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*Case Report*

# Plasticity of the adult circle of Willis in response to flow diversion stents

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## ABSTRACT

**Background:** We present five patients with remodeling of the adult circle of Willis in response to flow diverter stents (FDSs) at the anterior communicating artery (AComA) and the posterior communicating artery (PComA). The observed changes provide a paradigm of how flow change can institute anatomic changes in the adult circle of Willis vasculature.

**Case Description:** In the first two cases, after placement of the FDS covering the AComA, there was an increase in size and flow of the contralateral A1-anterior cerebral artery which had previously been hypoplastic. In one of the cases, this led to the filling of the aneurysm and required placement of coils within the lesion which was curative. In case three, the FDS effect led to asymptomatic occlusion of the PComA and associated aneurysm without change of the ipsilateral P1-segement of posterior-cerebral-artery (P1-PCA) caliber. In the fourth case, the FDS covering an aneurysm with a fetal PCA arising from its neck resulted in significant reduction of the aneurysm size, persistent flow and caliber of the fetal PCA, and the hypoplastic ipsilateral P1-PCA. Finally, in the fifth case, after FDS occlusion of the PComA and aneurysm there was increasement in diameter of the ipsilateral P1-PCA that was previously hypoplastic.

**Conclusion:** The use of FDS can affect vessels covered by the device and other arteries of the circle of Willis adjacent to the FDS. The phenomena illustrated in the hypoplastic branches appear to be a compensatory response to the hemodynamic changes induced by the divertor and to the altered flow in the circle of Willis.

**Keywords:** Circle of Willis, Flow diversion, Intracranial aneurysms, Vascular remodeling

## INTRODUCTION

Flow diverters have been established as safe and first-line devices for carefully selected intracranial aneurysms (IAs), representing more than a third of aneurysms treated in some centers.[13] Although initially approved for the treatment of large or giant aneurysms of the internal carotid artery (ICA), the indications have widened to other locations.[3,11] As flow diverter stents (FDSs) are used in various anatomic positions within the circle of Willis, there are observed alterations in vessel anatomy and flow.[8,9] We present here a series of patients with aneurysms treated in the anterior communicating segment and with origin of the posterior communicating artery (PComA) that illustrates the plasticity of the circle of Willis vessels in response to flow diverter placement.

## CASES REPORTS

### Patient 1

A 54-year-old man with anterior communicating artery (AComA) IA was initially treated with a pipeline flow-diverter implanted in the left anterior cerebral artery (ACA), jailing the AComA. In the control of 12 months, it was noted that the contralateral A1 segment of the ACA (A1-ACA) was hypoplastic initially. This vessel increased in diameter and recanalized the previously treated aneurysm. This led to the decision to embolize AComA IA with coils, accessing it through the contralateral ACA, which resulted in complete obliteration of the lesion which has remained stable in follow-up studies over 1 year [Figure 1].

### Patient 2

A 71-year-old woman with AComA IA was treated with a pipeline flow-diverter implanted in the left ACA from the A1 segment to the A2 segment, excluding the AComA. In the follow-up control angiogram at 2 years after, it was noted that the A1-ACA on the right had increased in diameter. However, in this case, there was no recanalization of the IA, which was completely obliterated [Figures 2 and 3].

### Patient 3

A 61-year-old man with PComA IA was treated with a pipeline flow-diverter implanted in the left ICA, covering the origin of the PComA. In the follow-up angiogram at 6 months, the IA and PComA were occluded. The patient incurred no neurologic deficit which suggests increase flow from the ipsilateral P1-segement of posterior-cerebral-artery (P1-PCA) without change in its caliber by visual angiographic analysis [Figures 4 and 5].

### Patient 4

A 72-year-old woman with IA of PComA and hypoplastic P1-PCA with a fetal type right PCA was treated with a pipeline flow-diverter implanted in the right ICA, across the origin of the PComA. In the follow-up angiogram at 8 months, it was noted that the IA had decreased in size and the fetal PCA remained patent with the same caliber emerging close to the IA neck. The left P1 segment of the left PCA remained hypoplastic with the same caliber. The patient had no neurologic deficits [Figures 6 and 7].

### Patient 5

A 61-year-old woman was found incidentally with a left PComA aneurysm on MRI during work-up for occipital neuralgia. On physical examination, she was neurologically intact. Decision was made to proceed with pipeline stent placement in the ICA across the aneurysm neck. She tolerated the procedure well with complete obliteration of her aneurysm at 2-year follow-up magnetic resonance angiography. However, curiously, in this follow-up examination, the left P1-PCA showed a significant increase in caliber and filling. She remained neurologically intact until her late follow-up at 2 years [Figures 8 and 9].

## DISCUSSION

We have presented five patients that demonstrate different patterns of arterial remodeling of the circle of Willis vessels in adult patient response to flow diversion. These changes

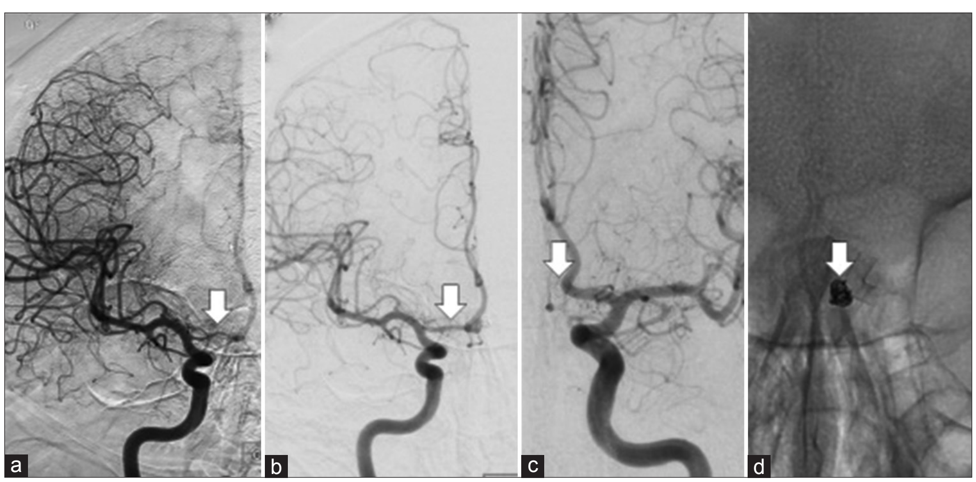


**Figure 1:** (a) Initial cerebral angiography image demonstrating hypoplastic A1-anterior cerebral artery (ACA) with minimal filling of right ACA (arrow). (b and c) Cerebral angiography image performed 26 months after coils and pipeline. Note increased caliber of the right A1 and filling of the ACA with a stable aneurysm occlusion (arrows). (d) Plain X-ray showing the flow diverter stents and coils (arrow).

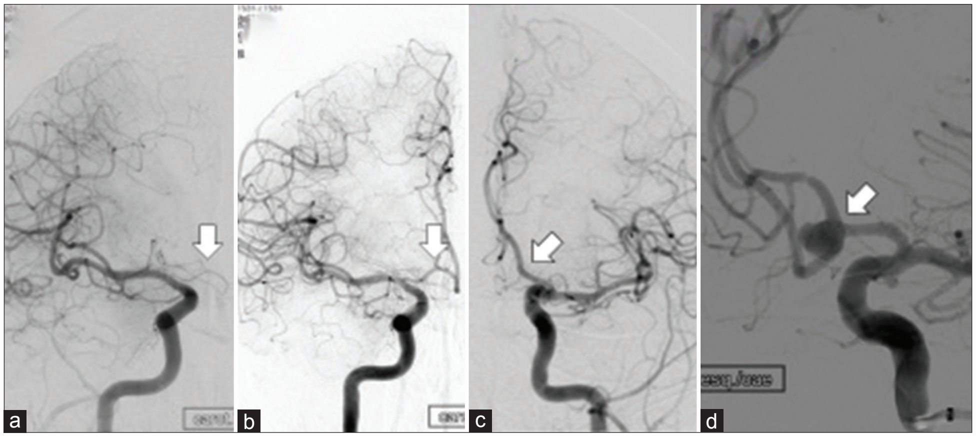


**Figure 2:** (a) Initial cerebral angiography image demonstrating a hypoplastic right A1-anterior cerebral artery (ACA) (arrow) without filling of the ipsilateral ACA. (b and c) Cerebral angiography follow-up almost 24 months after placement of the flow diverter stents in the left A1-A2 shows increased caliber of the right A1 segment and now filling of the right ACA (arrow). The aneurysm remained occluded (arrow). (d) Initial cerebral angiography image demonstrating the anterior communicating artery aneurysm before treatment (arrow).

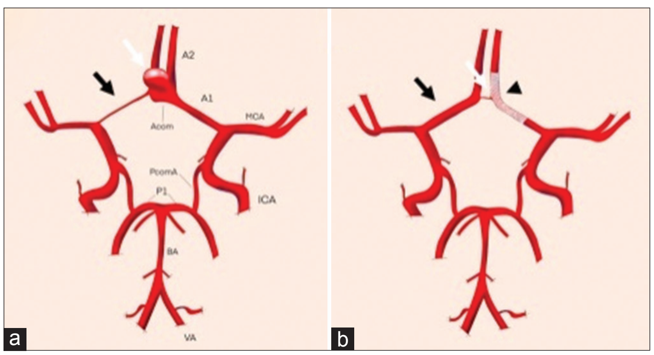


**Figure 3:** (a) Schematic drawings of patients 1 and 2 showing the anterior communicating artery aneurysm (white arrow) with its neck related to the left A1–A2 anterior cerebral artery and a hypoplastic right A1-anterior cerebral artery (black arrow) (b) Changes at the follow-up represented by the flow diverter stents (FDS) placement in the left A1–A2 with occlusion of the aneurysm sac (white arrow) and increase in the caliber of the right A1-anterior cerebral artery (black arrow) in response to the FDS (arrowhead) effect.

can be divided into two main phenomena: (1) in the AComA circulation, a patient with a of hypoplastic or reduced-caliber A1-ACA, can increase the caliber of this vessel in response to having the contralateral ACA segment A1 and A2 covered by the flow diverter. (2) In the posterior circulation, patients with hypoplastic or reduced-caliber P1-PCA or fetal PCA can indeed have increase in the P1-PCA diameter of the vessel after having the origin of the ipsilateral PComA covered by the flow diverter in the ICA and also no neurological deficits after coverage with or without a FDS, leading to occlusion of the ipsilateral PComA.

This phenomenon, which seems to be a compensatory response to the decrease in flow in arteries that emerge from the segment implanted with the flow diverter, is not new in this article, as it has already been reported by other authors.[8,9] However, something unprecedented for us was to observe these compensatory mechanisms in previously hypoplastic segments vessels in the circle of Willis.

In trying to understand more about vascular remodeling responses, two main types of studies have tried to address changes after placement of a flow diverter. Several studies have analyzed the artery adjacent to the device.[1,2,6,10,12,14] A few other studies have analyzed responses in the circle of Willis and other vessels in response to flow diverter placement.[5,7-9,16] The phenomena reported here in the response of hypoplastic arteries make up one of the three possible types of vascular response to the implantation of flow-diverting stents, which is the increase in the diameter or flow of the artery of the circle of Willis (A1-ACA or P1-PCA) to compensate for the territory of the artery covered by the device. This seems to be corroborated with the findings of Cornelissen *et al*.[4] 2018 who found significantly lower flows in the basilar artery in the presence of hypoplastic P1-PCA, and higher in A1-ACA when there is a contralateral hypoplastic segment. In addition, Narata *et al*.,[10] in 2018, identified a marked correspondence between asymmetric bifurcations and post device implantation caliber change, as well as a greater impact on shear stress in the "jailed" vessel when flow-diverters were implanted in asymmetric bifurcations. Vedantam *et al*.,[15] in 2015, studied clinical outcomes associated with occlusion of supraclinoid ICA branches after deployment of flow diverters and found that arteries without substantial collaterals were more likely to remain patent and, in cases where this collateral network was substantial, occlusion would likely be asymptomatic.

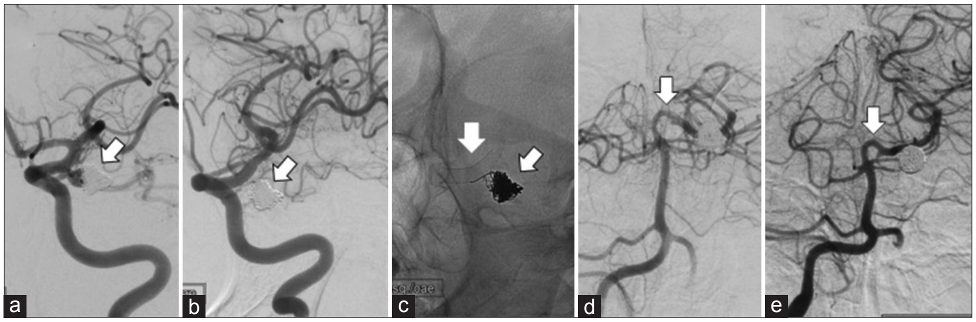

**Figure 4:** Patient 3 – (a) Coiled aneurysm before flow diverter stents (FDS) placement (arrow) with the posterior communicating artery (PComA) originating from the aneurysm. (b) Follow-up angiogram showing complete occlusion of the aneurysm (arrow) and PComA by the flow diversion effect. (c) Plain X-ray images showing coils and flow diverter stent (arrows). (d) Vertebral angiogram before internal carotid artery FDS placement showing a moderate size P1-segement of posterior-cerebral-artery (arrow) and (e) post FDS with stable size (arrow).

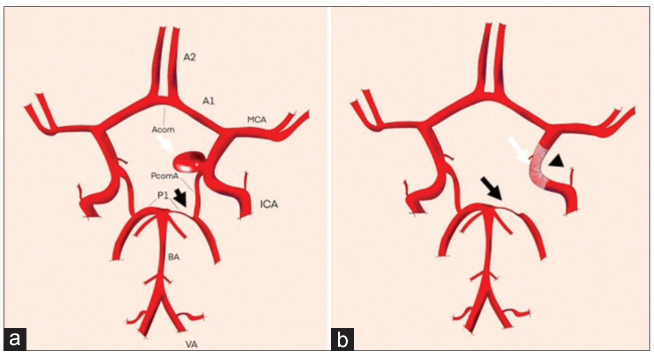


**Figure 5:** (a) Schematic drawing of patient 3 showing the posterior communicating artery (PComA) aneurysm (white arrow) and a left hypoplastic P1 (black arrow) before the flow diverter stents (FDS) late effect. (b) After late FDS (arrowhead) effect changes showing occlusion of the aneurysm (white arrow) and adjacent PComA with no significant visual increase in the diameter of the left P1-segement of posterior-cerebral-artery (black arrow).

**Figure 6:** Patient 4 – (a) Large bilobulated internal carotid artery aneurysm (arrow) with a fetal posterior-cerebral-artery (PCA) arising from the sac adjacent to its neck. (b) Follow-up angiogram showing significant reduction of the aneurysm sac (arrow) and patency of the fetal PCA.

One theory for non-arteries, occlusion of vessels without substantial collaterals, was that in these vessels, the pressure

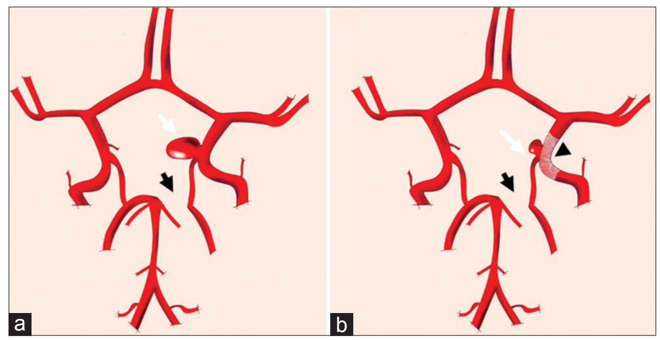

**Figure 7:** (a) Schematic drawing of patient 4 showing the posterior communicating artery aneurysm with a fetal posterior-cerebral-artery (PCA) arising close to its neck (white arrow) and a left hypoplastic P1 (black arrow) before the late flow diversion effect. (b) After late flow diverter stents (arrowhead) effect changes showing a reduction of the aneurysm size with patency and same size of the left fetal PCA (white arrow) and hypoplastic left P1 (black arrow) at the follow-up.

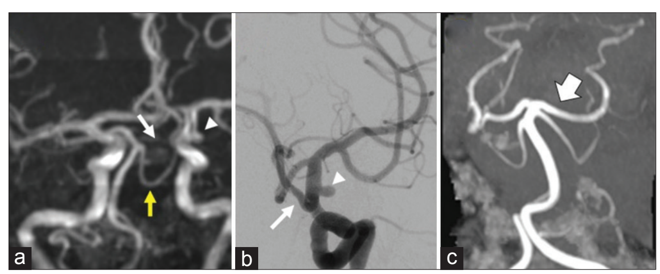

**Figure 8:** Patient 5 – (a) MRA showing hypoplastic P1-segement of posterior-cerebral-artery (P1-PCA) (arrow) and the left supraclinoid internal carotid artery (ICA) aneurysm measuring 3.9 mm (arrowhead). Superior cerebellar artery (yellow arrow). (b) Digital subtraction ICA angiogram in oblique view during the endovascular procedure showing the left fetal PCA (arrow) and the aneurysm (arrowhead) covered by the flow diverter stent. (c) Follow-up MRA after ICA FDS placement with increase in the size of the left P1-PCA (arrow) and filling of the ipsilateral PCA.

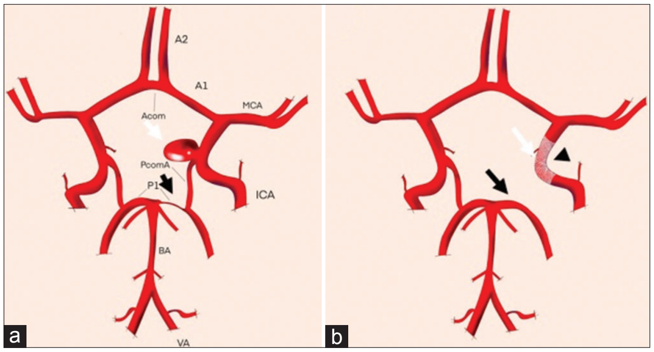


**Figure 9:** (a) Schematic drawing of patient 5 showing the posterior communicating artery (PComA) aneurysm (white arrow) and a left hypoplastic P1 (black arrow) before the flow diverter stents (FDS) late effect. (b) After late FDS (arrowhead) effect changes showing occlusion of the aneurysm (white arrow) and adjacent PComA with significant increase in the diameter of the left P1-segement of posterior-cerebral-artery (black arrow).

gradient would be greater than in those with collaterals, thus increasing the threshold for occlusion of these vessels. We identify another type of response in the collateral circuits of the circle of Willis. Thus, the lack of substantial collaterals, as in hypoplastic A1-ACA or P1-PCA, in addition to increasing the occlusion threshold of AcomA and PcomA, could also favor the increase in flow and caliber of these previously hypoplastic collaterals vessels. The other two responses are better known phenomena – and include occlusion or reduction of the artery covered by a flow diverter, or the appearance of retrograde pial collaterals in cases of placement of a device in more distal vessels such as the middle cerebral artery bifurcation.

The findings of this study in addition to others raise numerous questions on the subject including the precise hemodynamic mechanisms responsible for remodeling as well as the safety of treating patients with flow dependent on the AComA or PComA with flow diversion. The type of flow diverter used with different mesh density and design may also influence the observed anatomic changes. Future studies that hemodynamically compare these scenarios including use of computational fluid analysis may bring more insight on the subject.

## CONCLUSION

The use of flow diverters can affect both vessels "jailed" by the stent and other arteries of the circle of Willis, leading to significant changes in the flow and size of these vessels. These phenomena appear to be a compensatory response to the hemodynamic changes induced by the flow diversion. The issues raised, as well as the safety of treating patients with certain vascular anatomy, require further investigation.

### Declaration of patient consent

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

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Nil.

### Conflicts of interest

There are no conflicts of interest.

## REFERENCES

1. Brinjikji W, Kallmes DF, Cloft HJ, Lanzino G. Patency of the anterior choroidal artery after flow-diversion treatment of internal carotid artery aneurysms. Am J Neuroradiol 2015;36:537-41.
2. Brinjikji W, Lanzino G, Cloft HJ, Kallmes DF. Patency of the posterior communicating artery after flow diversion treatment of internal carotid artery aneurysms. Clin Neurol Neurosurg 2014;120:84-8.
3. Brouillard AM, Sun X, Siddiqui AH, Lin N. The use of flow diversion for the treatment of intracranial aneurysms: Expansion of indications. Cureus 2016;8:e472.
4. Cornelissen BM, Schneiders JJ, Sprengers ME, van den Berg R, van Ooij P, Nederveen AJ, *et al.* Aneurysmal parent artery-specific inflow conditions for complete and incomplete circle of willis configurations. Am J Neuroradiol 2018;39:910-5.
5. de Carvalho FM, Caroff J, dos Santos Neto E, Chalumeau V, Khalek HA, Neki H, *et al.* Flow changes in the posterior communicating artery related to flow-diverter stents in carotid siphon aneurysms. J Neurointerv Surg 2017;9:674-8.
6. Gascou G, Lobotesis K, Brunel H, Machi P, Riquelme C, Eker O, *et al.* Extra-aneurysmal flow modification following pipeline embolization device implantation: Focus on regional branches, perforators, and the parent vessel. Am J Neuroradiol 2015;36:725-31.
7. Iosif C, Berg P, Ponsonnard S, Carles P, Saleme S, Ponomarjova S, *et al.* Role of terminal and anastomotic circulation in the patency of arteries jailed by flow-diverting stents: From hemodynamic changes to ostia surface modifications. J Neurosurg 2017;126:1702-13.
8. Litao MS, Burkhardt JK, Tanweer O, Raz E, Huang P, Becske T, *et al.* Remodeling of the posterior cerebral artery P1-segment after pipeline flow diverter treatment of posterior communicating artery aneurysms. Neurol Int 2021;13:195-201.
9. Muneer MS, Todnem N, Gopal N, Marenco-Hillembrand L, Barakat E, Mbabuike N, *et al.* Pattern of changes in cross sectional area of arterial branches after jailing with pipeline embolization device: Beyond parent neck artery patency. Clin Imaging 2022;83:159-65.
10. Narata AP, de Moura FS, Larrabide I, Perrault CM, Patat F, Bibi R, *et al.* The role of hemodynamics in intracranial bifurcation arteries after aneurysm treatment with flow-diverter stents. Am J Neuroradiol 2018;39:323-30.
11. Patel PD, Chalouhi N, Atallah E, Tjoumakaris S, Hasan D,

Zarzour H, *et al*. Off-label uses of the Pipeline embolization device: A review of the literature. Neurosurg Focus 2017;42:E4.
12. Puffer RC, Kallmes DF, Cloft HJ, Lanzino G. Patency of the ophthalmic artery after flow diversion treatment of paraclinoid aneurysms. J Neurosurg 2012;116:892-6.
13. Ravindran K, Casabella AM, Cebral J, Brinjikji W, Kallmes DF, Kadirvel R. Mechanism of action and biology of flow diverters in the treatment of intracranial aneurysms. Neurosurgery 2020;86:S13-9.
14. Rouchaud A, Leclerc O, Benayoun Y, Saleme S, Camilleri Y, D'Argento F, *et al*. Visual outcomes with flow-diverter stents covering the ophthalmic artery for treatment of internal carotid artery aneurysms. Am J Neuroradiol 2015;36:330-6.
15. Vedantam A, Rao VY, Shaltoni HM, Mawad ME. Incidence and clinical implications of carotid branch occlusion following treatment of internal carotid artery aneurysms with the pipeline embolization Device. Neurosurgery 2015;76:173-8.
16. Wallace AN, Kayan Y, Austin MJ, Almandoz JE, Kamran M, Cross DT, *et al*. Pipeline embolization of posterior communicating artery aneurysms associated with a fetal origin posterior cerebral artery. Clin Neurol Neurosurg 2017;160:83-7.

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