



## Review Article

# Failure of tandem flow diversion for intracranial aneurysms: Literature review and illustrative case

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## ABSTRACT

**Background:** Flow diverters are becoming one of the main endovascular procedures used to treat aneurysms. Flow diverter devices (FDDs) have multiple types approved for endovascular procedure use. Although their indications are not well described, they are usually used for large or giant, wide-necked, and recurrent aneurysms. Multiple FDDs can be deployed to treat giant aneurysms to ensure and accelerate aneurysm occlusion and mitigate complications. We report a case of endovascular treatment of an intracranial aneurysm using three silk FDDs complicated by a delayed migration of the stents along the parent artery, along with a literature review of the related cases.

**Methods:** We conducted a PubMed Medline database search by the following combined formula of subjects headings: (((((intracranial aneurysm[MeSH Terms]) AND (endovascular procedure[MeSH Terms])) OR (endovascular technique[MeSH Terms])) AND (endovascular[Title/Abstract]) AND (Flow diverter[Title/Abstract])) OR (flow diversion[Title/Abstract])) OR (Pipeline[Title/Abstract])) AND (Multiple[Title/Abstract]).

**Results:** The result was eight cases of endovascular treatment of intracranial aneurysms with multiple FDD. The male-to-female ratio in these cases was 5:3, and there is a wide age range from 22 months to 69 years old. The cases differed in the type and number of FDDs used, yet, they all had similar results with aneurysm occlusion and recovery of the patient with no observed complications.

**Conclusion:** Tandem flow diverter deployment has technical challenges and complications such as complete obstruction can occur. Planning and learning from experience with those new technologies are the typical way to overcome such complications in the future.

**Keywords:** Flow diverter devices, Intracranial aneurysms, Stent migration

## INTRODUCTION

Flow diverter devices (FDDs) are relatively novel generation stents used in endovascular procedures to manage intracranial aneurysms.<sup>[3]</sup> FDDs contain a porous tubular tight meshwork;

they also have higher surface coverage and lower porosity than the classical intracranial stents. With recent developments in neuroendovascular technology, FDDs provided a new therapeutic option of total arterial reconstruction for treating intracranial aneurysms by disrupting the blood flow inside the aneurysm, therefore, inducing thrombosis.<sup>[13,19]</sup> FDDs are considered efficient and safe treatments, especially in complex aneurysms.<sup>[14]</sup>

There are five types of flow diverters currently approved for the treatment of intracranial aneurysms. These include Pipeline Embolization Device (PED), Silk, Flow Redirection Endoluminal Device (FRED), p64 Flow Modulation Device, and the Surpass Flow Diverter.<sup>[3]</sup> The exact indications of flow diversion are not yet precisely established. Nevertheless, they are primarily deployed for managing large and giant aneurysms, wide-neck aneurysms, and recurrent (ruptured or nonruptured) aneurysms.<sup>[14]</sup>

Here, we report a case of a delayed migration of three Silk flow diverter stents, leading to severe stenosis of the right cervical internal carotid artery (ICA). We explain the intricacies of FDDs and their complications, including delayed migration in the parent vessel. We have conducted a brief literature review of the published intracranial aneurysm cases managed with two or more FDDs, along with their outcomes.

## CASE REPORT

A 71-year-old female presented with the right eye ptosis and severe headache, with preserved vision. Computed tomography (CT) scan was done and it showed a subarachnoid hemorrhage in the basal cistern. In addition, CT angiography and magnetic resonance imaging were performed for the patient, and they revealed a giant aneurysm in the right ICA proximal to its bifurcation, with no evidence of the previous rupture [Figure 1].

The patient underwent diagnostic catheter angiography, which revealed a fusiform, thrombosed, and dissecting aneurysm in the cavernous segment of the right ICA, the dome width of 10.3 mm, and the dome height was 19.8 mm. The width of the proximal segment of the aneurysm was 4.7 mm [Figure 2].

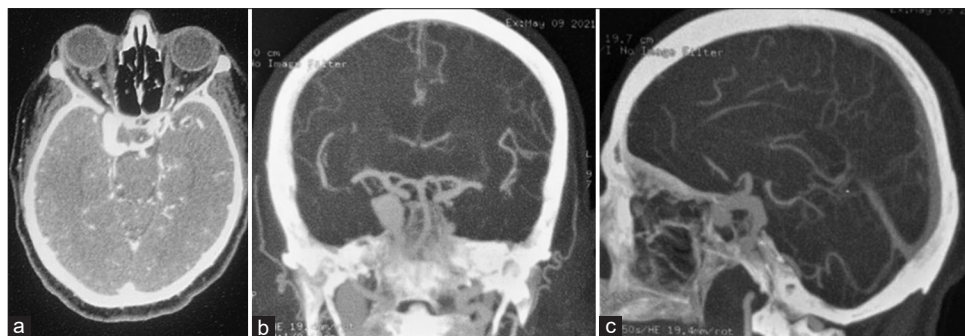
Due to the aneurysm's size and location, the decision for an endovascular approach using three sequential tandem SILK flow diverting stents was the most appropriate treatment for the case. The result of the stenting showed a significant reduction in blood flow within the aneurysm and an improvement in the patient's symptoms [Figure 3].

Six months later, the patient developed recurrent attacks of severe headache. She underwent diagnostic catheter angiography, which revealed severe stenosis of the cervical right ICA with intracranial obstruction, which was then known to be due to proximal migration of the stents inside the ICA with no recurrence of the aneurysm. The collateral blood flow showed sufficient compensation for the stenosed segment of the right ICA; therefore, the patient was started on conservative treatment along with monitoring and follow-up [Figure 4].

## LITERATURE REVIEW

### Methods

We conducted a PubMed Medline database search by the following combined formula of subjects headings: (((((intracranial aneurysm[MeSH Terms]) AND (endovascular procedure[MeSH Terms])) OR (endovascular technique[MeSH Terms])) AND (endovascular[Title/Abstract]) AND (Flow diverter[Title/Abstract])) OR (flow diversion[Title/Abstract])) OR (Pipeline[Title/Abstract])) AND (Multiple[Title/Abstract]). The reference list of the included papers was screened for additional sources.



**Figure 1:** (a) Contrast-enhanced computed tomography scan axial section is revealing a large enhancing lesion in the right internal carotid artery (ICA). (b) Computed tomographic angiography (CTA) coronal section is showing a right-sided large vascular lesion in the right ICA in its proximal segment before its bifurcation. (c) CTA sagittal section is showing a right-sided large vascular lesion in the right ICA in its proximal segment before its bifurcation.



**Figure 2:** (a) Initial diagnostic catheterization angiography illustrates a giant aneurysm in the cavernous segment of the right internal carotid artery. (b) Initial diagnostic catheterization angiography 3D image shows the diameters of the aneurysm.



**Figure 3:** Therapeutic cerebral catheter angiography showing the three silk flow diverter devices placed within the aneurysm.

## RESULTS

A total of 66 case reports were found. By excluding cases in which only a single FDD was deployed, only eight cases remained in which an intracranial aneurysm was treated by an endovascular approach using two or more FDDs. The male-to-female ratio in these cases was 5:3, and there is a wide age range from 22 months to 69 years old [Table 1].<sup>[4,5,7,8,11,12,15,16]</sup>

The most reported aneurysmal site was the cavernous segment of the ICA, with a total of three cases; two of the reported cases consisted of vertebral artery aneurysms, and the remaining cases were of middle cerebral artery aneurysms, basilar artery aneurysm, and two anterior communicating artery aneurysms.

The type of FDD used was PED in five reported cases; enterprise was used in two cases, while silk FDD was



**Figure 4:** (a) Six-month follow-up diagnostic catheter angiography showing the stenosis in the extracranial right internal carotid artery (ICA) along with intracranial obstruction. (b) Six-month follow-up diagnostic catheter angiography showing the collateral blood flow from the left ICA.

deployed in only one of the mentioned cases. The number of FDDs deployed to occlude the aneurysm differed between the reported cases. A total of two PEDs were deployed in two of these cases; two cases showed the use of three FDDs, two other cases described the use of five FDDs, while the two remaining cases either used four FDDs or did not specify the exact number.

The outcome was similar in all the reported cases, with complete occlusion of the aneurysm on follow-up with no signs of ischemia and no complications associated with the stents' placement.

## DISCUSSION

Management of intracranial aneurysms includes open surgical approaches by clipping the aneurysm or endovascular treatment, which consists of direct embolization, stenting alone, and flow diversion. FDDs are becoming more important in aneurysmal treatment due to the significant intraoperative complications associated with open surgical approaches, the shallow nature, the shape of the aneurysms, and the natural tortuosity in some vessels such as the ICA, which renders stent-assisted coiling ineffective.<sup>[1,17]</sup>

FDDs are new-generation stents used primarily in large and giant aneurysms, wide-necked, and recurrent aneurysms.<sup>[14]</sup> They are used for saccular, fusiform, and blister-type ruptured aneurysms.<sup>[10]</sup>

When deployed, FDDs produce vessel reconstruction by two main hemodynamic and biological effects, which consist of redirection of blood flow by bridging the neck of the aneurysm, leading to thrombosis inside the aneurysm. Therefore, excluding the sac from circulation, without the need to catheterize it, decreases the risk of aneurysmal rupture and tissue overgrowth by providing scaffolding for the production of endothelium and neointimal tissue across the neck of the aneurysm.<sup>[3,13,14]</sup> The use of FDDs in challenging and complex aneurysms aids in reducing the recanalization

**Table 1:** Presented cases of two or more flow diverters used for aneurysmal treatment.

Author/year	Age/gender	Aneurysm type and location	FDS type	Number of FDDs used	Patient's outcome
Crowley <i>et al.</i> , 2009 <sup>[5]</sup>	22 months/M****	Fusiform basilar artery aneurysm	Enterprise	Three	A 4-month follow-up showed near complete occlusion of the aneurysm with no signs of ischemia along the parent vessel.
Rouchaud <i>et al.</i> , 2013 <sup>[15]</sup>	61/M	Right AcomA* aneurysm and left A1/A2 junctions of the ACA**.	PED***	Two	A 3-month follow-up catheter angiogram confirmed complete exclusion of the aneurysms, complete exclusion of the AComA, and patency of the two ACAs
Cohen <i>et al.</i> , 2012 <sup>[4]</sup>	51/M	Giant dolichoectatic and fusiform aneurysms of the vertebrobasilar artery.	SILK	Four	Six months after his endovascular procedure, he showed marked improvement in cranial nerve function, and head CTA**** with 3D reconstruction revealed significant reduction in the aneurysm lumen
Ikeda <i>et al.</i> , 2015 <sup>[7]</sup>	12/F****	Recurrent giant middle cerebral artery aneurysm	PED	Three	There was no evidence of residual or recurrent aneurysm and no delay in filling of her distal jailed vasculature at her 6-month follow-up.
Miyachi <i>et al.</i> , 2018 <sup>[12]</sup>	48/F	Giant carotid cavernous aneurysm	PED	Five	Six months follow-up, the angiogram showed complete occlusion of the aneurysm and remodeling pathway formed with telescoping PEDs
Son <i>et al.</i> , 2018 <sup>[16]</sup>	24/M	Giant cavernous fusiform aneurysm	PED	Two	Three months later, follow-up CT angiography revealed complete flow diversion of the giant aneurysm.
Imahori <i>et al.</i> , 2019 <sup>[8]</sup>	69/F	Vertebral artery dissecting aneurysm	Enterprise	Five	On follow-up, the aneurysm was occluded, and there are no signs of ischemia
Mantripragada <i>et al.</i> , 2020 <sup>[11]</sup>	18/M	Bilateral giant fusiform aneurysm of the petrocavernous ICA*****	PED	Not specified	Six-month follow-up angiography showed occlusion of the left ICA at its origin, while the right ICA was normal.
Al-Ageely <i>et al.</i> , 2022 (Current study)	71/F	Right ICA giant aneurysm.	SILK	Three	Six months later, the patient developed recurrent attacks of severe headache. diagnostic catheter angiography revealed severe stenosis of the cervical right ICA with intracranial obstruction with proximal migration of the flow diverter.

AcomA\*: Anterior communicating artery, ACA\*\*: Anterior cerebral artery, PED\*\*\*: Pipeline embolization device, M, F\*\*\*\*: Male, female, CTA\*\*\*\*: Computed tomography angiography, ICA\*\*\*\*\*: Internal carotid artery

rate and evades the mass effect caused by coiling. FDDs can be used alone or in conjugation with coiling to accelerate the process of thrombosis inside the aneurysm.<sup>[2]</sup>

The decision of the best endovascular approach and indications for the use of FDDs are still a subject of debate. Flow diversion has five main types that have been approved for the management of intracranial aneurysm: the PED, which is a self-expanding, flexible, and cylindrical mesh-like device consisting of platinum tungsten and cobalt chromium,

made from 48 strands interwoven in a standard pattern, the Silk is a self-expanding stent made of 48 braided nitinol strands that have a wider range of diameters than in PED, the FRED, the p64 Flow Modulation, and the Surpass Flow Diverter.<sup>[3,14]</sup>

Significant disadvantages of using FDDs include their higher cost value, high reoperation rate, and increased risk of pressure effect on an aneurysm after the placement of a stent, which is still a subject of discussion and remains one of the critical



issues associated with FDDs.<sup>[9]</sup> Although the mortality and morbidity rates associated with FDDs are lower than those associated with open surgical management, there are still a few complications associated with flow diversion.<sup>[14]</sup> Blockage or significant stenosis of the parent artery during the placement of an FDD was seen in approximately 3.8%. Late occlusion, which is caused by embolization of the distal vessels due to the thrombus formed spontaneously after the deployment of the stent, or significant stenosis of the parent vessel, was found during the follow-up in almost 6.8% of the patients. This event is often incidental and occurs when stopping the antiplatelet therapy with clopidogrel. Although less commonly seen, ischemic complications can occur due to parent artery or side branch occlusion and perforator infarction.<sup>[3,20]</sup>

The delayed migration of a flow diverter stent is a severe but rare complication that could be associated with a high mortality rate. The migration of the device can be seen proximally or distally in the parent artery and can result in aneurysm rupture or thromboembolic incidents. The risk factors for FDD proximal or distal migration include a substantial mismatch in diameter between the inflow and outflow vessels; giant aneurysms with a long neck; tortuous parent vessels; and the patient's underlying vascular risk factors, such as smoking and hypertension, which can lead to the delay of the endothelialization of the FDD. Management of delayed FDD migration includes endovascular procedures such as stent-assisted coiling, balloon anchoring, and flow diverter placement, in addition to sacrificing the parent vessel. Prevention of the delayed flow diverter stents migration can be done through the accurate measurements of the diameters within the inflow and outflow vessels, vigilance is needed in choosing the correct size, length, and the number of stents to be placed.<sup>[18]</sup>

The utilization of multiple telescoped FDDs might be well tolerated in cases where neurosurgeons believe that multiple stents would improve the aneurysm occlusion rates compared with single devices.<sup>[6]</sup>

We conducted a brief review of the literature for using two or more FDDs in treating patients with intracranial aneurysms. We have found eight similar cases in the literature in which multiple FDDs were deployed to manage an intracranial aneurysm. Similar to our case, all the reported cases improved the patients' symptoms with successful occlusion of the aneurysm observed during follow-up. However, none of the cases mentioned showed delayed complications, including the migration of the FDDs deployed in the parent vessel, like in our case.

## CONCLUSION

Tandem flow diverter deployment has technical challenges and complications, which include complete obstruction. Planning and learning from experience with the continuous

advancement in such technologies are the typical way to overcome such complications in the future.

## Declaration of patient consent

Patients' consent not required as patients' identities were not disclosed or compromised.

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## Conflicts of interest

There are no conflicts of interest.

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