Despite advances in surgical techniques and endovascular innovations, fusiform aneurysms remain a formidable challenge for neurosurgeons. They may present with ischemic complications associated with distal embolization, subarachnoid hemorrhage, or neurological deficit from the mass effect and compression of critical neuroanatomical structures.\(^1\) These challenges are even more difficult in large or giant fusiform aneurysms.\(^5\) The pioneering work by Drake set the platform of understanding of flow dynamics in these lesions and set about forming the basis of many modern treatment strategies.\(^5\) Indeed, hunterian ligation is still used successfully in the treatment of many giant fusiform aneurysms.\(^5,6\) Advances in surgical technique saw modest improvements in outcomes; however, the relative rarity and the frequent necessity for complex surgical reconstruction continue to test even the most experienced neurovascular surgeons. The advent of endovascular therapy and the more recent development of flow-diverting stents offered a promising method of treatment. Early experience with flow diverters with large and wide-necked aneurysms was positive.\(^12,13\) The current literature on the use of flow diversion for the treatment of fusiform aneurysms is limited to small case series.\(^1\)

**Endovascular treatment of fusiform cerebral aneurysms with the Pipeline Embolization Device**

**Clinical article**

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**Object.** Despite advances in surgical and endovascular techniques, fusiform aneurysms remain a therapeutic challenge. Introduction of flow-diverting stents has revolutionized the treatment of aneurysms with wide necks and of complex morphology. The authors report their experience with the endovascular treatment of fusiform aneurysms using the Pipeline Embolization Device.

**Methods.** A retrospective review of 146 patients with cerebral aneurysms treated with the Pipeline Embolization Device between June 2011 and January 2013 was performed. Twenty-four patients were identified as having fusiform aneurysms. Twenty-four aneurysms in these 24 patients were treated. The mean patient age was 59 years. There were 9 men and 15 women. Angiographic and clinical data (including the modified Rankin Scale [mRS] score) were recorded at the time of treatment and at follow-up. The aneurysms were located in the internal carotid artery in 8 patients (33.3%), middle cerebral artery in 8 patients (33.3%), anterior cerebral artery in 1 patient (4%), and vertebrobasilar circulation in 7 patients (29%). The aneurysms were smaller than 10 mm in 3 patients, 10–25 mm in 16 patients, and larger than 25 mm in 5 patients. The mean largest dimension diameter was 18 mm.

**Results.** Stent deployment was successful in all cases. The minor procedural morbidity was 4% (1 case). Morbidity and mortality related to aneurysm treatment were 4.2% and 4.2%, respectively. The mean mRS scores preoperatively and at clinical follow-up (median 6.0 months, mean 6.9 months) were 0.71 and 2.2, respectively (91.7% presented with an mRS score of 2 or better, and 79.2% had an mRS score of 2 or better at the 6.0-month follow-up). At clinical follow-up, 82.6% of patients were stable or had improved, 13.0% worsened, and 4.2% had died. Twenty-two (91.7%) of 24 patients had follow-up angiography available (mean follow-up time 6.3 months); 59% had excellent angiographic results (> 95% or complete occlusion), 31.8% had complete aneurysm occlusion, 27.3% had greater than 95% aneurysm occlusion, 18.2% had a moderate decrease in size (50%–95%), 4.5% had a minimal decrease in size (< 50%), 13.6% had not changed, and 4.5% had an increase in size.

**Conclusions.** This series demonstrates that endovascular treatment of fusiform cerebral aneurysms with flow diversion was a safe and effective treatment. Procedural complications were low. Long-term morbidity and mortality rates were acceptable given the complex nature of these lesions.

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**KEY WORDS**

- aneurysm
- fusiform
- Pipeline Embolization Device
- flow diversion
- endovascular
- stent
- vascular disorders

**Abbreviations used in this paper:** DSA = digital subtraction angiography; ICA = internal carotid artery; MCA = middle cerebral artery; MRA = MR angiography; mRS = modified Rankin Scale; PED = Pipeline Embolization Device; PICA = posterior inferior cerebellar artery; TIA = transient ischemic attack.

This article contains some figures that are displayed in color online but in black-and-white in the print edition.
series or subgroup analysis from large series. We set out
to detail our experience at a single center using the Pipeline
Embolization Device (PED; Covidien/ev3) for the
treatment of fusiform aneurysms in a high-volume center.

Methods

A retrospective review of 146 patients treated at our
institution with the PED (Covidien/ev3) between June 2011
and January 2013 was performed. Angiograms and proce-
dure notes of the 146 cases were reviewed, and 24 patients
were found to have fusiform aneurysms that were treated
primarily with the PED. Patients who had undergone prior
treatment (either surgical or endovascular) were included.
Treatments that included coiling in addition to the place-
ment of the PED(s) were also included. Aneurysms were
categorized as fusiform based on 3D rotational digital
subtraction angiography (DSA) findings, as well as cross-
sectional imaging using 3D CT angiography and MR angi-
ography (MRA). Cases were considered for inclusion when
the entire diseased vessel segment was dilated without a
discrete aneurysm neck. All cases were reviewed for in-
cclusion by the senior author (P.J.). Aneurysms that had a
discrete neck or were large “side-walled” aneurysms were
excluded. Clinical data, including the modified Rankin
Scale (mRS) score, were collected prior to treatment, at
discharge, and at follow-up. Angiographic data were col-
clected at the time of the procedure and at 6–12 months. If
angiographic data were unavailable or the patient refused
follow-up angiography then aneurysm status was evaluated
using MRA (time of flight and Gd-enhanced MRI) when
available. Aneurysm size (in 3 dimensions) and location
were recorded, and the change in size was noted using
follow-up angiography. The presence of new contrast stasis
after PED placement was noted. Details of the PED (diam-
eter, length, and number of devices) and the recipient ves-
sels (inflow artery diameter and outflow artery diameter)
were measured. The length of normal proximal and distal
vessel purchase (distance of disease-free vessel covered by
the PED before the PED entered the aneurysm) was de-
termined. Perforator coverage (and the number of devices
covering them) was examined both during the procedure
and at follow-up angiography. Procedural data, including
platelet inhibition percentage at the time of procedure and
procedural complications, were noted.

Results

Patient Characteristics

Twenty-four aneurysms were treated in 24 patients
(Table 1). All aneurysms were unruptured. The mean age
was 59 years (range 26–81 years). There were 9 men and
15 women. Seven patients were treated after routine fol-
low-up following prior treatment (5 endovascularly and 2
surgically) revealed residual or recurrent aneurysm. Four
patients presented with cranial neuropathy or new neu-
rological deficit due to compressive effects. Two patients
presented primarily with severe headache (not subarach-
noid hemorrhage). Four patients presented with transient
ischemic attack (TIA) or stroke. Six patients had their
aneurysm discovered as an incidental finding, and 1 pa-
tient had the aneurysm discovered after screening was
performed because of a family history of aneurysms. The
average mRS score on admission was 0.71 and it was 1.2
at the last follow-up (mean clinical follow-up duration 6.9
months, median 6 months). At presentation 22 (91.7%) of
24 patients had an mRS score of 2 or better; the remain-
ing 2 patients (8.3%) had an mRS score of 3 or higher. At
follow-up 19 (79.2%) of 24 patients had an mRS score of
2 or better, and 5 (20.8%) had an mRS score of 3 or greater.
One patient who died of metastatic pancreatic cancer
after an uncomplicated procedure was excluded from the
clinical outcome analysis. Comparing mRS score on ad-
mission to last follow-up (Table 2) demonstrated that 2
patients improved (8.7%), 17 remained stable (73.9%), 3
worsened (13.0%), and 1 died (4.3%).

Aneurysm Characteristics

The details of the aneurysms treated are listed in
Table 3. The aneurysm was located in the internal carotid
artery (ICA) in 8 patients (33.3%), middle cerebral artery
(MCA) in 8 patients (33.3%), anterior cerebral artery in
1 patient (4.2%), and vertebrobasilar circulation in 7 pa-
tients (29.2%). Aneurysm size was < 10 mm in 3 patients,
10–25 mm in 16 patients, and > 25 mm in 5 patients (0
to <10 mm in 3 patients, 10 to <20 mm in 10 patients, 20
to 30 mm in 10 patients, and > 30 mm in 1 patient). The
mean largest diameter was 18.0 mm.

TABLE 1: Patient characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value*</th>
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<tr>
<td>sex</td>
<td></td>
</tr>
<tr>
<td>male</td>
<td>9 (37.5)</td>
</tr>
<tr>
<td>female</td>
<td>15 (62.5)</td>
</tr>
<tr>
<td>age in yrs</td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>59</td>
</tr>
<tr>
<td>range</td>
<td>26–81</td>
</tr>
<tr>
<td>presentation</td>
<td></td>
</tr>
<tr>
<td>follow-up after prior treatment</td>
<td>7 (29.2)</td>
</tr>
<tr>
<td>cranial neuropathy</td>
<td>4 (16.7)</td>
</tr>
<tr>
<td>headache</td>
<td>2 (8.3)</td>
</tr>
<tr>
<td>TIA or stroke</td>
<td>4 (16.7)</td>
</tr>
<tr>
<td>incidental</td>
<td>6 (25.0)</td>
</tr>
<tr>
<td>screening</td>
<td>1 (4.1)</td>
</tr>
</tbody>
</table>

* Values are the number of patients (%) unless noted otherwise.

TABLE 2: Clinical follow-up†

<table>
<thead>
<tr>
<th>Status at Follow-Up†</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>improved</td>
<td>2 (8.7)</td>
</tr>
<tr>
<td>stable</td>
<td>17 (73.9)</td>
</tr>
<tr>
<td>worse</td>
<td>3 (13.0)</td>
</tr>
<tr>
<td>death</td>
<td>1 (4.3)</td>
</tr>
</tbody>
</table>

† Based on the mRS scores.
Treatment of fusiform aneurysms with the PED

Procedure

Details of the cases are shown in Table 4. Patients were instructed to take aspirin (81 mg/day) and clopidogrel (75 mg/day) for 10 days prior to treatment. Clopidogrel response with the Accuthetics test was performed prior to the procedure with a goal of 30%–80% inhibition. Analysis of available data in our series demonstrated a mean percentage inhibition of 61% (range 24%–98%). Two patients did not respond to clopidogrel and were placed on a regimen of prasugrel preoperatively. Steroids were not prescribed routinely unless patients developed new symptoms thought to be due to swelling or aneurysm thrombosis postoperatively. Such patients were placed on a regimen of 1-week dexamethasone taper on discharge. Clopidogrel was generally discontinued at 6 months if the aneurysm was completely obliterated on follow-up angiography. Aspirin (81 mg) was continued indefinitely. All patients received heparin for the procedure with an activated clotting time maintained at 2–2.5 times baseline.

Two patients underwent 2 procedures. One patient had 2 PEDs placed on 2 occasions. The other patient underwent placement of 4 PEDs in the first procedure and 2 additional PEDs in the second procedure. Excluding these cases, 1–3 devices were placed in 22 patients (mean 1.8 devices). Multiple devices were placed in an overlapping fashion. The mean inflow vessel diameter was 3.3 mm (range 1.7–5.0 mm), and the mean outflow vessel diameter was 2.6 mm (range 1.5–4.5 mm). The mean length of normal vessel covered by the PED proximal to the aneurysm (“proximal purchase”) was 9.9 mm (range 4.4–17.0 mm). The “distal purchase” of the PED extending past the aneurysm into normal vessel was 7.6 mm (range 4.4–17.0 mm). Twenty-one (87.5%) of the 24 patients had perforator vessels or side branches covered by the PED. Fifteen had 1 PED covering the perforator, and 2 had 1–2 PEDs covering perforators (MCA) depending on where the overlapping component was. Three patients had 2 devices, and 1 patient had 3 PEDs covering a perforating vessel. Coils were added to supplement flow diversion in 2 cases. Dense packing was performed in one case and loose packing in another case. Postoperative imaging with angiography was performed in all cases with supplementary DynaCT performed in 8 cases. Three-dimensional angiography was performed in 1 case postoperatively.

Delivery of the PED(s) was successful in all cases without technical complication. Vessel wall apposition was achieved with the PED in all cases; however, 1 patient presented with a nonsignificant endoleak on follow-up angiography despite good vessel wall apposition. There was no significant in-stent thrombosis or significant thrombotic complication that required lysis intraoperatively. Twenty patients (83.3%) exhibited immediate new contrast stasis in the aneurysm following placement of the PED(s).

Complications

Twenty-three of 24 patients had no procedural complications (96%). One patient had a groin pseudoaneurysm that was managed conservatively. Of 24 patients, 4 (16.7%) had major complications related to aneurysm treatment and there was 1 death (4.2%). One patient died of cancer during the follow-up period.

Two patients with MCA aneurysms (Cases 9 and 20), and 1 patient with a basilar aneurysm (Case 19) had perforating vessel infarctions in the vascular territory of the region covered by the PED. One patient (Case 20) with an MCA aneurysm stopped taking clopidogrel without medical consultation at 5 months and his MCA PED became occluded, resulting in caudate, putamen, and cortical infarcts associated with hemiplegia. A 32-year-old man (Case 19) had an extremely complex case of a 46-mm basilar trunk aneurysm. He had undergone multiple stent-assisted coiling procedures at an outside institution; he presented to our institution with multiple cranial neuropathies and difficulty ambulating. After spanning the aneurysm with 4 PEDs he presented again with a thalamic infarct and worsening mass effect. Two further PEDs were placed in the proximal basilar artery; however, the aneurysm continued to fill. Despite further flow diversion, his clinical state declined, and he is bedridden and required percutaneous endoscopic gastrostomy tube placement and a tracheostomy. One patient (Case 1) with a 29-mm symptomatic cavernous aneurysm treated with 4 PEDs suffered a significant frontal intracerebral hemorrhage 1 week postoperatively and was discharged to a long-term care facility with hemiplegia and a percutaneous endoscopic gastrostomy tube.

Deaths

Two patients died. One patient (Case 14) was a 77-year-old man with progressive ataxia and a sixth cranial nerve palsy due to mass effect from a 23-mm basilar trunk aneurysm. Prior to PED placement a ventriculoperitoneal shunt was placed in preparation for the predicted swelling and aqueductal closure resulting from aneurysm thrombosis. He required bur hole drainage of a subdural hygroma following the shunt procedure. Once stabilized, the patient was given a loading dose of aspirin and clopidogrel for the PED placement. In an attempt to divert flow away from the aneurysm sac, a single PED was placed from the dominant vertebral artery across into the contralateral vertebral artery. Preoperative angiography demonstrated that the nondominant vertebral artery was only filling retrograde due to a chronic proximal occlusion. The patient initially

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### TABLE 3: Aneurysm characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No. of Patients (%)</th>
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<tbody>
<tr>
<td>rupture status</td>
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</tr>
<tr>
<td>ruptured</td>
<td>24 (100)</td>
</tr>
<tr>
<td>unruptured</td>
<td>0 (0)</td>
</tr>
<tr>
<td>location</td>
<td></td>
</tr>
<tr>
<td>ICA</td>
<td>8 (33.3)</td>
</tr>
<tr>
<td>MCA</td>
<td>8 (33.3)</td>
</tr>
<tr>
<td>anterior cerebral artery</td>
<td>1 (4.2)</td>
</tr>
<tr>
<td>vertebrobasilar</td>
<td>7 (29.2)</td>
</tr>
<tr>
<td>size (mm)</td>
<td></td>
</tr>
<tr>
<td>&lt;10</td>
<td>3 (12.5)</td>
</tr>
<tr>
<td>10–25</td>
<td>16 (66.7)</td>
</tr>
<tr>
<td>&gt;25</td>
<td>5 (20.8)</td>
</tr>
<tr>
<td>Case No</td>
<td>Age (yrs), Sex</td>
</tr>
<tr>
<td>---------</td>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
<td>81, F</td>
</tr>
<tr>
<td>2</td>
<td>66, M M₀</td>
</tr>
<tr>
<td>3</td>
<td>74, F V₄</td>
</tr>
<tr>
<td>4</td>
<td>60, M V₄</td>
</tr>
<tr>
<td>5</td>
<td>79, F cavernous</td>
</tr>
<tr>
<td>6</td>
<td>61, F cavernous</td>
</tr>
<tr>
<td>7</td>
<td>50, F basilar trunk</td>
</tr>
<tr>
<td>8</td>
<td>74, F cavernous</td>
</tr>
<tr>
<td>9</td>
<td>31, M M₁</td>
</tr>
<tr>
<td>10</td>
<td>75, F cavernous</td>
</tr>
<tr>
<td>11</td>
<td>66, F petrous</td>
</tr>
<tr>
<td>12</td>
<td>43, F basilar trunk</td>
</tr>
<tr>
<td>13</td>
<td>67, M M₁</td>
</tr>
<tr>
<td>14</td>
<td>77, M basilar trunk</td>
</tr>
<tr>
<td>15</td>
<td>73, F cavernous</td>
</tr>
</tbody>
</table>
| 16      | 66, M M₁       | 25 × 6 × 9  | 3.5 × 35, 3.5 × 20, 3.5 × 18 | 3             | 1        | M, perforators | 1–2                             | MRI for pancreatic cancer workup; TIA s | NA                    | NA                    | 3                      | 6                     | 2                      | (continued)
| Case No. | Age (yrs), Sex | AN Location | AN Size (mm)† | Size of Device(s) Used (mm)‡ | No. of Devices | No. of Tx | Perforator Covered by PED | No. of PEDs Covering Perforators | Clinical Presentation | FU Angiogram Time (mos) | FU Angiographic Result | mRS Score on Admission | mRS Score at FU | Clinical FU Duration (mos) |
|----------|----------------|-------------|---------------|-----------------------------|----------------|----------|--------------------------|-------------------------------|-----------------------|------------------------|-------------------------|------------------------|-------------------------|----------------------|--------------------------|
| 17       | 58, F          | carotid cave | 11 x 4 x 8    | 4.25 x 18                   | 1              | 1        | OphA                     | 1                            | incidental finding        | 6                      | 50% ↓ in size           | 0                       | 0                      | 6                     |
| 18       | 48, F          | pericallosal | 4 x 5 x 4     | 2.5 x 14                    | 1              | 1        | callosomarginal          | 1                            | found on imaging posttrauma| 6                      | complete occl of AN    | 0                       | 0                      | 6                     |
| 19       | 32, M          | basilar trunk| 38 x 46 x 29  | 3.25 x 20, 3.25 x 18, 3.25 x 16 then 3.75 x 18, 3.25 x 20| 6 (4 in 1st, 2 in 2nd Tx) | 2 | AICA | 1 multi cranial neuropathies; after multi stent & coiling procedures at outside institution | 2nd procedure 5 mos post 1st procedure | ongoing filling of AN prompting addition of 2 PEDs | 4 | 5 | 8 (after 1st procedure) |
| 20       | 51, M          | M1          | 12 x 14 x 12  | 3.0 x 16                    | 1              | 1        | M1 perforators          | 1                             | incidental finding        | 4                      | complete M1 occl; AN obliterated | 1 | 4 | 5 |
| 21       | 26, F          | M3          | 5 x 5 x 5     | 2.5 x 12                    | 1              | 1        | M3 branches             | 1                             | screening MRA for family Hx of ANs | 6                      | complete occl of AN    | 0                       | 0                      | 6                     |
| 22       | 44, F          | vertebro-basilar | 18 x 20 x 17  | 3.0 x 20                    | 1              | 1        | basilar perforators     | 1                             | multi prior endovascular procedures; ↑ AN size on MRA | 6 | improved AN occl; slight filling at neck | 1 | 1 | 1 |
| 23       | 69, M          | M1          | 13 x 13 x 12  | 2.75 x 18                   | 1              | 1        | M1 perforators          | 1                            | residual AN post-clipping 3 | 3 | vessel remodeled; AN almost completely obliterated | 0 | 0 | 3 |
| 24       | 56, F          | M1          | 25 x 18 x 17  | 3.25 x 35, 3.5 x 20         | 1              | 1        | M1 perforators          | 1                            | TIA                       | 6 | >95% occl of AN          | 0                       | 0                      | 6                     |

* AChA = anterior choroid artery; AICA = anterior inferior cerebellar artery; AN = aneurysm; FU = follow-up; HA = headache; Hx = history; multi = multiple; NA = not applicable; oblit = obliteration; occl = occlusion; OphA = ophthalmic artery; Tx = treatment; VA = vertebral artery; ↑ = increase; ↓ = decrease.
† Aneurysm size is reported as the left to right, superior to inferior, and anterior to posterior dimensions, respectively.
‡ Device size is reported as the diameter and length, respectively.
did well; however, he presented at 7 months with a Hunt and Hess Grade V subarachnoid hemorrhage, and care was withdrawn by the family. He did not undergo angiography prior to his death. The other patient who died (Case 16), a 66-year-old man, was treated for a 25-mm M1 aneurysm that was found on imaging during a cancer workup. At the time of treatment he had an additional diagnosis of pancreatic cancer, and his oncologist predicted survival of 12 months at the time of considering treatment for his aneurysm. Given the reasonable prognosis for his cancer, the patient wished to have his aneurysm treated. Three PEDs were used to treat the aneurysm without complication, and the patient was discharged without complication or neurological deficit. Unfortunately, he died of metastatic pancreatic cancer 2 months after his procedure. He had no complications associated with the endovascular procedure at the time of death.

**Angiographic Outcomes**

Twenty-two of 24 patients had follow-up angiography available for review (mean follow-up 6.3 months, range 1 week to 12 months) (Table 5). One patient who died and another who refused to undergo follow-up did not undergo postoperative angiography. Seven (31.8%) had complete aneurysm occlusion, 6 (27.3%) had greater than 95% occlusion, 4 (18.2%) had a moderate decrease in size (50%–95%), 1 (4.5%) had a minimal decrease in size (<50%), 3 (13.6%) had no change, and 1 (4.5%) had an increase in size.

**Illustrative Cases**

**Case 15**

This 73-year-old woman presented with diplopia and was found to have a fusiform 24-mm cavernous aneurysm. She was treated with a single 3.5 × 20-mm PED that spanned the entire diseased segment of the ICA. There was immediate intraaneurysmal contrast stasis (Fig. 1). The PED covered the opthalmic artery; however, the vessel was noted to be filling immediately after placement of the device. The patient did have a small groin pseudoaneurysm that was managed conservatively. At the 6-month clinical and angiographic follow-up, the aneurysm was completely occluded and the cavernous ICA was remodeled. The opthalmic artery was not filling from the ICA; however, collateral vessels from the external carotid artery were present. The patient’s vision was normal, and the diplopia had resolved.

**Table 5: Angiographic follow-up**

<table>
<thead>
<tr>
<th>Finding</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>complete occlusion</td>
<td>7 (31.8)</td>
</tr>
<tr>
<td>&gt;95% occlusion</td>
<td>6 (27.3)</td>
</tr>
<tr>
<td>moderate decrease (50–95%)</td>
<td>4 (18.2)</td>
</tr>
<tr>
<td>minimal decrease (&lt;50%)</td>
<td>1 (4.5)</td>
</tr>
<tr>
<td>no change</td>
<td>3 (13.6)</td>
</tr>
<tr>
<td>worse</td>
<td>1 (4.5)</td>
</tr>
</tbody>
</table>

*Angiographic follow-up was performed in 22 of the 24 patients.

**Case 23**

This 69-year-old man presented after suffering a seizure while he was sleeping. He was found to have a complex distal M1 fusiform aneurysm that involved the MCA bifurcation (Fig. 2). Due to the complex involvement of the bifurcation, surgical clip reconstruction was performed. The aneurysm was noted to be particularly atheromatous. Intraoperative angiography demonstrated a residual aneurysm; however, further manipulation of the clips was not performed for fear of causing occlusion of perforators with thrombus. Follow-up angiography demonstrated an increase in the size of the lesion. Open surgical exploration was offered, but the patient declined further surgery. A single 2.75 × 18-mm PED was placed from the M1 to the trunk of a large M1 division. Radiological follow-up at 3 months revealed >95% occlusion of the aneurysm, M1 remodeling, and no evidence on MRI of ischemic complications from covering the M1 perforators. At the 3-month clinical follow-up, the patient remains neurologically intact.

**Case 21**

This 26-year-old woman underwent screening with MRA because of a family history of aneurysms. A fusiform 5 × 5 × 5–mm M1 aneurysm was found on subsequent angiography (Fig. 3). The patient declined an open surgical approach with clip reconstruction. She was treated with a single 2.5 × 12-mm PED without complication. Angiographic follow-up at 6 months demonstrated complete aneurysm obliteration with normal filling of distal vasculature. She remains neurologically intact at 6 months.

**Case 3**

This 74-year-old woman was previously treated for a fusiform V1 aneurysm with a stent coil procedure. An 11-mm recurrence of the aneurysm on follow-up angiography was found (Fig. 4). Two PEDs (4 × 14 mm and 3.75 × 20 mm) were placed with both devices overlapping and were noted to cover the posterior inferior cerebellar artery (PICA). Care was taken to achieve good endoluminal apposition by extending the coverage of the PEDs beyond both the proximal and distal limits of the old stent. The procedure was uncomplicated and at 6 months follow-up she remains neurologically intact. Angiography at 6 months demonstrated complete occlusion of the aneurysm, remodeling of the vertebral artery, and normal flow through the PICA.

**Case 24**

This 56-year-old woman presented with a TIA secondary to a 25 × 18 × 17–mm fusiform M1 aneurysm. She was treated with a 3.25 × 35–mm and a 3.5 × 20–mm PED, as well as supplemental coiling using a “jailing” technique (Fig. 5). The coils were relatively tightly packed. Immediate stasis was noted in the aneurysm. The procedure was uncomplicated. Postoperatively, the patient did well and remained neurologically intact until the last clinical follow-up at 6 months. Angiographic follow-up at 6 months revealed a tiny amount of residual aneurysm (>95% occlusion). All major efferent vessels were patent.
The treatment of fusiform aneurysms by open surgery or endovascular techniques remains a challenge for neurosurgeons. In the endovascular era this can be performed with parent vessel deconstruction using coil embolization. Hunterian ligation may be effective at decreasing flow and may indeed result in flow reversal and shrinkage of the aneurysm. If flow is diminished too much then complex bypass techniques may need to be used to prevent ischemic complications.

Treatment of fusiform aneurysms with endovascular flow diversion has been limited to a discussion in small case series or as a subgroup in larger series of all aneurysm types. In a series by Siddiqui et al., 7 patients underwent flow diversion for large or giant fusiform vertebro-
basilar aneurysms. The PED was used in 6 patients, and the Silk (Balt Extrusion) device was used in 1 patient. At last clinical follow-up 4 patients had died and the other 3 had severe disability (mRS Score 5). Klisch et al. reported 2 cases of flow diversion for large fusiform basilar trunk aneurysms. In both cases the aneurysm was nearly completely obliterated at follow-up; however, both patients had recent thrombosis after stopping clopidogrel after 1 year. One patient died and the other underwent successful urgent revascularization. Kan et al. reported a multicenter US study; 62 PED procedures were performed to treat 58 aneurysms in 56 patients. Ninety percent of the aneurysms were saccular. Four of the 8 vertebrobasilar aneurysms were fusiform, and 1 of these patients suffered a perforator infarction with resultant permanent neurological deficit after placement of a flow diverter. In the current series 59.1% of cases demonstrated complete or >95% occlusion on follow-up angiography. An additional 18.2% had 50%–95% decrease in aneurysm size. From a clinical standpoint 82.6% of patients did well: 2 patients improved (8.7%), 17 remained stable (73.9%), 3 worsened (13.0%), and 1 died (4.3%). Experience from our group is similar to previous studies and suggests that in selected patients flow diversion using the PED is a reasonable treatment option.

The concept of flow diversion in the setting of compressive symptoms is intuitive. Decreasing the mass effect of a partially thrombosed aneurysm with flow diversion without the placement of additional coil mass has been used to relieve pressure on surrounding neural elements. In a series of 30 aneurysms (3 fusiform), Szikora et al. demonstrated significant improvement in symptoms due to mass effect from large aneurysms treated with flow diversion. In their series 6 patients had vision loss, 10 had double vision, and 1 had brainstem compression and hemiparesis. At follow-up, vision loss had improved in 9 of 10 patients, and double vision completely resolved in 7 of 10 and partially in an additional 3 patients. The patient with hemiparesis became asymptomatic. Clinical improvements in cranial neuropathies due to aneurysm mass effect were not borne out in our series. Four patients in this series primarily presented with cranial neuropathy as a result of the compressive effects of the aneurysm. Of these, 2 patients are in a long-term care facility with significant disability (follow-up angiography in both cases demonstrated <50% aneurysm occlusion), 1 patient has had stable diplopia (follow-up angiogram demonstrated >95% occlusion), and the remaining patient has had resolution of diplopia (angiography demonstrated 100% occlusion). The less than satisfactory outcomes in these patients should be taken in the context that we treated only a small number of patients in our series for symptoms of mass effect or compression. In addition, the lesions treated in these patients were of a particularly complex nature, and salvage therapy was performed in 1 case following multiple stent and coiling procedures at an outside institution.

Remodeling (>95% aneurysm obliteration) of the parent vessel to close to a normal anatomic configuration occurred in 59.1% of cases in this series. A moderate decrease (50%—95%) in aneurysm size was seen in an additional 18.2%, yielding significant angiographic improvement in 77.3% of cases. In the current series 21 of 24 patients had PEDs that covered perforating vessels (87.5%), including large vessels such as the ophthalmic artery and PICA. Of those patients with PEDs covering perforators, 2 patients (8.3%; one with a basilar trunk aneurysm and the other with an M1 aneurysm) had symptomatic perforator...
Treatment of fusiform aneurysms with the PED

Infarctions during the follow-up period despite continuing dual antiplatelet therapy with aspirin and clopidogrel. One device was placed in the patient with an M1 aneurysm, and a total of 6 devices were placed in the patient with the giant basilar trunk aneurysm. Phillips et al. treated 32 posterior circulation aneurysms with the PED but reported perforator infarctions in 14%, with a permanent morbidity of 9.4%. In this current series, only 1 case (a symptomatic cavernous aneurysm) of a large perforating vessel was seen to be occluded (ophthalmic artery) at angiographic follow-up after initially filling immediately post-stenting. The patient was not symptomatic, and at follow-up the collaterals from the external carotid artery continued to perfuse the orbital contents; the patient’s vision remained normal. This finding is similar to that in previous studies in which the ophthalmic artery was occluded by the PED. Puffer et al. examined the patency of the ophthalmic artery after placement of 1–3 PEDs for 20 paraclinoid aneurysms. The authors found that the mean number of PEDs in the patients with change in flow or occluded ophthalmic arteries was 2.4 compared with 1.9 in the patients with no change in flow in the ophthalmic artery (p = 0.09). At angiographic follow-up normal antegrade flow was seen in 68% of patients and slow flow in 11% of patients. The ophthalmic artery was occluded in 21% of cases; however, no patient developed clinical sequelae as a result of ophthalmic artery occlusion due to the development of collateral vessels. One patient in our series had a thrombus in the MCA (and MCA aneurysm) that caused a stroke after self-discontinuing his dual antiplatelet therapy prior to angiographic follow-up. Such cases illustrate the need for patient education and compliance with regard to the importance of antiplatelet medications. The optimal regimen for antiplatelet therapy in the use of the PED is physician dependent, and currently there is a lack of clear guidelines. We favor dual antiplatelet therapy until follow-up angiography (usually at 6 months initially) demonstrates that the parent vessel is completely remodeled and the aneurysm is occluded. Following this, the patient is kept on a regimen of 81 mg daily aspirin for life. Several groups advise stopping aspirin therapy completely. While the number of cases in this series and others is too small to draw any firm conclusions, we recommend avoiding using overlapping multiple devices in the MCA and basilar trunk. Placement of overlapping devices in these regions where the perforators are small and of relatively low-flow demand places the patient at risk for ischemic complications.

Two patients were treated with the PED as salvage treatment for residual aneurysm following clipping of complex M1 aneurysms. Both patients had greater than 95% aneurysm obliteration at angiographic follow-up; however, 1 patient suffered a perforator stroke. This patient made a good recovery and at 12 months of follow-up is neurologically intact. Such cases illustrate the benefits

Fig. 5. Case 24. A: Preoperative T2-weighted MR image demonstrating a large fusiform MCA aneurysm with components of thrombus. B: Preoperative anteroposterior projection DSA showing a complex fusiform aneurysm involving the entire M1. C: Three-dimensional reconstructed DSA showing the involvement of the M1 throughout its entire course. D: Postoperative radiograph demonstrating the placement of 2 PEDs spanning from the ICA into an M2 branch. Coils were used to supplement the flow diversion with the PEDs. E: Immediate postoperative 3D rotational CT angiogram showing the PED construct spanning the entire aneurysm from the ICA into a large M2 trunk, as well as the coil mass. F: Six-month follow-up Towne’s progression DSA demonstrating a tiny residual aneurysm with parent vessel reconstruction.
of a multidisciplinary approach to the management of complex cases, and the PED can be a useful option in cases of residual aneurysms.

Conclusions

This series of endovascular treatment for fusiform cerebral aneurysms with flow diversion represents the largest series of its type. At last follow-up, angiographic improvement was seen in more than 80% of cases, with complete or greater than 95% aneurysm obliteration in 59.1% of the cases. Given the complex nature of the aneurysms treated, the complication rates were acceptable. Eighty-three percent of patients did well after the procedure and were neurologically stable or improved after intervention. Overall, in this series endovascular treatment of fusiform aneurysms with flow diversion appears to be a safe and effective treatment. Further larger studies will be needed to determine the absolute risk of perforator occlusion in the regions of the MCA and basilar trunk. Fusiform aneurysms of the basilar trunk remain a therapeutic challenge.

Disclosure

Drs. Dumont and Jabbour are consultants for ev3.

Author contributions to the study and manuscript preparation include the following. Conception and design: Jabbour, Montheith, Tsimpas, Dumont, Gonzaleda, Rosenwasser. Acquisition of data: all authors. Analysis and interpretation of data: Jabbour, Montheith, Dumont, Tjoumakaris, Gonzaleda, Rosenwasser. Drafting the article: Jabbour, Montheith, Tsimpas. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Jabbour. Administrative/technical/material support: Jabbour.

References


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