers to 5.3 Fr distally. The larger proximal OD compared to other 0.058 catheters (e.g., Navien) contributes to the stability and pushability of Cat5. The larger OD of Cat5 does not prohibit flush and contrast injections through commonly used guide sheaths (e.g., 0.088-inch ID AXS Infinity). The 5.3-Fr distal end of Cat5 is slightly larger than the 5.2-Fr distal end of a 0.058

Navien catheter. Despite the slightly larger size, the Cat5 catheter tracked easily and reliably in our experience. This includes ultra-distal positioning of the Cat5 into the supraclinoid ICA and even A1 segment without vessel injury or flow-limiting vasospasm (Fig. 3).

The Cat5 115-cm catheter is constructed with 12 transition zones (132-cm length has 14 transition zones) that represent variable durometers along the length of the catheter. Proximally, the catheter has a stainless steel coil and thicker jacket. These features add significant proximal stiffness, resulting in enhanced pushability and stability. Distally, Cat5 has a nitinol coil of variable pitch that facilitates flexibility of the 5 cm distal zone to navigate tortuous anatomy and resist kinking and ovalization. As with other DICs (e.g., Navien), the soft and flexible distal end achieves added stability and support from being positioned in vessel turns, such as the cavernous genu system. The Cat5 tip is rounded in shape to facilitate atraumatic forward movement. Despite the inevitable step-off between a Cat5 inner lumen and the outer boundaries of a 0.027 microcatheter, the Cat5 tracked forward without vessel dissection. This improved performance was particularly notable when advancing Cat5 around and past the anterior genu in a variety of tortuosity without getting caught on the ophthalmic artery origin (Fig. 3).

The distal 82 cm of Cat5 has significant hydrophilic properties. When hydrated, this distal catheter has a “slick” and “slippery” feel. The hydrophilic coating facilitates passage of Cat5 through a guide sheath and likely reduces friction forces on the vessel walls. The proximal catheter does not have the hydrophilic coating, and this uncoated portion is easy to handle while advancing Cat5 to intracranial position. When using a 90-cm guide sheath, Cat5 (115-cm length) can be safely advanced just past the area of hydrophilic coating without the need for fluoroscopy. Immediately after introducing the Cat5, we recommend advancing it past the zone of hydrophilic coating so that the silicon valve of the Tuohy Borst Valve or Rotating Hemostatic Valve is locked on the nonhydrophilic zone. This prevents Cat5 from inadvertently slipping backwards. Many key design and construction attributes of Cat5 are highlighted in Figure 4l.

Using a tri-axial system, we were able to reliably track the Cat5 over a 0.027 microcatheter and 0.016 microwire combination. Tracking Cat5 to the posterior genu of the cavernous segment was typically performed with the 0.027 microcatheter and microwire in the horizontal segment of the cavernous ICA. If the intended position of Cat5 was the cavernous anterior genu, the supraclinoid ICA, or past the ICA termination, then the microcatheter and microwire were typically positioned in the distal MCA prior to tracking the Cat5. For cases of severe cavernous tortuosity, but relatively straight cervical ICA anatomy, the guide sheath was advanced to the midcervical ICA prior to advancing Cat5 through the cavernous genu system. This maneuver is not always necessary, but it is helpful to facilitate forward movement of Cat5 through difficult tortuosity and limit unwanted slack buildup in the catheter system.

The stability of Cat5 is apparent during each portion of a PED case. Stability was particularly noted when advancing the PED to a distal target (e.g., ACA) in patients with proximal tortuosity of the ICA and/or A1 origin (recurved take-off). Pushing the larger delivery wire of PED Flex can cause significant kickback if the intracranial support catheter is not stable. This was not observed to any significant degree with Cat5. For proper PED deployment, opening and vessel wall apposition of the braided device relies on device foreshortening. This is achieved either by pushing the stent out of the microcatheter (facilitated by the stiff pusher wire of PED Flex) or by wagging the device forward with a load on the microcatheter. Each of these movements causes backward forces on the distal intracranial support system. Cat5 performed extremely well in these scenarios, maintaining position with good stability in a variety of complex PED deployments. The stability of Cat5 also facilitated PED resheathing and recapture of the distal delivery wire. These maneuvers rely on stability of the intracranial support, particularly as the 0.027 microcatheter is tracked over the 0.008-inch diameter distal PED delivery wire.

A PED Flex was successfully implanted in each case, despite a wide variety of case complexity. Fluoroscopy times, which serve as a surrogate marker of case complexity, ranged from 11.2 to 151.7 min. Furthermore, moderate to severe cavernous ICA tortuosity ($\geq$ grade 2) was present in 48 (45%) patients. Grade 3 and 4 cavernous geometry adds significant complexity to PED deployment secondary to a Simmons-like effect on microcatheter movements [9]. Robust support from a distal access catheter helps reduce this effect and facilitates more favorable 1:1 movements. Even with a high rate of complex cavernous geometry, balloon angioplasty was used to improve PED vessel wall apposition in only 8 cases (7%). This low rate of balloon angioplasty for postprocessing the PED is a function of the deployment characteristics of PED Flex [8, 10, 11], microcatheter selection, and the stability plus trackability of Cat5.

In addition to facilitating the distal position of the support system, advanced techniques to improve access and PED deployment success are possible with the enhanced trackability of Cat5 (Fig. 4 and 5). Firstly, the Cat5 catheter can be readily advanced over the microcatheter to “bump” and foreshorten the proximal PED device. This technique is particularly helpful to achieve improved wall apposition for larger-diameter PEDs that might not fully open with standard techniques, and it often obviates the need for balloon angioplasty. Secondly, endoluminal Cat5 access within the PED can also be obtained with the easy trackability of Cat5 (Fig. 4). This facilitates multidevice deployments when needed. Thirdly, Cat5 works well for the intra-DIC deployment technique (Fig. 4) [12]. This advanced maneuver was previously reported using the Navien catheter as a salvage technique for failed opening of the proximal PED in tortuous anatomy. Likewise, the improved support of Cat5 facilitates “pushing” a partially open PED out of the distal Cat5 lumen when using this technique. Fourthly, Cat5 can be used to “recapture” a partially open or twisted PED across the neck of a large or giant aneurysm when standard resheathing techniques would result in lost access (Fig. 5). Finally, the distal flex zone of Cat5 is soft and flexible enough to loop inside a giant aneurysm to facilitate access across the aneurysm or device deployment (Fig. 5).

Despite our significant success with Cat5 in PED cases, the catheter is limited in certain circumstances. Most notably, the larger OD of Cat5 (5.3 Fr distal and 5.6 Fr proximal) excludes its use directly through a standard 5-Fr sheath. Direct 5-Fr sheath access is commonly used for radial or brachial approaches to the posterior circulation and for direct carotid puncture. The Cat5, therefore, cannot be used as a stand-alone guide catheter in this situation. The Navien catheter, with its smaller 5.2-Fr OD, works well directly through a 5-Fr sheath for these approaches [13]. Additionally, the Cat5 catheter is intended to be used as part of a tri-axial system, and it would not be sufficient as the primary guide catheter in a bi-axial system for a transfemoral approach to the cerebral circulation. Other centers have published use of the Benchmark catheter (Penumbra) as part of a bi-axial system for PED cases and other aneurysm treatments [14, 15]. Our group prefers tri-axial systems for their greater flexibility (more possible catheter combinations for various anatomy) and improved distal access.

The Cat5 catheter was used with excellent safety results in this series of 110 PED cases. Major neurological morbidity or mortality, defined as major stroke or death, occurred in 1 patient (1%) with ischemic stroke. Although complications are potentially due to a large variety of factors during endovascular cerebral aneurysm treatment, this safety profile using Cat5 is as good or better than widely published complication rates in large series of flow diversion for treatment of cerebral aneurysms. Furthermore, Cat5 use for PED Flex deployment was associated with statistically significant improvements in procedural success and more distal placements of the catheter as compared to PED Flex deployment using the Navien 0.058 ID catheter (Table 5). Although not statistically significant, there were trends toward shorter fluoroscopy times, less use of intraarterial verapamil for spasmolysis, decreased need for postprocessing balloon angioplasty, decreased PED removal, and less iatrogenic dissection

Table 5. Comparison data: Cat5 cases vs. Navien cases

	Cat5	Navien 058	<i>p</i> value
Cases using PED Flex	110	161	
Procedural success (PED implantation)	110 (100)	153 (95)	0.02*
Fluoroscopy time, min	32.1 ± 21.6	33.6 ± 21.3	0.57
Supraclinoid ICA catheter position	20 (18)	12 (9)	0.01*
Intra-arterial verapamil	15 (14)	32 (20)	0.18
Balloon angioplasty	8 (7)	21 (13)	0.13
PED removal	2 (2)	8 (5)	0.18
Iatrogenic dissection	0 (0)	1 (1)	0.79

Data are presented as *n* (%) or mean ± SEM. PED, pipeline embolization device. * Statistically significant.

when the Cat5 catheter was used for PED Flex deployment. A larger series with groups controlled for aneurysm size, location, and vessel tortuosity would be needed to further differentiate some of these categories for statistical significance.

Conclusions

The Cat5 is a next-generation, multidurometer distal intracranial support catheter. It is uniquely trackable and supportive in various complex vessel geometries during aneurysm treatment. This catheter represents a new tool for achieving the robust intracranial support for safe and effective modern neurointervention.

Statement of Ethics

This research was approved by the Johns Hopkins Institutional Review Board.

Disclosure Statement

A.L.C. is a proctor for the Pipeline embolization device (Medtronic, Minneapolis, MN, USA) and a consultant for Medtronic, a proctor for the Surpass device (Stryker Neurovascular, Fremont, CA, USA) and a consultant for Stryker Neurovascular, a proctor for the FRED and WEB devices (MicroVention, Tustin, CA, USA) and a consultant for Microvention. G.P.C. participates in clinical trials for Medtronic and Stryker. L.-M.L. participates in clinical trials for Stryker and is a proctor for the Pipeline embolization device. The other authors have no conflict of interest. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contributions

G.P.C. performed treatment procedures, data collection, analysis of data, drafted the manuscript and critically revised the manuscript for important intellectual content. L.-M.L. assisted in analysis of data, drafting the manuscript, and critically revising the manuscript. R.X., N.B., M.T.B., and B.J. assisted with the data collection, analysis, and drafting the manuscript. N.B. helped to collect data and draft the manuscript. J.H. and R.J.T. critically reviewed the important intellectual content of the manuscript. A.L.C. performed treatment procedures, performed data analysis and critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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