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ABSTRACT

BACKGROUND AND PURPOSE: Treatment of cerebral aneurysms with flow diverters often mandates placement of the device across the ostia of major branches of the internal carotid artery. We determined the patency rates of the anterior choroidal artery after placement of flow-diversion devices across its ostium.

MATERIALS AND METHODS: We analyzed a consecutive series of patients in whom a Pipeline Embolization Device was placed across the ostium of an angiographically visible anterior choroidal artery while treating the target aneurysm. Patency of the anterior choroidal artery after Pipeline Embolization Device placement was determined at immediate postoperative and follow-up angiography. Data on pretreatment aneurysm rupture status, concomitant coiling, number of Pipeline Embolization Devices used, neurologic status at follow-up, and follow-up MR imaging/CT findings were collected.

RESULTS: Fifteen patients with 15 treated aneurysms were included in this study. In the immediate postprocedural setting, the anterior choroidal artery was patent on posttreatment angiography for all 15 patients. Of the 14 patients with follow-up angiography at least 6 months after Pipeline Embolization Device placement, 1 (7%) had occlusion of the anterior choroidal artery and 14 had a patent anterior choroidal artery (93%). No patients had new neurologic symptoms or stroke related to anterior choroidal artery occlusion at follow-up. Of the 9 patients with follow-up CT or MR imaging, none had infarction in the vascular territory of the anterior choroidal artery.

CONCLUSIONS: In this small study, placement of a Pipeline Embolization Device across the anterior choroidal artery ostium resulted in occlusion of the artery in only 1 patient. It was not associated with ischemic changes in the distribution of the anterior choroidal artery in any patient.

ABBREVIATIONS: AchoA = anterior choroidal artery; PED = Pipeline Embolization Device

Flow-diverter devices such as the Pipeline Embolization Device (PED; Covidien, Irvine, California) are increasingly being used in the embolization of intracranial aneurysms as both alternatives and adjuncts to endovascular coiling.[1-4] Flow diverters limit aneurysmal blood flow but maintain blood flow into large vessels and perforating vessels covered by the device.[5] Although many in vitro and experimental models have demonstrated long-term patency rates of branch vessels covered by the PED, the long-term patency of major branch vessels is not well-established.[6-8] In this study, we assessed the immediate and long-term patency rates of the anterior choroidal artery (AchoA) in patients following the placement of a PED across the AchoA ostium.

MATERIALS AND METHODS

After institutional review board approval, we examined a consecutive series of patients undergoing treatment of intracranial aneurysms with the PED, in which the PED was placed across the ostium of the anterior choroidal artery, from January 2010 to December 2013. Current on-label use of PEDs is for aneurysms of >10 mm in diameter with a neck of >4 mm in the ICA up to but not including the posterior communicating artery. In this study, we used the PED off-label for wide-neck aneurysms considered likely to require stent coiling.

All patients undergoing treatment were premedicated with aspirin and clopidogrel, and full anticoagulation was maintained during the procedure (target activated clotting time between 250 and 300 seconds). Following the procedure, patients were maintained on dual antiplatelet therapy for 3 months. After 3 months,

Table 1: Patient characteristics

Patient No.	Presentation	Side	Aneurysm Location	Prior Coiling	Aneurysm Size (mm)
1	VF deficit	Left	Carotid terminus	Yes	25
2	Headache	Left	PcomA	No	27
3	SAH	Left	ICA blister	No	4
4	Asymptomatic	Right	PcomA	No	3
5	Prior SAH	Left	Paraclinoid	Yes	13
6	Headache	Left	PcomA	Yes	16
7	Prior SAH	Left	Carotid terminus	Yes	20
8	Asymptomatic	Left	PcomA	No	7
9	Asymptomatic	Left	AchoA	No	11
10	Symptomatic	Left	PcomA	No	20
11	Prior SAH	Right	PcomA	Yes	10
12	Asymptomatic	Left	PcomA	No	11
13	Asymptomatic	Left	Paraclinoid	No	13
14	Prior SAH	Left	Paraclinoid	Yes	16
15	Asymptomatic	Right	PcomA	No	4

Note:—VF indicates visual field; PcomA, posterior communicating artery.

clopidogrel was discontinued and aspirin was continued indefinitely. This antiplatelet regimen was the same in all patients, and no platelet responsiveness studies were used in these cases. All the procedures were performed with the patient under general endotracheal anesthesia. A bi- or triaxial access technique and, in all cases, a Marksman microcatheter (Covidien) were used to obtain distal access past the segment of the vessel harboring the target aneurysm. Pipeline Embolization Devices were sized to match the maximum diameter of the target vessel. One or multiple devices were used at the discretion of the operators to maximize the changes of complete aneurysm occlusion and/or to ensure adequate coverage of the aneurysm neck and a segment of the parent artery proximal and distal to it. Digital subtraction angiography was performed at 2 frames per section before and following placement of the PED.

Determination of AchoA patency by all authors was made for each patient immediately after the original procedure and at the follow-up angiography performed furthest from the initial procedure. Note was also made of any subjectively determined change in flow patterns (slowing of angiographic flow after PED deployment and/or at follow-up). All patients underwent a detailed clinical examination before the procedure, immediately after the procedure, the following day, and at each corresponding follow-up angiography. In addition to AchoA patency, patient age, sex, presentation, aneurysm size, previous coiling, neurologic status on last follow-up, and follow-up MR imaging and CT results were collected. Postoperative follow-up CT and MR imaging results were divided into 2 time periods: 1) within 1 month of the procedure, and 2) >1 month after the procedure. Infarction location in the AchoA distribution was defined as infarctions localized to the posterior limb of the internal capsule and thalamus as described by Damasio.[9] All images were reviewed by 2 neuroradiologists. Patient neurologic status on last follow-up was scored by using the modified Rankin Scale and was assessed on follow-up with the Neurosurgery Department.

Statistical Analysis
Summary statistics are presented for all data available by using means ± SDs for continuous variables and frequency tabulations for categoric variables. All statistical analyses were performed by using JMP 9.0 (SAS Institute, Cary, North Carolina).

RESULTS
Patient and Aneurysm Characteristics
Fifteen patients (12 women and 3 men) with 15 PED-treated aneurysms were included in this study. Mean patient age was 56.0 ± 14.4 years (range, 34–75 years). Aneurysm sizes ranged from 3 to 27 mm with a mean of 13.0 ± 7.4 mm. Twelve aneurysms were unruptured; 3 were previously ruptured and were treated with coil embolization in the acute phase and staged Pipeline placement after patients had recovered from the acute SAH. Two patients had their aneurysm treated after it was discovered during treatment of a different, ruptured aneurysm. Three patients with unruptured aneurysms had prior aneurysm coiling. One PED was placed in 11 patients. These data are summarized in Table 1.

Clinical and Angiographic Follow-Up
Initial postoperative angiography demonstrated patency of the AchoA in all 15 patients. One patient (patient 3) died 10 days after PED placement from intraparenchymal hemorrhage but had a follow-up angiography on postprocedural day 1, which demonstrated a patent AchoA. Of the remaining 14 patients, angiographic follow-up times ranged from 6 to 30 months, with a mean follow-up of 12.0 ± 7.2 months. Of these 14 patients, 13 had a patent AchoA (93%) and 1 had occlusion of the AchoA (7%) (Figure). There were no instances of slowing of flow in the AchoA.

The mean clinical follow-up time was 12 ± 8.6 months, with a minimum follow-up of 10 days and a maximum follow-up of 30 months. One patient (patient 3) presented with SAH resulting from an ICA blister aneurysm and was treated in the acute phase with a PED. One day following the procedure, this patient was found to have multiple watershed infarcts in the bilateral anterior cerebral artery/MCA distribution and a large frontal lobe intraparenchymal hematoma ipsilateral to the treated aneurysm. This patient died 10 days after the procedure because of the intraparenchymal hematoma. Of the remaining patients, the mRS scores at last follow-up ranged from 0 to 2 (mean = 1 ± 0.76). None of these patients had neurologic complications related to the procedure. No patients had clinical strokes in the perioperative period or during long-term follow-up. The most common cause for an mRS of >0 was headache. The 1 patient with occlusion of the AchoA had an mRS of zero at 6 months and experienced no symptoms related to AchoA occlusion. These data are summarized in Table 2.

MR Imaging/CT Follow-Up
Eight patients had postoperative MR imaging or CT within 1 month of PED placement. Patient 3, described above, had an intraparenchymal hemorrhage with multiple bilateral watershed infarcts on CT on postoperative day 1. Seven patients underwent early postoperative MRI (1–5 days postopera-
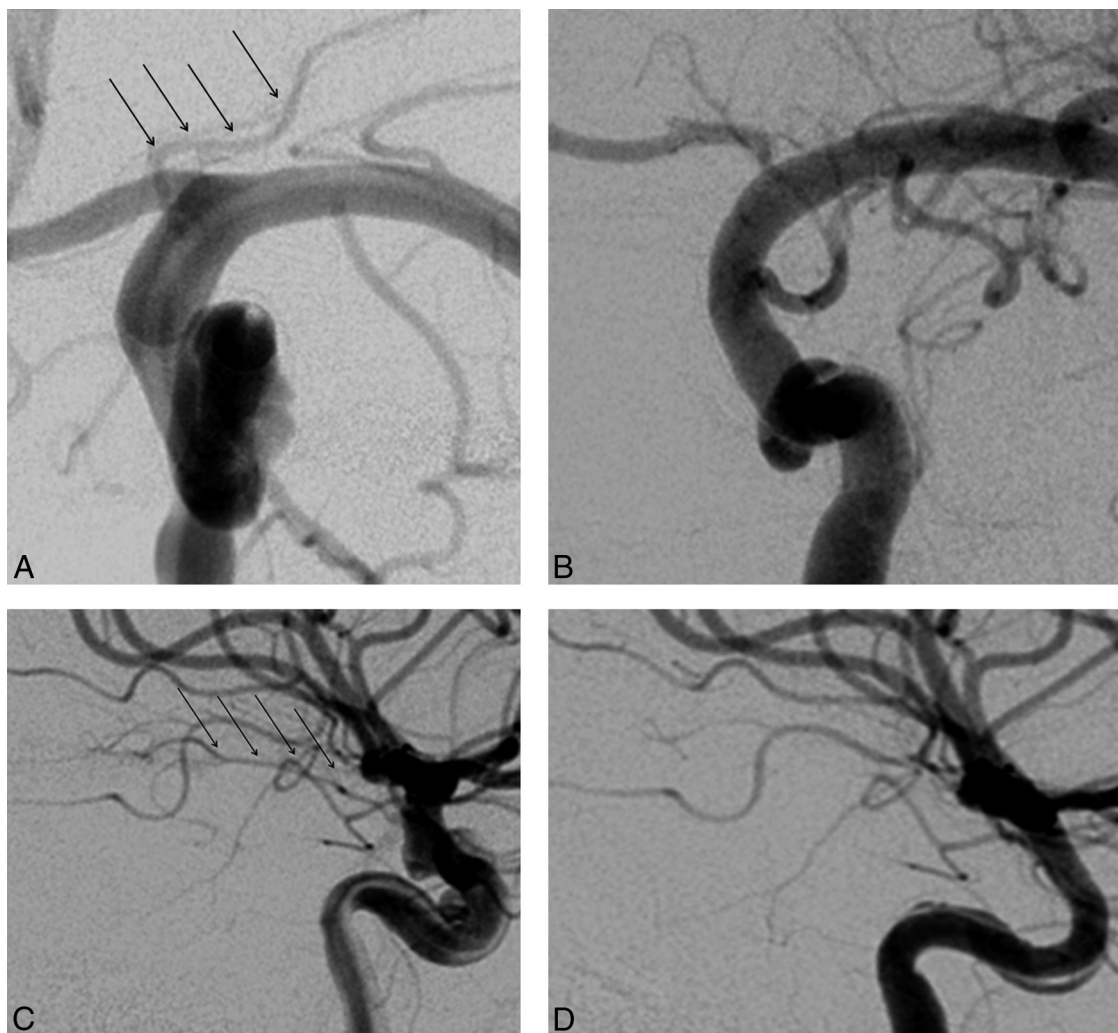
FIGURE. Occlusion of anterior choroidal artery on follow-up angiography. *A*, Anteroposterior view of the anterior choroidal artery on pretreatment angiography demonstrates a patent anterior choroidal artery (*black arrows*). *B*, Follow-up angiogram 7 months posttreatment demonstrates absence of filling of the anterior choroidal artery. *C*, Lateral view of the anterior choroidal artery on pretreatment angiography demonstrates that it is patent (*black arrows*). *D*, Follow-up angiogram 7 months posttreatment demonstrates absence of filling of the anterior choroidal artery.

Table 2: Angiographic results

Patient No.	No. of Devices	Immediate Postangiography AchoA Patency	Long-Term Patency	Angiographic Follow-Up (mo)	Aneurysm Occlusion, Last Follow-Up
1	3	Patent	Patent	14	Occluded
2	2	Patent	Patent	30	Residual aneurysm
3	1	Patent	NA	1 day	NA
4	2	Patent	Patent	25	Residual aneurysm
5	1	Patent	Patient	13	Residual neck
6	1	Patent	Patent	6	Residual neck
7	1	Patent	Patent	9	Occluded
8	1	Patent	Patent	12	Residual aneurysm
9	1	Patent	Patent	12	Residual aneurysm
10	2	Patent	Patent	12	Residual aneurysm
11	1	Patent	Patent	6	Occluded
12	1	Patent	Patent	6	Occluded
13	1	Patent	Patent	12	Occluded
14	1	Patent	Patent	6	Occluded
15	1	Patent	Occluded	7	Occluded

Note:—NA indicates not available; patient died within 10 days of treatment.

tively). Seven patients demonstrated multiple small infarcts, generally in the MCA distribution. No patients had infarcts in the AchoA distribution. Eight patients underwent postopera-

tive MR imaging or CT at >1 month after PED placement. No patients had permanent neurologic deficits corresponding to the infarct location. These findings are summarized in Table 3.

DISCUSSION

Our study demonstrated that the ostium of the AchoA can be covered with the PED for aneurysm treatment without resulting in neurologic complications related to AchoA occlusion. Following flow-diverter placement across its ostium, the AchoA was patent in 13 of 14 patients who underwent follow-up angiography at least 6 months after the procedure. Of the patients who underwent postoperative CT or MR imaging, none experienced infarctions that were definitely in the territory of the AchoA. The rarity of angiographic occlusion of the AchoA and lack of neurologic sequelae following placement of the PED across its ostium are

Table 3: Clinical and MRI/CT Results

Patient No.	mRS at Last Follow-Up	Reason for mRS	Clinical Follow-Up Time (mo)	Follow-Up MRI/CT Findings at <1 Month	Follow-Up Imaging Findings at >1 Month
1	2	Headaches	27	MRI: tiny silent infarcts, none in AchoA territory	MRI: no new infarcts
2	1	Abdominal pain	30	NA	CT: tiny infarcts, none in AchoA territory
3	6	Death	0.3	CT: watershed infarcts, intraparenchymal hemorrhage	
4	0	–	25	NA	NA
5	2	CN IV paresis, double vision	13	MRI: tiny silent infarcts, none in AchoA territory	CT: no new infarcts
6	0	–	6	MRI: tiny silent infarcts, none in AchoA territory	MRI: no new infarcts
7	1	Shoulder pain	9	MRI: tiny silent infarcts, none in AchoA territory	MRI: no new infarcts
8	0		12	NA	NA
9	1	Headaches	12	NA	NA
10	1	Headaches	12	MRI: tiny silent infarcts, none in AchoA territory	MRI: no new infarcts
11	0	–	6	NA	NA
12	0	–	6	NA	NA
13	0	–	12	NA	CT: no new infarcts
14	0	–	6	MRI: tiny silent infarcts, none in AchoA territory	NA
15	0	–	7	MRI: tiny silent infarcts, none in AchoA territory	MRI: no new infarcts

Note:—NA indicates not available; CN, cranial nerve.

particularly important, given the large number of aneurysms in the supraclinoid ICA that are amenable to flow-diverter treatment.[10]

Previous clinical, animal, and computational studies have examined the propensity for branch artery occlusion following flow-diversion implantation.[5,6,11,12] Kallmes et al[13,14] found that on occlusion of lumbar branch vessels in the rabbit aorta with overlapping flow-diversion devices, these perforating vessels remained patent on follow-up. While a device placed across the origin of a perforating vessel (traditionally considered end vessels with no distal collaterals) may maintain flow across the ostium due to a pressure gradient across its ostium, the same is not true when larger vessels like the ophthalmic artery and the posterior communicating artery (which often have significant distal collateral potential) are covered by these devices. In such cases, the pressure gradient across the device struts is not enough to maintain patent flow due to the opposing effect of the distal collateral flow, which creates a neutral gradient and angiographic occlusion. Puffer et al[15] examined ophthalmic artery patency rates following flow-diverter placement and found that nearly 25% of ophthalmic arteries were occluded on long-term follow-up with no clinical sequelae. Brinjikji et al[16] demonstrated a long-term occlusion rate of the posterior communicating artery of approximately 27%, with no patients experiencing focal neurologic deficits.

In the case of the anterior choroidal artery, prior studies have demonstrated collateral flow in the setting of chronic ICA occlusion from the lateral posterior choroidal artery, posterior cerebral artery, and posterior communicating artery. Takahashi et al[17] described 7 cases of retrograde filling of the anterior choroidal artery on vertebral angiography. In most cases, this retrograde filling was demonstrated following thrombotic occlusion of the supraclinoid ICA. The normal AchoA has anastomoses with the posterior communicating artery and the posterior cerebral artery. Anastomoses with the posterior circulation occur at the level of the choroid plexus, lateral geniculate body, or proximal portions of the posterior cerebral artery.[18,19]

All 6 patients who had MR imaging in the immediate postoperative period had small foci of restricted diffusion. These findings are consistent with those of the coiling literature, in which up to 75% of patients have high-signal lesions on DWI, most of which are silent infarcts. In a series of 34 consecutive patients undergoing elective coiling for unruptured aneurysms, Matsushige et al[20] reported that 76% of patients had high-signal spots on DWI. Hahnemann et al[21] found that nearly two-thirds of patients undergoing stent-assisted coiling had postprocedural ischemic lesions on DWI in a series of 75 patients. Our study is considerably smaller, and further studies reporting the incidence of DWI changes following PED placement are necessary. In all cases, these infarcts were clinically silent.

There was 1 death in our series. The patient had a small ruptured blister aneurysm and was treated in the acute phase with a PED. One day following the procedure, this patient was found to have multiple watershed infarcts in the bilateral anterior cerebral artery/MCA distribution and a large frontal lobe intraparenchymal hematoma ipsilateral to the treated aneurysm. Ruptured blister aneurysms have a very poor natural history and are generally associated with poor clinical outcomes regardless of treatment technique. However, the PED is emerging as a valid therapeutic option for ruptured blister aneurysms of the ICA. Yoon et al[22] reported a series of 11 patients treated with the PED for ruptured blister ICA aneurysms. In this series, 3 patients (27%) had major perioperative ischemic complications and 1 patient died. Further research is needed to determine the role of the PED in the treatment of blister aneurysms.

Our study was limited by the relatively small number of treated aneurysms. Given the rarity of angiographic occlusion of the anterior choroidal artery in the patients included in our study, we could not determine which variables were associated with anterior choroidal artery occlusion. Therefore, we did not perform any statistical comparisons in our study. Lack of angiographic opacification of a vessel may not indicate complete absence of flow through the vessel. On follow-up angiography, most patients did not have vertebral artery injections; thus, filling of the AchoA from the posterior circulation could not be appreciated. Platelet responsiveness, a potentially important factor in determining arterial patency following PED placement, was not examined in this study. A mean follow-up of approximately 12 months may not have been enough time to determine the long-term patency of the AchoA in these patients; however, the 1 case of angiographic occlusion of the AchoA was demonstrated at the 6-month follow-up.

Another important limitation is our lack of consistent imaging follow-up. Only 9 patients underwent posttreatment imaging. This small number makes it difficult to understand why no patients with a jailed AchoA had an infarct in the AchoA territory. As discussed in an article by Hanley and Lippman-Hand,[23] a zero numerator does not necessarily mean "no risk." In this article, Hanley and Lippman-Hand discuss the concept of "the rule of 3," essentially stating that the 95% confidence interval estimate of the risk of an event occurring when the numerator is 0 is, at most, 3 in n (n = denominator). Thus, with the rule of 3, the 95% confidence interval for risk of AchoA territory infarction in our study ranges from 0.0% (0/9) to 33.3% (3/9). These results suggest that further larger studies with consistent imaging follow-up are needed to determine the risk of AchoA territory infarct when the artery is jailed by flow-diverter devices. Last, while none of the silent infarcts seen on MR imaging were in the traditional territory of the AchoA, vascular territories are known to be inexact. However, all images were reviewed by 2 neuroradiologists, and in no cases were there definite findings of AchoA-related infarct.

CONCLUSIONS

In this small study, placement of a Pipeline Embolization Device across the AchoA ostium resulted in occlusion of the artery in only 1 patient. It was not associated with ischemic changes in the distribution of the AchoA in any patient.

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