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ABSTRACT

BACKGROUND AND PURPOSE: Flow diversion is an effective treatment for aneurysms of the ICA with compression-related neuro-ophthalmologic symptoms, especially when treatment is initiated early after symptom onset and aneurysm occlusion is complete. However, non-negligible complication rates have been reported. Our aim was to identify risk factors for morbidity/mortality and incomplete aneurysm occlusion.

MATERIALS AND METHODS: We performed a secondary analysis of a previous publication, which included all patients treated with flow diversion for an unruptured aneurysm of the ICA with compression-related symptoms.

RESULTS: Fifty-four patients with 54 aneurysms (48 women, 88.9%; mean age, 59.2 [SD, 15.9] years; range, 21–86 years) treated with flow diversion were included. We observed morbidity and mortality rates of 7.4% and 3.7%. Increasing age (OR per decade, 3.2; 95% CI, 1.23–8.49; $P = .02$) and dual-antiplatelet therapy with ticagrelor (OR, 13.9; 95% CI, 1.16–165.97; $P = .04$) were significantly associated with morbidity/mortality. After a median follow-up of 13.3 [SD, 10.5] months, the rates of complete aneurysm occlusion, neck remnant, and aneurysm remnant were 74%, 14%, and 12%. Incomplete occlusion at follow-up was less frequently observed in aneurysms treated with additional coil embolization (OR, 0.1; 95% CI, 0.01–0.86; $P = .04$).

CONCLUSIONS: Although a promising treatment for compressive ICA aneurysms, flow diversion carries a relevant risk for complications and incomplete aneurysm occlusion. Our results may help identify patients in which flow diversion may not be the ideal treatment method. Additional coil embolization increased the likelihood of complete aneurysm occlusion at follow-up.

ABBREVIATIONS: CN = cranial nerve; FD = flow diverter; PVO = parent vessel occlusion

Intracranial aneurysms of the ICA may cause mass effect and induce neuro-ophthalmologic disorders by compressing cranial nerves (CNs). Visual impairment or diplopia induced by CN palsy is disabling and often leads to urgent treatment of the underlying aneurysms, which are often large and/or rapidly growing.[1]

Since their introduction, flow diverters (FDs) have revolutionized endovascular treatment paradigms, particularly for unruptured intracranial aneurysms. FDs have a positive effect on resolving the mass effect of aneurysms by reducing intrasaccular filling and promoting collapse and healing, while preserving the vessel in contrast to parent vessel occlusion (PVO).[2] However, the literature on the use of FDs in ICA aneurysms causing compressive neuro-ophthalmologic symptoms is scarce.[2-6] In a recent study, we have shown that FDs are very effective for this indication

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Table 1: Factors associated with morbidity/mortality

	Morbidity/Mortality (n = 6)	No Morbidity/Mortality (n = 48)	Univariate Analysis	Multivariate Analysis	
			P Value	OR (95% CI)	*P* Value
Patient characteristics					
Female sex	6/6 (100%)	42/48 (87.5%)	.36		
Age (yr)	Mean, 73.8 (SD, 13.4)	Mean, 57 (SD, 15.3)	.03	3.27 (1.23–8.49)[a]	.02
Hypertension	6/6 (100%)	19/48 (39.6%)	.05		NS[b]
Current smoker	1/6 (16.7%)	11/48 (22.9%)	.73		
Previous smoker	2/6 (33.3%)	12/48 (25%)	.66		
Diabetes mellitus	1/6 (16.7%)	1/48 (2.1%)	.08		
Family history	0/6 (0%)	2/48 (4.2%)	.61		
Aneurysm characteristics					
Aneurysm size (mm)	Mean, 19.4 (SD, 8.4)	Mean, 15.8 (SD, 7.4)	.28		
Left-sided aneurysm	3/6 (50%)	33/48 (68.8%)	.36		
Intradural aneurysm	5/6 (83.3%)	28/48 (58.3%)	.24		
Fusiform aneurysm	3/6 (50%)	18/48 (37.5%)	.55		
Aneurysmal thrombus	2/6 (33.3%)	14/48 (29.2%)	.83		
Treatment-related data					
Ticagrelor	5/6 (83.3%)	19/48 (39.6%)	.04	13.9 (1.16–165.97)	.04
≥2 flow diverters	1/6 (16.7%)	2/48 (4.2%)	.21		
Additional coiling	3/6 (50%)	16/48 (33.3%)	.42		

Note:—NS indicates not significant.
[a] Age was grouped into decades for regression analysis.
[b] Variable not included in the regression mode.

regarding both clinical and anatomic outcome. Recovery of CN palsies was associated with early initiation of treatment after symptom onset and with complete aneurysm occlusion.[7] However, we observed a non-negligible risk of permanent neurologic deficits and death. Furthermore, a substantial number of aneurysms were not completely occluded at follow-up.

By analyzing the factors associated with treatment-related morbidity/mortality and incomplete aneurysm occlusion, we aimed to define patient and aneurysm characteristics for which flow diversion should be indicated with caution and other treatment strategies may be preferable.

MATERIALS AND METHODS

Study Design and Cohort

We conducted a retrospective, observational, binational multicenter study with data from 9 hospitals in Germany and France. We included consecutively treated patients between January 1, 2015, and December 31, 2020, with unruptured intracranial aneurysms of the ICA and associated compression-induced neuropathy of the oculomotor nerves (ie, CNs III, IV, VI) and/or the optic pathway. Treatment was performed using flow diversion alone or in conjunction with coil embolization. The study methods are described in detail in our previous publication.[7] The present work is a secondary analysis of the data set.

Ethics

The study was approved by the ethics committee of Dresden/Germany (Ethikkommission an der Technischen Universität Dresden) and was conducted in accordance with the Declaration of Helsinki. Patient consent was waived due to the retrospective nature of the study. The contributing centers obtained ethics committee approval in accordance with regional or national standards.

Patient and Aneurysm Characteristics

We collected the following patient characteristics: age, sex, and the presence of high blood pressure, diabetes mellitus, family history of intracranial aneurysms/nontraumatic SAH, and other relevant comorbidities. We collected information on the patients' current and previous smoking habits.

Target aneurysms were classified as either saccular or fusiform and were rated as located in the intra- or extradural space. We measured the maximum aneurysm sac diameter and assessed the presence of intra-aneurysmal thrombus.

Morbidity/Mortality and Imaging Outcomes

We assessed treatment-related mortality and morbidity. Morbidity was defined as neurologic deficits at last follow-up not present at the initial patient presentation. Hemorrhagic and ischemic complications were defined as cross-sectional imaging evidence of hemorrhage or infarction associated with a permanent neurologic deficit or death.

Imaging outcomes obtained by DSA, MRA, or CTA were graded by the respective contributing center according to the widely accepted classification: "aneurysm remnant," "neck remnant," and "complete occlusion."[8] If retreatment of the target aneurysm was performed with an FD, final clinical and imaging results of the patient were assessed at the last follow-up, and these patients were not excluded from the analysis.

Statistical Analysis

Frequency counts are presented as percentages. Continuous and ordinally scaled variables were tested for normal distribution using the Kolmogorov-Smirnov test and are presented as mean (SD). Continuous parameters were compared using the Student *t* test. Contingency analyses for categoric variables were performed

Table 2: Factors associated with incomplete aneurysm occlusion at last anatomic follow-up

Variable	Incomplete Occlusion (n = 13)	Complete Occlusion (n = 37)	Univariate Analysis	Multivariate Analysis	
			P Value	OR (95% CI)	*P* Value
Patient characteristics					
Female sex	10/13 (76.9%)	34/37 (91.9%)	.15		
Age (yr)	Mean, 62.3 (SD, 19.1)	Mean, 55.8 (SD, 13.5)	.19		
Hypertension	5/13 (38.5%)	17/37 (45.9%)	.64		
Current smoker	1/13 (7.7%)	11/37 (29.7%)	.11		
Previous smoker	2/13 (15.4%)	11/37 (29.7%)	.31		
Diabetes mellitus	1/13 (7.7%)	1/37 (2.7%)	.43		
Family history	1/13 (7.7%)	1/37 (2.7%)	.43		
Aneurysm characteristics					
Aneurysm size (mm)	Mean, 17.3 (SD, 6.7)	Mean, 15.4 (SD, 7.5)	.42		
Left-sided aneurysm	10/13 (76.9%)	25/37 (67.6%)	.52		
Intradural aneurysm	5/13 (38.5%)	26/37 (70.3%)	.04	0.28 (0.05–1.56)	.15
Fusiform aneurysm	8/13 (61.5%)	9/37 (24.3%)	.02	5.2 (0.97–27.56)	.05
Aneurysmal thrombus	5/13 (38.5%)	10/37 (27%)	.44		
Treatment-related data					
Ticagrelor	5/13 (38.5%)	17/37 (45.9%)	.64		
≥2 flow diverters	1/13 (26%)	0/37 (0%)	.09		NS[a]
Additional coiling	2/13 (10.5%)	17/37 (45.9%)	.05	0.1 (0.01–0.86)	.04
Follow-up					
Last anatomic follow-up (mo)	Mean, 9 (SD, 7)	Mean, 14.6 (SD, 11.1)	.097	0.88 (0.78–0.99)	.03

Note:—NS indicates not significant.
[a] Variable not included into the regression model.

using the χ^2 test. Multivariate analyses were performed using a logistic regression analysis with stepwise backward selection, with an entry and exit threshold of 0.20. Factors with a $P < .10$ at univariate analysis were included in the regression analysis. Age was grouped into decades for multivariate analysis. The OR is presented with its 95% CI. Statistical significance was defined as a P value $< .05$. Statistical analysis was performed using SPSS 27 (IBM).

RESULTS

Study Demographics

Fifty-four patients with 54 aneurysms were identified and included in the analysis (48 women, 88.9%). The mean age was 59.2 (SD, 15.9) years with a range from 21 to 86 years. Detailed demographics are described in the Online Supplemental Data. In the current analysis, we excluded 1 patient of the previous data set who was retreated with carotid artery deconstruction after asymptomatic intra-aneurysmal migration of the proximal end of an FD construct (2 devices) and balloon test occlusion in the first week after the index procedure.[7,9]

Procedural Characteristics

We treated 51 patients (94.4%) with a single FD; 1 patient (1.9%) was treated with a construct of 2; and 2 patients (3.7%), with a construct of 3 devices. We used the following devices: Derivo (Acandis), FRED (MicroVention), p64 (phenox), Pipeline Embolization Device (Medtronic), and Surpass (Stryker Neurovascular). Additional coiling during the procedure was performed in 19 patients (35.2%). Five patients (9.3%) underwent retreatment with implantation of additional FD stents. All patients received periprocedural dual-antiplatelet therapy started before the intervention and continued it for at least 3 months after the intervention. Ticagrelor was used as a second medication in addition to acetylsalicylic acid or clopidogrel in 24 (44.4%) patients; the remaining patients received acetylsalicylic acid/clopidogrel in combination.

Morbidity/Mortality

During follow-up, 2 patients (3.7%) had hemorrhagic complications with permanent neurologic deficits, and 1 patient (1.9%) died from a hemorrhagic complication. Two patients (3.7%) experienced ischemic complications with permanent deficits. One patient (1.9%) died within the first month after the intervention from an unknown cause. Due to absence of other identifiable causes, we considered this death to be treatment-related. With total morbidity and mortality rates of 7.4% and 3.7%, respectively, the cumulative treatment-related morbidity/mortality rate was 11.1%.

Risk Factors for Morbidity/Mortality

In univariate analysis, 2 factors were significantly associated with morbidity/mortality: older age (mean, 73.8 [SD, 13.4] years versus 57 [SD, 15.3] years; $P = .03$) and ticagrelor intake (5/6 [83.3%] versus 19/48 [39.6%]; $P = .04$). A tendency toward a significant association with morbidity/mortality was furthermore observed for hypertension (6/6 [100%] versus 19/48 [39.6%]; $P = .05$). In multivariate analysis, age (OR per decade of age, 3.2; 95% CI, 1.23–8.49; $P = .02$) and ticagrelor intake (OR, 13.9; 95% CI, 1.16–165.97; $P = .04$) were significantly associated with morbidity/mortality. Data are presented in Table 1. We assessed the association of ticagrelor intake with ischemic and hemorrhagic morbidity/mortality by univariate analysis (Online Supplemental Data) and found no statistically significant differences ($P = .19$).

Anatomic Outcomes

Vascular imaging follow-up was available for 50 patients at a mean of 13.3 (SD, 10.5) months after the initial procedure. Rates of

complete aneurysm occlusion, neck remnant, and aneurysm remnant were 74% (37/54), 14% (7/54), and 12% (6/54), respectively.

Risk Factors for Incomplete Aneurysm Occlusion

In univariate analysis, incomplete aneurysm occlusion occurred significantly more frequently in fusiform aneurysm morphology (8/13 [61.5%] versus 9/37 [24.3%]; $P = .02$) and less frequently in an intradural aneurysm location (5/13 [38.5%] versus 26/37 [70.3%]; $P = .04$). In the multivariate analysis, additional coil embolization (OR, 0.1; 95% CI, 0.01–0.86; $P = .04$) and a longer time interval from treatment to last anatomic follow-up (OR, 0.88; 95% CI, 0.78–0.99; $P = .03$) were less frequently associated with incomplete aneurysm occlusion. Fusiform aneurysm morphology (OR, 5.2; 95% CI, 0.97–27.56; $P = .05$) showed a nonsignificant trend toward incomplete occlusion in multivariate analysis. Data are presented in Table 2.

DISCUSSION

In this study, we found patient-, aneurysm-, and treatment-related factors that were associated with a higher likelihood of morbidity/mortality and incomplete aneurysm occlusion in flow diversion treatment of patients with neuro-ophthalmologic symptoms due to compressive ICA aneurysms. Our findings may help to identify patients in which flow diversion may not be the ideal treatment method and risk factors that can potentially be avoided in advance.

As pointed out in our previous study, flow diversion for compressive ICA aneurysms with ophthalmologic symptoms is associated with a high risk of complications.[7] With morbidity and mortality rates of 7.4% and 3.7%, respectively, the cumulative treatment-related morbidity/mortality rate was 11.1% in our study population. This is considerably higher compared with the findings of the Pipeline Embolization Device for Uncoilable or Failed Aneurysms (PUFS) trial (morbidity/mortality rate of 5.6%,[10] but it is in line with data from the International Retrospective Study of the Pipeline Embolization Device (IntrePED) trial, in which neurologic morbidity/mortality was observed in 9.2% of patients with unruptured aneurysms of the ICA measuring >10 mm.[11] In our study, 2 factors were associated with treatment-related morbidity/mortality in multivariate analysis: patient age and ticagrelor intake.

Patient age has been previously described as a risk factor for morbidity/mortality in a subgroup analysis of the IntrePED data.[12] In that study, mortality rates after flow diversion were significantly higher in patients older than 70 years of age (7.4%). Moreover, in a multivariate analysis, the authors found a significant association of increasing age with neurologic mortality, combined neurologic morbidity and mortality, all-cause mortality, and intracranial hemorrhage. The mean patient age in the IntrePED trial was 57.7 (SD, 13.8) years. In our study, the mean patient age was comparable, with 58.9 (SD, 15.9) years, and the risk of morbidity/mortality increased 3.2 times per decade of age. These results indicate that in elderly patients, FDs for compressive ICA aneurysms should be considered only after careful weighing of the risk-benefit ratio and discussion of alternative options with the patient. Most important, treatment decisions should take into account that chances of complete symptom recovery may decrease with increasing age, fusiform aneurysm morphology, and a longer delay between the onset of ocular symptoms and endovascular treatment.[7]

A valuable, well-established alternative to flow diversion for ICA aneurysms is PVO. In a study from 2016, symptoms improved or resolved after PVO in 88% of 62 patients with large or giant ICA aneurysms and cranial nerve dysfunction; the rate of permanent neurologic complications was 1.1% (1/88).[13] Another study reported improved or resolved symptoms in 72% of 32 patients with ophthalmologic symptoms; major persistent ischemic symptoms (mRS > 1) occurred in 5.5% of 56 patients with ICA aneurysms treated with PVO.[14] However, the oldest patient in that study was 66 years of age; thus, the cohort is not comparable with ours. One must additionally take into account that PVO is not feasible in about one-third of patients without prior bypass surgery in case of a failed occlusion test.[13] On the other hand, surgical clipping is also an effective, well-established alternative for symptomatic aneurysms of the para- and supraclinoid ICA, including the posterior communicating artery.[5,6,15] In summary, all available methods should be discussed for each treatment indication, and we believe that conservative management should be preferred in elderly patients with low chances of symptom recovery and a low, or rather nonexistent, risk of SAH, particularly from extradural aneurysms.

The association of ticagrelor intake with morbidity/mortality is surprising because several studies have reported a favorable efficacy and safety profile of ticagrelor in neuroendovascular procedures.[16-19] We did not observe statistically significant differences regarding hemorrhagic or ischemic complications depending on the antiplatelet medication. Our finding should encourage further studies to seek an explanation. However, we suppose that the association is rather related to a center-based selection bias.

Ophthalmologic symptom relief is related to complete aneurysm occlusion.[7] We observed increased rates of complete occlusion at follow-up when additional coil embolization was performed. The literature on this aspect is currently ambiguous, with studies showing increased rates of complete aneurysm occlusion[20,21] and studies reporting similar results after flow diversion with additional coiling.[22] Of note, additional coil embolization had no effect on clinical symptom recovery in our previous study.[7]

We observed increased rates of incomplete aneurysm occlusion after flow diversion for fusiform aneurysm morphology, but this finding was not significant in multivariate analysis. Fusiform aneurysm morphology is also a risk factor for incomplete ophthalmologic recovery.[7] A postmortem histopathologic study of 4 giant fusiform aneurysms revealed that endothelialization of an FD may not occur at all and that thrombus organization may not be initiated inside these aneurysms for as long as 1 year.[23] Altogether, incomplete healing after flow diversion of fusiform aneurysms with persisting mass effect and nonorganized intra-aneurysmal thrombus may be a hypothesis for our observation. The association between longer follow-up and complete occlusion is obvious, and progressive aneurysm occlusion with time has been described.[24]

Our study has limitations, its retrospective nature being the most important one. It also has decreased external validity because anatomic results are self-reported, and the severity and relevance of complications were not adjudicated by an independent clinical event committee. Further limitations are the nonstandardized

follow-up protocols and antiplatelet regimens. These limitations should be addressed in a large, prospective, consecutive patient cohort investigating this subject under controlled circumstances.

CONCLUSIONS

Flow diversion for compressive ICA aneurysms with ophthalmologic symptoms, though a promising technique, is associated with a significant complication rate. The most important risk factor for morbidity/mortality may be increasing patient age. Because relief of neuro-ophthalmologic symptoms is linked to complete aneurysm occlusion, risk factors for incomplete occlusion after flow diversion should be considered when making individual treatment decisions. Additional coil embolization increased the likelihood of complete aneurysm occlusion at follow-up in our study cohort.

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Contributions

D.P.O.K.: Acquisition of data, drafting of manuscript, critical review of manuscript, approval and submission of manuscript.

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M.G.: Acquisition of data, data analysis, drafting of manuscript, critical review of manuscript, approval of manuscript, guarantor of the study.

Collaborators: Acquisition of data.

Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

REFERENCES

1. Micieli JA, Newman NJ, Barrow DL, et al. **Intracranial aneurysms of neuro-ophthalmologic relevance.** *J Neuroophthalmol* 2017;37:421–39 CrossRef Medline
2. Szikora I, Marosfoi M, Salomváry B, et al. **Resolution of mass effect and compression symptoms following endoluminal flow diversion for the treatment of intracranial aneurysms.** *AJNR Am J Neuroradiol* 2013;34:935–39 CrossRef Medline
3. Binyamin TR, Dahlin BC, Waldau B. **Resolution of third nerve palsy despite persistent aneurysmal mass effect after flow diversion embolization of posterior communicating artery aneurysms.** *J Clin Neurosci* 2016;31:207–09 CrossRef Medline
4. Sahlein DH, Fouladvand M, Becske T, et al. **Neuroophthalmological outcomes associated with use of the Pipeline Embolization Device: analysis of the PUFS trial results.** *J Neurosurg* 2015;123:897–905 CrossRef Medline
5. Silva MA, See AP, Dasenbrock HH, et al. **Vision outcomes in patients with paraclinoid aneurysms treated with clipping, coiling, or flow diversion: a systematic review and meta-analysis.** *Neurosurg Focus* 2017;42:E15 CrossRef Medline
6. Silva MA, See AP, Khandelwal P, et al. **Comparison of flow diversion with clipping and coiling for the treatment of paraclinoid aneurysms in 115 patients.** *J Neurosurg* 2019;130:1505–12 CrossRef Medline
7. Boulouis G, Soize S, Maus V, et al; Compressive Aneurysm Study Group. **Flow diversion for internal carotid artery aneurysms with compressive neuro-ophthalmologic symptoms: clinical and anatomical results in an international multicenter study.** *J Neurointerv Surg* 2021 Nov 18. [Epub ahead of print] CrossRef Medline
8. Raymond J, Guilbert F, Weill A, et al. **Long-term angiographic recurrences after selective endovascular treatment of aneurysms with detachable coils.** *Stroke* 2003;34:1398–1403 CrossRef Medline
9. Gawlitza M, Soize S, Manceau P-F, et al. **Delayed intra-aneurysmal migration of a flow diverter construct after treatment of a giant aneurysm of the cavernous internal carotid artery.** *J Neuroradiol* 2020;47:233–36 CrossRef Medline
10. Becske T, Kallmes DF, Saatci I, et al. **Pipeline for uncoilable or failed aneurysms: results from a multicenter clinical trial.** *Radiology* 2013;267:858–68 CrossRef Medline
11. Kallmes DF, Hanel R, Lopes D, et al. **International retrospective study of the Pipeline Embolization Device: a multicenter aneurysm treatment study.** *AJNR Am J Neuroradiol* 2015;36:108–115 CrossRef Medline
12. Brinjikji W, Kallmes DF, Cloft HJ, et al. **Age-related outcomes following intracranial aneurysm treatment with the Pipeline Embolization Device: a subgroup analysis of the IntrePED registry.** *J Neurosurg* 2016;124:1726–30 CrossRef Medline
13. Bechan RS, Majoie CB, Sprengers ME, et al. **Therapeutic internal carotid artery occlusion for large and giant aneurysms: a single center cohort of 146 patients.** *AJNR Am J Neuroradiol* 2016;37:125–29 CrossRef Medline
14. Labeyrie MA, Lenck S, Bresson D, et al. **Parent artery occlusion in large, giant, or fusiform aneurysms of the carotid siphon: clinical and imaging results.** *AJNR Am J Neuroradiol* 2015;36:140–45 CrossRef Medline
15. Gaberel T, Borha A, di Palma C, et al. **Clipping versus coiling in the management of posterior communicating artery aneurysms with third nerve palsy: a systematic review and meta-analysis.** *World Neurosurg* 2016;87:498–506.e4 CrossRef Medline
16. Chien SC, Chen CC, Chen CT, et al. **Ticagrelor versus clopidogrel in stent-assisted coil embolization of unruptured intracranial aneurysms.** *Interv Neuroradiol* 2021 Nov 18. [Epub ahead of print] CrossRef Medline
17. Moore JM, Adeeb N, Shallwani H, et al. **A multicenter cohort comparison study of the safety, efficacy, and cost of ticagrelor compared to clopidogrel in aneurysm flow diverter procedures.** *Neurosurgery* 2017;81:665–71 CrossRef Medline
18. Park KY, Ozaki T, Kostynskyy A, et al. **Ticagrelor versus clopidogrel in the dual antiplatelet regimen for intracranial stenting or flow-diverter treatment for unruptured cerebral aneurysms: a single-center cohort study.** *AJNR Am J Neuroradiol* 2021;42:1638–44 CrossRef Medline
19. Soize S, Foussier C, Manceau P-F, et al. **Comparison of two preventive dual antiplatelet regimens for unruptured intracranial aneurysm embolization with flow diverter/disrupter: a matched-cohort study comparing clopidogrel with ticagrelor.** *J Neuroradiol* 2019;46:378–83 CrossRef Medline

20. Zhang Q, Shao Q, Chang K, et al. **Safety and efficacy of coils in conjunction with the Pipeline Flex Embolization Device for the treatment of cerebral aneurysms.** *Front Neurol* 2021;12:651465 CrossRef Medline
21. Lin N, Brouillard AM, Krishna C, et al. **Use of coils in conjunction with the Pipeline Embolization Device for treatment of intracranial aneurysms.** *Neurosurgery* 2015;76:142–49 CrossRef Medline
22. Sweid A, Atallah E, Herial N, et al. **Pipeline-assisted coiling versus Pipeline in flow diversion treatment of intracranial aneurysms.** *J Clin Neurosci* 2018;58:20–24 CrossRef Medline
23. Szikora I, Turányi E, Marosfoi M. **Evolution of flow-diverter endothelialization and thrombus organization in giant fusiform aneurysms after flow diversion: a histopathologic study.** *AJNR Am J Neuroradiol* 2015;36:1716–20 CrossRef Medline
24. Becske T, Brinjikji W, Potts MB, et al. **Long-term clinical and angiographic outcomes following Pipeline Embolization Device treatment of complex internal carotid artery aneurysms: five-year results of the Pipeline for Uncoilable or Failed Aneurysms trial.** *Neurosurgery* 2017;80:40–48 CrossRef Medline