Case Report

Flow diverter stenting for intracranial aneurysms in the pediatric population: Two case reports and literature review

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The Pipeline Embolization Device (PED) is a flow-diverting intraluminal device that is approved for use in adults 18 years or older with internal carotid artery aneurysms. However, it can also be used off-label in pediatric patients with aneurysms that cannot be resolved with traditional endovascular treatments. Herein, we present two cases of flow diversion in the pediatric population with complete obliteration of the aneurysm and excellent outcomes. Flow diversion has been shown to be a safe endovascular option in treating complex aneurysms in children. Larger-sized, multicenter trials are encouraged to compare outcomes between flow diversion and other aneurysm treatment options given the rarity of pediatric aneurysms.

Keywords Pediatrics, Flow diversion, Intracranial aneurysms, Neurosurgery, Pipeline Embolization Device

INTRODUCTION

Intracranial aneurysms (IAs) are characteristically rare in the pediatric population and their treatment is often more difficult and complex than that of adults.[18] Additionally, in the pediatric population, ruptured aneurysms are more common than unruptured ones.[20] Management options for pediatric IAs range from observation with serial follow-up imaging to microsurgical or endovascular intervention.[15]

Endovascular coil embolization involves placing coils, densely packed inside the aneurysm to induce thrombosis and occlusion. The Pipeline Embolization Device (PED) is a flow-diverting intraluminal device that induces thrombosis and occlusion of the aneurysm with reendothelialization of the device.[15)27)30] The device is approved for use in adults 18 years or older with internal carotid artery (ICA) aneurysms arising from the petrous segment to the terminus. However, it can also be used off-label in pediatric patients with aneurysms that cannot be resolved with traditional endovascular treatments.[26] During flow diversion, a microcatheter is navigated past

the aneurysm in the native vessel (without needing to enter the aneurysm). The PED is then deployed across the neck of the aneurysm in the parent blood vessel. If successful, the aneurysm should completely thrombose and occlude in the following 6 weeks to 6 months.[6)26)]

CASE DESCRIPTION

First case

A 15-year-old girl with a sibling affected by a vascular anomaly presented to neurosurgery clinic following incidental discovery of a left-sided vascular abnormality during imaging after sustaining a concussion. Since her concussion three weeks prior, she had been complaining of post-concussive symptoms as well as intermittent bilateral visual blurriness. Magnetic resonance angiography (MRA) showed a dysplastic, fusiform aneurysmal dilatation of the left supraclinoid terminal carotid artery with some compression of the adjacent chiasm and left optic nerve. The aneurysm measured 11 mm×9 mm via catheter angiography (Fig. 1). Additionally, multiple secondary daughter sacs arose from the supraclinoid and communicating segment of the ICA to the carotid terminus with aneurysmal incorporation of the proximal M1 segment. The anterior choroidal artery with fusiform, dysplastic morphology originated from the dome of the aneurysm.
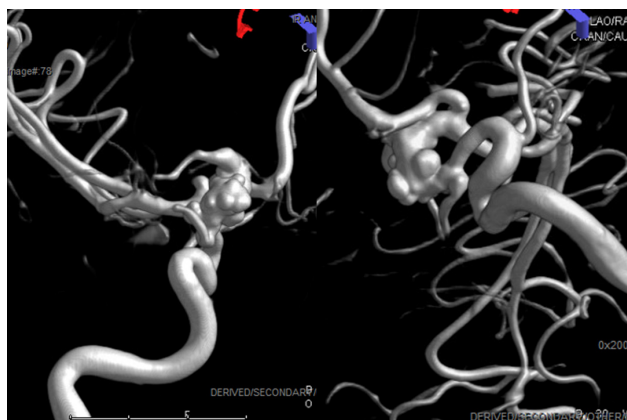
It was determined that this aneurysm was concerning for risk of rupture given the dysplastic, fusiform shape. Flow diversion stent placement via right common femoral artery approach was offered off-label. Under fluoroscopic magnification and roadmap imaging, a microcatheter was advanced through the ICA and into the frontal M2 branch, and wire was removed. Under continuous fluoroscopic guidance, a 4.75 by 35 mm Pipeline Flow Diverting stent was then deployed from the ophthalmic segment of the ICA to the middle of the M1 segment of the left middle cerebral artery, ensuring that the device was completely expanded and well opposed. Fluoroscopic images determined good wall apposition and final angiographic images demonstrated stagnant flow within the aneurysmal daughter sacs with preserved, albeit slower, flow within the anterior cerebral artery as well as the ophthalmic artery. There was well-maintained flow within the anterior choroidal artery.

Two months post-flow diverter stenting, the patient had resolution of headaches and no new neurological symptoms. MRA showed continued diminishment of aneurysm filling, encouraging for aneurysm exclusion. A 6-month follow-up catheter angiogram showed near complete resolution of the left terminal ICA aneurysm; however, evidence of non-flow-limiting tapering stenosis of the left supraclinoid carotid was noted and has continued to be monitored (Fig. 2).

Fig. 1. A 3D reconstruction angiogram reveals a dysplastic, fusiform, multilobular aneurysm measuring 11 mm×9 mm. 3D, three-dimensional
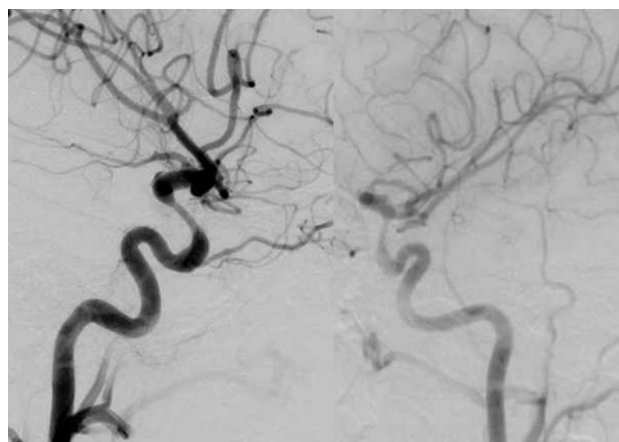

Fig. 2. Six-month follow-up angiogram shows complete resolution of the left terminal ICA aneurysm and non-flow-limiting tapering stenosis of the left supraclinoid carotid. ICA, internal carotid artery

Second case

A 15-year-old boy with past medical history of Juvenile myoclonic epilepsy (JME) as a sequela of viral meningitis two years prior was admitted to the hospital for evaluation after changes in seizure semiology. During this admission, his MRI (magnetic resonance imaging) brain showed a suspected left supra-clinoid carotid artery aneurysm that was further confirmed using MRA. Subsequently, a catheter angiogram revealed a dysplastic segment of the left-sided supraclinoid ICA with a broad-based, saccular 6.2 mm aneurysm and a 2 mm aneurysm arising on the opposite wall of the ICA (Fig. 3).

After discussing risks and benefits, family agreed with PED as a treatment for the left ICA aneurysm. Under a traditional fluoroscopic roadmap, a PED of 4.72 mm×14 mm was subsequently deployed uneventfully with good wall apposition and coverage of the aneurysm extending from just beyond the ophthalmic artery proximally to just proximal to the origin of the posterior communicating artery distally.

Three months after the procedure, the patient obtained a repeat MRA that showed partial obliteration of the aneurysm with a thrombus noted in the aneurysm dome. A six-month follow-up catheter angiogram showed complete thrombosis of the aneurysm and patent PED in the left ICA (Fig. 4). The patient continued to follow up in the clinic and at 18 months after PED placement,
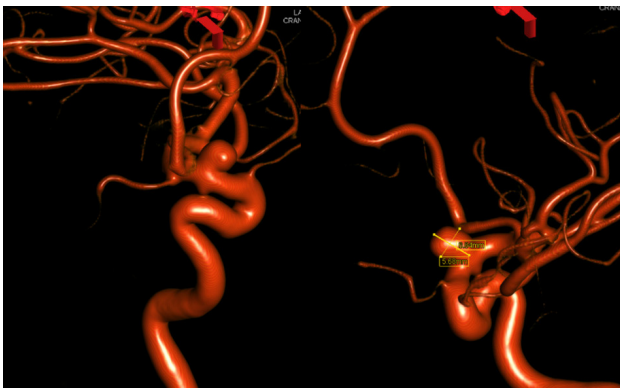
Fig. 3. A 3D reconstruction angiogram reveals a dysplastic segment of the left-sided supraclinoid ICA with a broad-based, saccular 6.2 mm aneurysm. 3D, three-dimensional; ICA, internal carotid artery
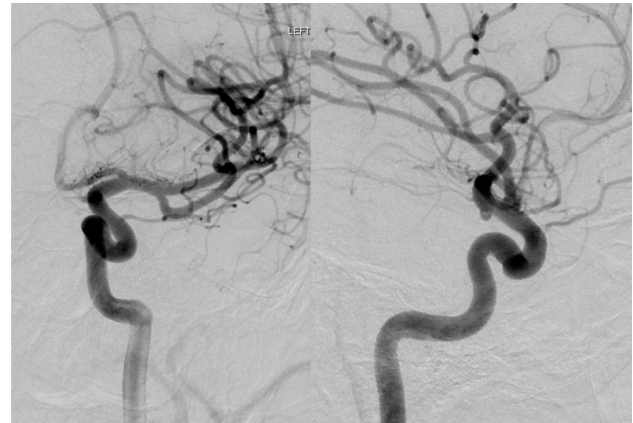
Fig. 4. Six-month follow-up angiogram shows complete thrombosis of the left ICA aneurysm. ICA, internal carotid artery

MRA showed no evidence of aneurysmal recurrence; he continues to do well clinically.

DISCUSSION

Aneurysm characteristics in the pediatric population, such as large size, fusiform shape, or dissecting vessel walls make them difficult to treat using conventional microsurgical treatment or endovascular options. This is in part due to the fact that both the blood vessels and the surgical field are smaller in the pediatric population. The pediatric population is also more sensitive to blood loss.[6)15)18-20)25] Thus, choosing the appropriate treatment option between endovascular and microsurgery is controversial; there remains no protocol for IA management in the pediatric population.[20] Despite this, with treatment for aneurysms shifting from microsurgery to endovascular methods in adults, this trend has started to extend to the pediatric population as well.[10)35]

Some endovascular options, such as coiling have shown significant rates of recanalization and high mortality and morbidity rates in the general population.[16] Recently, flow diverters have shifted from on-label use in ICA aneurysms only to distal and posterior circulation aneurysms as well.[11)16)17)26)31)36)37] Moreover, flow diverter use has expanded to treat ruptured aneurysms in the acute phase with favorable outcomes despite the need for dual

antiplatelet therapies.[12] Flow diverters work by inducing vessel reconstruction. As the parent vessel's endothelial layer starts remodeling, the aneurysm becomes isolated from the circulation; thus, creating aneurysmal flow disruption and aneurysm thrombosis.[8] The use of flow diverters in the pediatric population is limited to a small number of cases reported in the literature (Table 1) and discussed further below with each underlying etiological aneurysm subtype.

While children do not have chronic exposure to the environmental factors or medical comorbidities associated with aneurysm development as with adults, up to 30% of the pediatric population has underlying conditions related to aneurysm development and growth. These include polycystic kidney disease, Ehlers-Danlos syndrome, fibromuscular dysplasia, infectious endocarditis, and trauma.[27)30)32] Both of our patients did not undergo genetic evaluation, however, given that the first patient has a sibling with a vascular anomaly, he may have had a genetic predisposition.

One etiology of pediatric aneurysms is trauma. Traumatic aneurysms occur due to penetrating or closed trauma of the head.[34] In contrast to adults, the incidence of traumatic aneurysms in pediatrics is very high, reaching 39% in some studies.[20] Furthermore, aneurysm recurrence risk, aneurysmal growth rate, and rupture incidence are higher in the pediatric population, thus raising the importance of early treatment over just observation.[20)33] Similarly, dissecting aneurysms are more common in children, and in contrast to arterial dissection that can heal alone or with medications, dissecting aneurysms tend to grow, thus warranting treatment.[13]

Infectious aneurysms, on the other hand, result from the inflammatory reaction to an infectious agent within the adventitia and then muscularis layer, resulting in a very friable, thin-walled aneurysm. Typically these aneurysms appear without a distinguishable neck, so they are considered pseudoaneurysms.[14)28] About 15% of IAs in pediatrics are infectious.[21] Due to their histopathology, infectious aneurysms in pediatric patients have a high risk of rupture along with a latency of complete obliteration. It is additionally challenging to treat infectious aneurysms using flow diversion given the nature of placing an endovascular device in the context of potential bacteremia.[4] Yet, many studies have shown success using flow diverters to treat infectious aneurysms in the pediatric population. Ares et al. reported using PED to treat a two-year-old male with an infectious basilar apex aneurysm; 6-month angiography showed complete obliteration.[4] Another case reported by Appelboom et al. showed complete occlusion of a ten-year-old female's infectious cavernous carotid aneurysm treated with a flow diverter.[3] A third case reported by Samples et al. showed a 10-year-old female with two reputed, infectious, MCA (middle cerebral artery) aneurysms. The proximal one was treated with coil embolization and the distal one was treated with a flow diverter. Again, 6-month angiogram showed complete obliteration of both aneurysms.[29]

While seen to be successful in many case reports, there are four main potential problems related to using flow diverters in pediatrics. First, antiplatelet treatment prior to flow diverters is essential to decrease peri- and post-procedural thromboembolic events.[2] However, due to ADP-induced hyporeactivity, Aspirin-induced Reye syndrome, possible hyper response to antiplatelets and the absence of standard guidelines, using antiplatelets and adjusting their doses is challenging in pediatric patients; additionally, antiplatelet administration is extremely variable.[5)7)9] In a trial studying the appropriate antiplatelet doses in children having heart disease, Li et al. found that to achieve a sufficient therapeutic effect, 0.2 mg/kg of clopidogrel may be enough.[23] The second potential problem of utilizing flow diverters in the pediatric population is that the continuous growth of children raises concerns regarding the presence of a foreign body inside the growing blood vessels and potential long-term complications.[5] Third, the lack of experience in using flow diverters in the pediatric population can pose technical challenges for the operator.[22] Fourth, flow diverters can theoretically increase the risk of developing perforator strokes, particularly after dual antiplatelets are de-escalated to a single antiplatelet.[1)24]

Table 1. Summary of pediatric intracranial aneurysms treated with flow diversion

Author and year	Ref.	N. of PEDs	Aneurysm locations	Age (years)	Sex	Aneurysm features
Kumaria et al. 2021	22	1	ICA	8	1 male	Serpiginous
Colby et al. 2018	10	1	MCA	0.75	1 female	Saccular
Mohammad et al. 2017	26	1	Basilar	15	1 male	Partially thrombosed aneurysm
Vachhani et al. 2016	35	1	A2	12	1 female	Fusiform
Vargas et al. 2016	36	1	A2	8	1 male	Saccular
		2	Basilar, ICA	9	1 male	Fusiform
Kan et al. 2016	19	1	Basilar	16	1 male	Fusiform
Takemoto et al. 2014	32	2	ICA, Acom	N/A	N/A	N/A
Burrows et al. 2013	6	1	M2	15	1 male	Fusiform
Saraf et al. 2012	30	1	Basilar	N/A	N/A	Partially thrombosed aneurysm
Crowley et al. 2009	11	1	Basilar	1.8	1 male	Fusiform
Ares et al. 2019	4	1	Basilar	2	1 male	Infectious, Sub occlusive thrombosed aneurysm
Tonetti et al. 2021	33	1	A2	15	1 male	Fusiform, Partially thrombosed
Cherian et al. 2021	7	46	N/A	Range (3-21)	27 male 12 female	N/A
Samples et al. 2021	29	1	M1	10	1 female	Ruptured, Infectious
Cunegatto-Braga 2018	12	1	PCA	4	1 male	Ruptured, Dissecting
Ghali et al. 2018	15	1	ICA	13	1 male	N/A
		1	ACA	14	1 male	Traumatic
		1	Basilar	1.16	1 male	Dissecting
Sastry et al. 2018	31	1	Basilar	13	1 male	Iatrogenic
Navarro et al. 2015	27	1	Pcom	4	Male	Saccular
		2	Vertebrobasilar, ICA	11	1 female	Saccular
Jia et al. 2020	17	1	Vertebrobasilar	N/A	1 female	Dissecting
Barburoglu and Arat 2017	5	7	(4) ICA, (1) A2, (1) M1, (1) V4	Range (3-16)	6 males 1 female	N/A
Ikeda et al. 2015	16	1	M2	12	1 female	Fusiform
Appelboom et al. 2010	3	1	ICA	10	1 female	Infectious
Lin et al. 2016	24	1	A2	13	1 male	Dissecting
		3	M2	16	1 male	Fusiform
De Barros et al. 2011	13	2	Basilar	12	1 female	Dissecting
		2	Basilar	5	1 female	Dissecting
		4	Vertebrobasilar	7	1 male	Dissecting
Cinar et al. 2013	8	1	ICA	8	1 female	Saccular
Zarzecka et al. 2014	37	2	V4	15	1 male	Fusiform
Abla et al. 2014	1	1	ICA	10	1 male	Fusiform
Trivelato et al. 2017	34	1	ICA	9	1 female	Traumatic
Cobb et al. 2017	9	1	ICA	13	1 female	Iatrogenic
Lubicz et al. 2010	25	1	Basilar	17	1 female	Fusiform
		1	ICA	10	1 female	Saccular

Ref., reference number; N. of PEDs, number of pediatric patients; ICA, internal cerebral artery; MCA, middle cerebral artery; A2, second segment of the anterior cerebral artery; Acom, anterior communicating artery; M1, first segment of the middle cerebral artery; M2, second segment of the middle cerebral artery; PCA, posterior cerebral artery; ACA, anterior cerebral artery; Pcom, posterior communicating artery; V4, fourth segment of the vertebral artery

CONCLUSIONS

Flow diversion has been shown to be a safe endovascular option in treating complex aneurysms in children and can lead to complete occlusion with excellent outcomes. Larger-sized, multicenter trials are encouraged to compare outcomes between flow diversion and other aneurysm treatment options given the rarity of pediatric aneurysms.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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