Multimodality Treatment of Complex Unruptured Cavernous and Paraclinoid Aneurysms

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BACKGROUND: Unruptured aneurysms of the cavernous and paraclinoid internal carotid artery can be approached via microsurgical and endovascular approaches. Trends in treatment reflect a steady shift toward endovascular techniques.

OBJECTIVE: To analyze our results with multimodal treatment.

METHODS: We reviewed patients with unruptured cavernous and paraclinoid internal carotid artery aneurysms proximal to the posterior communicating artery treated at a single center from 2007 to 2012. Treatment included 4 groups: (1) stent-assisted coiling, (2) pipeline endovascular device (PED) flow diverter, (3) clipping, and (4) trapping/bypass. Follow-up was 2 to 60 months.

RESULTS: The 109 aneurysms in 102 patients were studied with the following treatment groupings: 41 were done with stent-assisted coiling, 24 with Pipeline endovascular device, 24 by microsurgical clipping, and 20 by trap/bypass. Group: (1) two percent had delayed significant intraparenchymal hemorrhage; (2) thirteen percent had central nerve palsies, 8% had small asymptomatic infarcts, and 4% had small, asymptomatic remote-site hemorrhages; (3) twenty-nine percent of patients suffered from transient central nerve palsies, 4% experienced major stroke, and 8% had small intracerebral hemorrhages; (4) thirty-five percent had transient central nerve palsies, 10% had strokes, and 10% had intracerebral hemorrhages. In terms of follow-up obliteration, 83% had complete/nearly complete obliteration at last follow-up, 17% had residual aneurysms, and 10% required retreatment. Ninety-six percent of group 1 (35/38), 100% of group 2 (23/23), 100% of group 3 (21/21), and 95% of group 4 had modified Rankin Scale scores of 0 to 1.

CONCLUSION: Treatment of these aneurysms can be carried out with acceptable rates of morbidity. Careful patient selection is crucial for optimal outcome. Endovascular treatment volumes likely will continue to predominate over microsurgical techniques as changing skill sets evolve in neurosurgery, but individualized application of all available treatment options will continue.

KEY WORDS: Bypass, Cerebral aneurysms, Clipping, Coiling, Flow diverter, Stenting, Treatment

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Unruptured cavernous and paraclinoid aneurysms are familiar entities to all neurosurgeons. However, when treatment is indicated, management paradigms are complex and require careful case-by-case evaluation to optimize the risk-benefit ratio.[1-47] We present a contemporary and cotemporaneous series of complex, broad-based unruptured cavernous and supraclinoid internal carotid artery (ICA) aneurysms proximal to the posterior communicating artery that were treated at a single large-volume center via a multidisciplinary team approach. This anatomic specificity was chosen given the current on-label indication for the Pipeline Embolization Device (PED) for comparative purposes. Aneurysms suitable for stand-alone coil embolization or balloon remodeling technique were not included to maintain the focus on complex, broad-based aneurysms. The 4 treatment techniques include the following groups: stent-assisted coil embolization, flow-diverter treatment, clip reconstruction, and bypass/trapping.

ABBREVIATIONS: ICA, internal carotid artery; **MCA,** middle cerebral artery; **mRS,** modified Rankin Scale; **PED,** Pipeline Embolization Device

PATIENTS AND METHODS

Study Population

All patients with unruptured ICA aneurysms from October 2007 to October 2012 were analyzed under an Institutional Review Board–approved prospective cerebrovascular registry. The patients were treated by 2 interventional neuroradiologists (B.G., D.H.) and 2 dually trained neurosurgeons (L.K., L.N.S.). All patients with paraclinoid and cavernous segment aneurysms proximal to the posterior communicating artery were included, and the patients with communicating segment, ICA terminus, or A1 segment aneurysms were excluded. Aneurysms treated with coiling only or balloon remodeling were excluded. Four different treatment modalities were used to treat patients, including stent-assisted coiling, flow diverter, microsurgical clipping, and bypass/parent vessel trapping. Information on clinical presentation and the patient's neurological status was obtained retrospectively from patient records or telephone interviews. The follow-up period ranged from 2 to 60 months.

Treatment Strategy

The cerebrovascular treatment team at our institution consists of 4 individuals trained in neurointerventional techniques, of whom 2 are also cerebrovascular neurosurgeons. Treatment choice ultimately was dictated by 1 of the 4 principles after careful discussion of options available with the patient. Hence, although there is substantial selection bias inherent in the treatment choice performed, in general, certain parameters molded the treatment selection process.

Patient Age and Comorbidities

Age was not an absolute indicator or contraindicator for any treatment. Patients with multiple comorbidities were considered better candidates for endovascular therapy.

Anticoagulation

For those considered for endovascular treatment, the need for antiplatelet anticoagulation was a major consideration. Patients were evaluated for medical compliance and financial willingness to maintain aspirin and clopidogrel/prasugrel daily. Other contraindications for antiplatelet therapy were evaluated such as a history of idiopathic thrombocytopenic purpura, aspirin allergy, or a hypercoagulable state. Seventeen percent (4 of 23 patients) were resistant to clopidogrel on the basis of platelet assays, and these patients were switched to prasugrel.

Angioarchitecture

Patients with extremely tortuous ICA course and perianeurysmal ICA diameters >5.25 mm were considered more strongly for surgical treatment. Patients with large or giant paraclinoid aneurysms spanning the cavernous to supraclinoid carotid junction were considered more strongly for endovascular treatment.

Patient Preference

Patients often had preconceived notions of optimal treatment that were based on prior and concurrent discussions. This phenomenon is increasingly common in today's patient, who has increased access to medical information previously provided only by local physicians. Ultimately, the physicians counseled patients according to their own experience and clinical bias.

Statistical Methods

All statistical analyses were carried out with SPSS version 17.0 (SPSS, Inc, Chicago, Illinois) and analyzed by a biostatistician. Differences in baseline characteristics were analyzed with the Mann-Whitney *U* and Fisher exact tests (J.B.).

RESULTS

A total of 109 aneurysms were treated in 102 patients. Forty-one aneurysms (37.6%) in 38 patients were treated by stent-assisted techniques; 24 aneurysms (22%) in 23 patients were treated with the PED, 24 aneurysms (22%) in 21 patients were treated with microsurgical clipping, and 20 aneurysms (18.3%) in 20 patients were treated by bypass These were compared and analyzed, and the results are shown in Tables 1-4.

Demographic Analysis

Although older patients with multiple comorbidities were considered more strongly for endovascular treatment, statistically, there was no difference among the treatment groups ($P = .54$). Sex distribution was statistically significant ($P = .002$ by Fisher exact test), with more female patients treated in the stent-assisted coiling, PED, and clipping groups. The reasons for this difference are not clear (Table 1).

Geometric Analysis

Geometric analysis was performed with respect to larger aneurysm size, unfavorable dome-to-neck ratio, and aspect ratio. Aneurysms selected for 1 of the 4 treatments were considered complex on the basis of size and/or aspect ratio, or dome-to-neck ratio. Aneurysms considered anatomically suitable for primary or balloon-assisted coil embolization were excluded from our series. The aneurysms treated by bypass were about 2 to 3 times as large as the other groups (bypass, 19.1 ± 11.1 mm; PED, 10.1 ± 4.8 mm; stent-assisted coiling, 8.4 ± 5.4 mm; clipping, 6.7 ± 3.1 mm), and this difference was statistically significant ($P = .001$). Aspect ratio was also different, but the difference was less significant ($P = .001$).

Presentation

In the cohort of 109 aneurysms, the following primary modes of presentation occurred: transient ischemic attacks (11%), cranial nerve palsy (17%), headache (25%), and incidental (47%).

Major Neurological/Procedure-Related Complications

Stent-Assisted Coiling Group

In the stent-assisted coiling group, 1 patient (2%) suffered a spontaneous posttreatment intraparenchymal hemorrhage 3 days after stent placement. The antiplatelet agents were discontinued, platelets were administered, and a craniotomy and clot evacuation was performed. Five days later, the antiplatelet agents were restarted in a nonbolus fashion, and the patient was discharged to inpatient rehabilitation. Ultimately, the patient recovered substantially and was capable of independent living (modified Rankin Scale [mRS] score, 3) but remains with a fixed

TABLE 1. Descriptives[a]

	Group 1, Stent-Assisted Coiling	Group 2, PED	Group 3, Clipping	Group 4, Bypass	P, ANOVA
Age, y	55.9	53.2	48.2	55.2	.22
Size, mm	8.4	10.2	6.7	19.1	.001
Aspect ratio	1.4	1	1.1	0.8	.001
Dome-to-neck ratio	1.4	1.1	1.3	1.1	.3
Hospital stay, d	2.8[a]	2.0	5.6	10.4	.001

	Group 1, Stent-Assisted Coiling	Group 2, PED	Group 3, Clipping	Group 4, Bypass	P, Fisher Exact
Sex, n (%)					
0 (Female)	35 (92)	14 (61)	15 (71)	10 (50)	.002
1 (Male)	3 (8)	9 (39)	6 (29)	10 (50)	
Comorbidities					
0 (No)	16 (42)	14 (61)	15 (71)	14 (70)	.08
1 (Yes)	22 (58)	9 (39)	6 (29)	6 (30)	

[a]PED, Pipeline Embolization Device.

upper-extremity paresis. One patient (2.5%) suffered an ischemic stroke (Table 2).

PED Group

Three patients (13%) had new cranial nerve deficits after treatment (Table 4). During early follow-up, 1 patient suffered from diplopia that was corrected by prism glasses, and 2 patients had partial visual field cuts at the 6-week follow-up. Long-term follow-up is pending on these patients. Two patients (8%) had small asymptomatic infarcts on magnetic resonance imaging or computed tomography discovered on follow-up imaging 6 weeks after treatment. One patient (4%) had a small, asymptomatic, ipsilateral frontal lobe hemorrhage immediately after the procedure but recovered without deficit. There were 2 cases of stent migration that required retreatment when discovered at a routine 6-week posttreatment computed tomography angiography. Two cases (8%) of intraprocedural incomplete device opening required follow-up balloon angioplasty to fully expand the device. No complications occurred as result of this additional maneuver. One patient (4%) suffered a gastrointestinal bleed related to prasugrel anticoagulation but did not require transfusion or treatment. Four patients (17%) were found to be resistant to the clopidogrel on the VerfiyNow platelet assay (Accumetrics San Diego, CA) and were placed on prasugrel.

Microsurgical Clipping Group

Development of postoperative cranial nerve palsies was one of the major complications in the surgically treated groups (both clipping and bypass); however, many of them had improved/resolved by 3 months. In the clipping group, 7 patients (29%) developed new or worsened postoperative cranial nerve deficits. All 7 patients suffered from third nerve palsy, and 1 patient also developed a partial visual field cut. At the 3-month follow-up, 3 patients (43% of the 7 patients) had complete resolution of symptoms, 2 patients (28.5%) had partial resolution (mild but present ptosis), and 2 patients (28.5%) had residual significantly restricted eye movements along with the ptosis. Two patients overall (8%) developed small asymptomatic intracerebral hemorrhages, and 1 patient (4%) developed a major stroke, a middle cerebral artery (MCA) territory infarct with hemiparesis and

TABLE 2. Summary of Complications and Outcomes[a]

Complication	Group 1, Stent-Assisted Coiling (n = 41), n (%)	Group 2, PED (n = 24), n (%)	Group 3, Clipping (n = 24), n (%)	Group 4, Bypass (n = 20), n (%)	P Value
Ischemic stroke	0	2 (8)	1 (4)	2 (10)	.1
Intraparenchymal hemorrhage	1 (2)	1 (4)	2 (8)	2 (10)	.5
Total stroke (ischemic + hemorrhagic)	1 (2)	3 (12)	3 (12)	4 (20)	.09
Cranial nerve palsies (posttreatment)	0	3 (13)	7 (29)	7 (35)	.001
Raymond 1 and 2	34 (83)	20 (83)	23 (96)	20 (100)	.1
Follow-up mRS score of 0-1	39 (96)	24 (100)	24 (100)	19 (95)	.5
Mean follow-up, mo	23	6	14	24	

[a]mRS, modified Rankin Scale; PED, Pipeline Embolization Device.

TABLE 3. Procedure-Related Cranial Nerve Palsy[a]

Cranial Nerve Palsy	Group 1, Stent-Assisted Coiling, n (%)	Group 2, PED, n (%)	Group 3, Clipping, n (%)	Group 4, Bypass, n (%)
Diplopia	0	1 (4)	7[b] (29)	6 (30)
Full recovery		1	3 (44)	3 (50)
Partial recovery			2 (28)	2[c] (33)
None			2 (28)	1 (16)
Visual field cut	0	2 (8.6)	1[b] (4)	1 (5)
Full recovery				
Partial recovery				
None		2	1	1

[a]PED, Pipeline Embolization Device.
[b]One patient in group 3 (clipping) had both diplopia and visual field cut.
[c]Of these 2 patients, one had third nerve palsy and had a partial recovery, and the other patient had a sixth nerve palsy that was corrected by prism glasses.

aphasia. At the 3-month follow-up, the hemiparesis had resolved completely, but a persistent mild aphasia remained. Another patient developed an embolic MCA stroke postoperatively that was only indirectly related to the surgical treatment. This occurred during a postoperative diagnostic angiography and required a decompressive hemicraniectomy to compensate for brain swelling. The patient recovered dramatically from her stroke with persistent and mild expressive aphasia.

Bypass Group

In the bypass group, 7 of 20 patients (35%) developed new or worsened cranial nerve deficits immediately after their surgeries. One patient (5%) lost vision in the ipsilateral eye; 5 patients (25%) developed third nerve dysfunction (1 patient also had visual loss); and 1 patient (5%) developed a sixth nerve palsy. At the 3-month follow-up, 3 patients with third nerve palsy recovered completely; 1 patient had partial improvement, and the patient with visual deficit did not improve. One patient with sixth nerve palsy required prism glasses. Two patients (10%) developed diffusion positive infarcts: 1 with resultant hemiparesis, which resolved by 6 months without any deficit, and a second with internal capsule and basal ganglia strokes that resulted in long-term cognitive dysfunction. A third patient (5%) suffered heparin-induced thrombocytopenia with small infarcts noted but recovered completely in follow-up. Two patients developed intracerebral hemorrhage (10%); 1 patient required surgical removal of the clot, and the other had an asymptomatic intracerebral hemorrhage.

Radiographic Outcomes: Recurrence and Retreatments

Stent-Assisted Coiling Group

In the stent-assisted coiling group, 90% of patients (37 of 41) had a Raymond 1 or 2 score after treatment, and 10% (4 patients) were categorized as Raymond 3 (significant residual). On follow-up (mean, 23 months; range, 2-60 months), 3 patients (7%) with Raymond 2 had converted to Raymond 3. From the 7 total Raymond 3 patients (17%) who were discovered in follow-up, 4 patients (10%) had retreatments and 3 patients (7%) were elected for follow-up only (Table 2).

PED Group

In the PED group, at a mean of 6 months of follow-up, there were 17 complete obliterations (81%), 3 small (<2 mm) residuals (13%), and 3 cases with pending radiographic follow-up (13%). Two cases of stent migration (8%) were identified at their 6-week posttreatment computed tomographic angiography and required placement of an additional device. Overall, Raymond 1 or 2 status was confirmed through radiography in 95% of aneurysms (20 of 21) on follow-up.

Microsurgical Clipping Group

Over 14 months of follow-up, there were 7 cases (29%) of clip residue in patients with microsurgical clipping, and 6 patients (6 of 7, 86%) had a dog-ear remnant (Raymond 2), giving a 96% complete or nearly complete obliteration rate. One patient had a significant residue (Raymond 3) that was left intentionally because the ICA was dysplastic and a subsequent PED procedure was planned (Case Illustration 3).

TABLE 4. Preoperative Cranial Nerve Deficit Recovery Rates[a]

Status	Stent-Assisted Coiling, n (%)	PED, n (%)	Clipping, n (%)	Bypass, n (%)
Cranial nerve full recovery	2/5 (40)	2/2 (50)	3/5 (60)	5/7 (71.4)
Cranial nerve partial recovery	1/4 (20)	2/2 (50)	2/5 (40)	1/7 (14.2)
No improvement	2/4 (40)			1/7 (14.2)

[a]Cranial nerve, second, third, fourth, and sixth nerves; PED, Pipeline Embolization Device.

Bypass Group

Radiographic results in the bypass group over a mean follow-up period of 24 months showed complete occlusion of aneurysms without any residual, recurrence, or retreatments. One graft had mild narrowing along its midportion but without a thrombus or flow limitation. All grafts were patent immediately after surgery. In long-term follow-up, 1 graft silently occluded with no clinical sequelae.

Clinical Outcomes

Stent-Assisted Coiling Group

Forty-one aneurysms were treated in 38 patients. Four patients presented with cranial nerve dysfunction: 1 recovered completely, 2 had partial functional improvement, and 1 did not show any improvement after treatment. At follow-up (mean, 23 months; range, 2-60 months), 92% of patients had mild or no deficit (mRS score = 0, 32 patients; mRS score = 1, 3 patients), 5.5% returned to baseline function or mRS score of 1 or 2, and 1 patient (2.5%) worsened (intraparenchymal hemorrhage patient) (mRS score = 3).

PED Group

Four patients (17%) presented with pretreatment diplopia. Two patients recovered completely after the treatment, and 2 patients had a partial recovery. Follow-up duration was a mean of 6 months (range, 1-14 months). All patients remained or recovered to an mRS score of 0 or 1.

Microsurgical Clipping Group

Preoperatively, 7 patients presented with headaches, 2 patients presented with transient ischemic attacks, 19 were incidentally discovered, and 1 patient presented with cranial nerve palsy, which resolved in follow-up. Seven patients developed postoperative new or worsened cranial nerve palsy. Three patients recovered completely, and 4 had partial recovery of cranial nerve function. At follow-up (mean, 16 months; range, 1-51 months), all patients retained or recovered to an mRS score of 0 or 1. Fifty-two percent of the patients had no deficit (mRS score = 0), and 48% had only a mild deficit (mRS score = 1).

Bypass Group

In the bypass group, 9 patients presented with cranial nerve palsy (4 [44%] of which resolved in follow-up), 4 presented with transient ischemic attacks, 5 were incidental, and 2 presented with headaches. At follow-up (mean, 26.5 months; range, 1-61 months), 55% of the patients had no deficit (mRS score = 0), and 45% demonstrated an mRS score of 1 or 2. Notably, 1 patient with an mRS score of 2 with a basal ganglia stroke suffered persistent cognitive deficits at the last follow-up but was living independently at home without a focal deficit.

Average Hospital Stay

Average hospital stay was much shorter in the endovascular treatment groups (stent-assisted coiling, 2.6 days; PED, 2 days) compared with the surgically treated patients. Individuals undergoing clipping spent an average of 5.6 days and bypass patients an average of 10 days in the hospital (P = .001; Table 2).

ILLUSTRATIVE CASES

Case 1

This 75-year-old man presented with a history of progressive diplopia, blurry vision, and new onset of ptosis in the left eye. The workup revealed a giant left ICA aneurysm measuring 20 mm in the greatest dimension and fetal origin of the posterior cerebral artery (Figure 1A-1C). The patient was treated by PED and coiling. Posttreatment images showed stagnation of blood flow in the aneurysm (Raymond score, 0; Figure 1D-1F). The patient did well after the procedure and was discharged home the next day. At the 6-week follow-up, the patient had a mild ptosis with resolution of diplopia and blurry vision. The patient returned to the hospital 3 months after treatment with worsening ptosis, headaches, and fixed and dilated pupils. The angiogram revealed progressive growth of the aneurysm and retraction of the PED into the lumen of the aneurysm (Figure 1G and 1H). The patient underwent placement of a second PED. First, the Marksman microcatheter was placed in the lumen of the MCA. A Solitaire FR retriever was used to anchor the Marksman catheter, and the second PED was placed in the prior stent. Balloon dilatation of the PED was performed to ensure apposition. Stagnation of flow was noted at the end of the procedure (Figure 2). The patient developed a mild left-sided hemiparesis on the second day of treatment. His magnetic resonance imaging showed multiple punctate areas of restricted diffusion in the left MCA distribution. The patient was discharged home with outpatient physical therapy. At the 4-month follow-up, he had resolution of both the hemiparesis and third nerve palsy. There was a significant reduction of aneurysm size but with residual filling at the neck.

Case 2

This 56-year-old woman was diagnosed with a right supraclinoid right ICA aneurysm during a workup for headaches and dizziness. The aneurysm was bilobed and measured 5 mm in diameter (Figure 3A). We elected to treat this aneurysm because of its irregular shape. The patient underwent stent-assisted coiling of the aneurysm without any complications (Figure 3B). The 6-month follow-up showed significant recurrence of the aneurysm (Figure 3C). The patient underwent retreatment via coil embolization without any complications (Figure 3D). The 1-year follow-up angiogram showed complete exclusion of the aneurysm from the circulation without recurrence (Figure 3E).

Case 3

This 69-year-old woman presented with a 1-year history of double vision. Workup revealed a partially thrombosed giant ICA cavernous segment aneurysm, directed laterally and measuring 22 mm in its maximum dimension (Figure 4A and 4B). We decided to perform a bypass and trapping of the aneurysm. She underwent a right frontotemporal craniotomy, orbital osteotomy, optic nerve decompression, and radial artery graft placement from

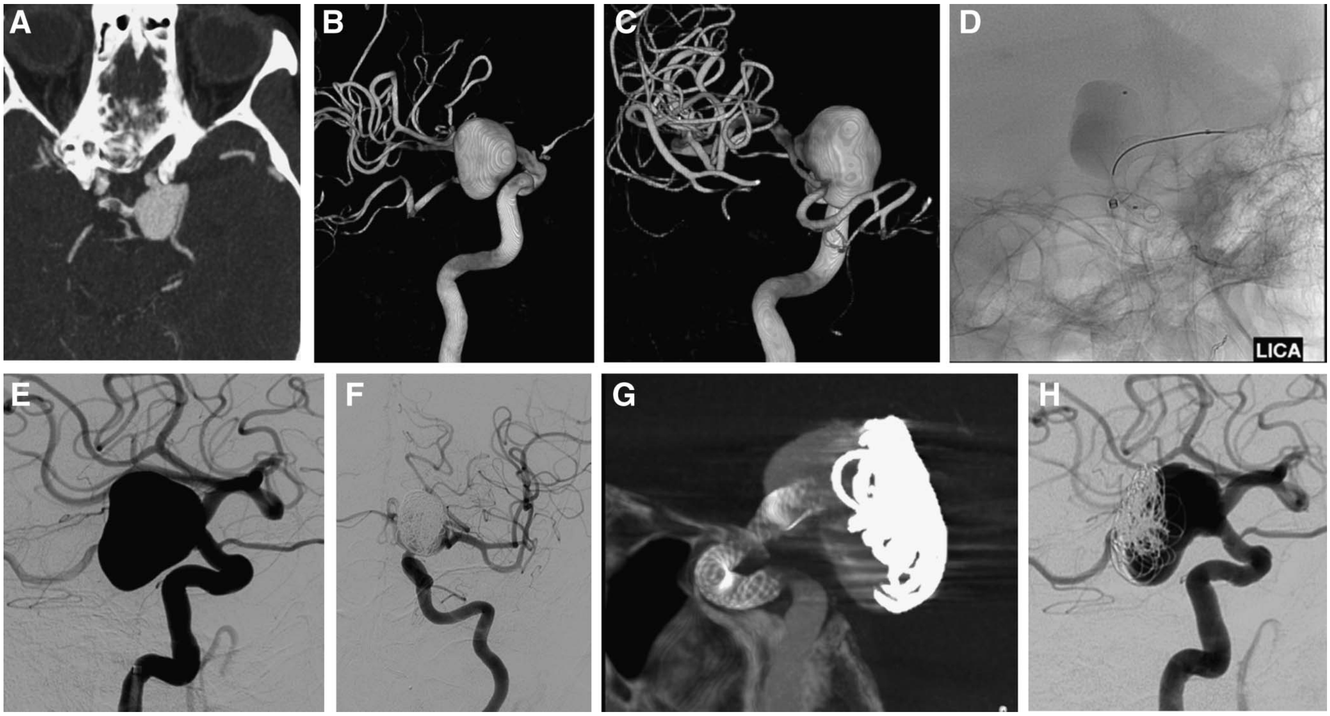

FIGURE 1. *A, magnetic resonance imaging scan of a 75-year-old man presenting with third nerve palsy showing a large internal cerebral artery aneurysm. B and C, cerebral angiogram showing a giant supraclinoid aneurysm with fetal posterior cerebral artery measuring 20 mm in diameter. D, angiogram showing deployment of the Pipeline Embolization Device. LICA, left internal carotid artery; E, postdeployment scan showing stagnation of blood in the aneurysm. F, angiogram showing near complete obliteration of the aneurysm after placement of the coils without any residual. G, patient scan at 3 months showing stent migration and (H) progressive enlargement of the aneurysm.*

the cervical external carotid artery to the M2 segment of the MCA (Figure 4C). The patient suffered an intraparenchymal hemorrhage postoperatively and decreased movement of the left upper extremity (Figure 4D), thought to be a complication of intraoperative heparin and perioperative aspirin. The patient was taken back to the operating room, and the hematoma was evacuated (Figure 4E). Immediately after treatment, the patient did not have any focal neurological deficits but suffered from generalized fatigue, impaired balance, and significant cognitive deficits. At the 6-month follow-up, her double vision had completely resolved, and she had returned to normal function (mRS score, 0).

DISCUSSION

This single-institution series represents a unique cohort of complex, unruptured cavernous and paraclinoid aneurysms treated cotemporaneously via 4 distinct treatment modalities. Such retrospective analysis presents a "real-world" application of these 4 methodologies. The facts that aneurysm size varied distinctly by technique and that surgically treated patients were younger in our series indicate the significant treatment and selection bias built into our team's decision-making algorithm. Therefore, these data cannot be used to determine a single best treatment for these varied and complex lesions. Nevertheless, every surgical method should and must be evaluated in terms of safety and efficacy. Combined procedure-related ischemic and hemorrhagic strokes in groups 1 through 4 (group 1, stent/coil; group 2, PED; group 3, clipping; group 4, bypass/trap) were 2%, 12%, 12%, and 20%, respectively. Only 2 of the resultant strokes, 1 ischemic and 1 hemorrhagic, affected mRS outcome at the last follow-up. The former occurred in the stent/coil group and the latter in the bypass/trap group. None of the strokes resulted in major disability.

Not surprisingly, immediate posttreatment cranial nerve deficits were significantly higher in the microsurgical groups: 0%, 13%, 29%, and 35%, respectively (Table 3). Resolution of cranial nerve palsies occurred, but a significant percentage of patients were left with partial or complete deficits (Table 4).

Obliteration rates of Raymond 1 and 2 were as follows: 83%, 83%, 96%, and 100% for groups 1 through 4, respectively. Note that the mean follow-up for the stent/coil group was a robust 23 months but for the PED group was only 6 months. Despite this, the obliteration rates were similar. In fact, if the 3 cases in the PED group still awaiting their initial 6-month follow-up angiogram are excluded, the obliteration rate for PED climbs to 95%. Obliteration rates were the best in the bypass group, despite the large size of the aneurysm. The mRS scores at the last follow-up were 96%, 100%, 100%, and 95%, respectively. Despite the minor deficits present in some patients, overall, all groups demonstrated an

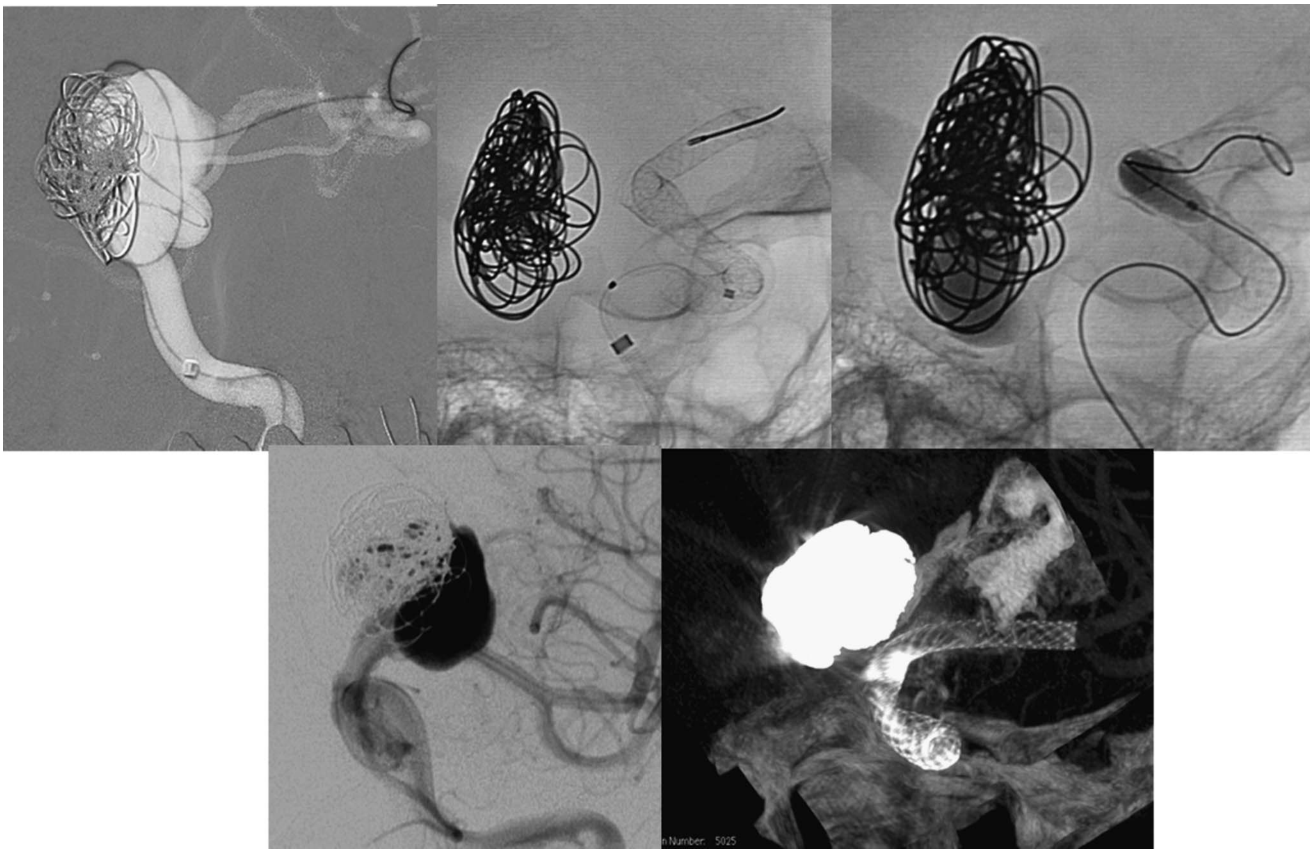

FIGURE 2. *Angiogram showing Marksman microcatheter placement into the lumen of the middle cerebral artery, along with the Solitaire FR retriever, and placement of second Pipeline Embolization Device into the prior stent.*

acceptable level of functional recovery. In fact, only 2 patients in this 103-patient cohort suffered an mRS score >1.

Recent refinements in the microsurgical management of paraclinoid aneurysms through the introduction of skull base approaches, increased knowledge of anatomy, and intraoperative monitoring have produced excellent results in surgical clip occlusion of this group. However, the associated surgical morbidity is uniformly higher than for unruptured anterior circulation aneurysms in general.[12-14] Our data reconfirm this finding but also fall within the ranges of acceptable morbidity and obliteration rates. Various series have reported good results in terms of both angiographic cure and clinical outcome. Several major surgical series[15-27] have reported complete occlusion rates of 80% to 95% (with good/excellent outcome [mRS scores of 0-2/Glasgow Outcome Scale scores of 4 and 5] ranging from 80% to 96.4%). However, morbidity is not insignificant. Overall complication rates range from 6% to 35%, including permanent visual impairment (visual loss/visual field deficit) ranging from 1% to 26% (both ruptured and unruptured) and a mortality rate up to 1.1% (unruptured paraclinoid).[15-27] The literature on bypass and trapping for paraclinoid aneurysms showed aneurysm occlusion rates of up to 100%, with excellent clinical outcome achieved in 87% to 100% of the patients. This came with relatively low morbidity (5%-10%) but a variable risk of mortality (0%-5%).[23-36] Postoperatively, new cranial nerve deficits (including visual deficits and third, fourth, and sixth nerve palsies) are high and have been reported in the literature from 8% to 33%. The resolution of ocular symptoms (including visual field deficits and third, fourth, and sixth nerve palsies) after any microsurgical treatment (clipping and bypass/trap) has been reported at 20% to 40%, depending on the size of the aneurysm, mass effect, and duration of symptoms before the treatment was performed.

Our observed rates of aneurysm obliteration and periprocedural complications in the endovascular groups (stent/coil and PED) are similar to those in existing published series. Reported rates of periprocedural complications with aneurysmal stent/coiling range from 2% to 7%.[37-41] As intracranial stent technology has evolved, complications of stent/coiling have been reduced[42] but still must be considered a significant treatment risk. Flow diversion with the PED is associated with 1-year occlusion rates of 85% to 90%.[43-45] In a previous series specifically studying paraclinoid aneurysms, flow diversion was associated with improved occlusion rates

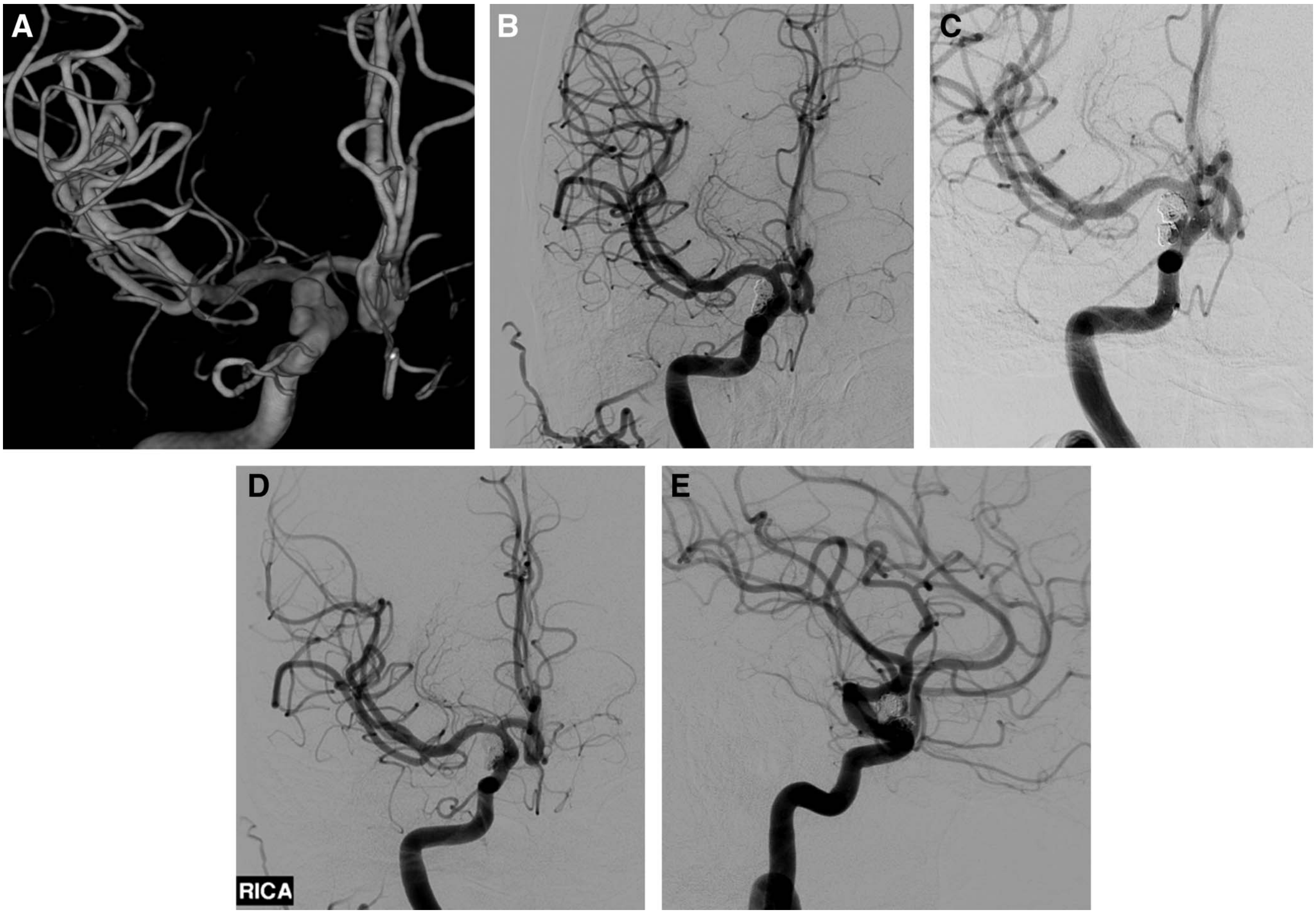

FIGURE 3. **A**, *angiogram a 56-year-old woman showing a bilobed supraclinoid aneurysm.* **B**, *patient treated by stent-assisted coiling.* **C**, *patient presented with significant recurrence at 6 months.* **D**, *patient underwent recoiling, and the posttreatment angiogram showed complete obliteration of the aneurysm. RICA, right internal carotid artery.* **E**, *1-year follow-up showed near complete obliteration of the aneurysm without recurrence.*

compared with other endovascular techniques.[46] However, up to 9.3% of patients treated with PED suffer significant periprocedural complications (most often thromboembolic), which must be taken into consideration in the treatment algorithm.[44,45,47]

Decision-Making Algorithm

Undoubtedly, selection bias is a major issue in our team's treatment algorithm. However, the general principles of our management algorithm for unruptured cavernous and supraclinoid aneurysms can be identified and discussed as follows. Currently, our algorithm for complex, broad-based aneurysms favors endovascular treatment as the first line of treatment. In cases when aneurysms still demonstrate favorable dome-to-neck ratio (>1.5) and are relatively small (<8-10 mm), stent/coiling or even stand-alone coil embolization with balloon remodeling is considered. Higher rates of residual/recurrent aneurysms are expected with these procedures compared with PED and microsurgical options, and this must be factored into the decision-making process. In cases with broad-based (dome-to-neck ratio ≤ 1.5; neck size >4 mm), fusiform, or large (>10 mm) aneurysms, a flow-diverting stent is considered the first option. Relative contraindications to endovascular treatment include antiplatelet medication resistance as indicated by aspirin and clopidogrel assays, size <10 mm (off-label use for PED), unreliable or noncompliant patients (for follow-up angiography and medication compliance), extremely tortuous cervical and/or intracranial ICA anatomy, severe stenosis of the intracranial ICA, and patient desire for immediate aneurysm occlusion.[48] In addition, in younger patients (<40 years of age) with surgically accessible and clippable aneurysms, microsurgery is strongly considered, but both endovascular treatment and microsurgical treatment are presented as reasonable options. Certain patients have a strong desire or need (eg, sentinel headaches) for immediate aneurysm obliteration or are reluctant to perform close angiographic follow-up at 6 and 12 months after treatment. In these cases, surgical options should be weighed more heavily. Over the time period studied, there was a clear shift toward

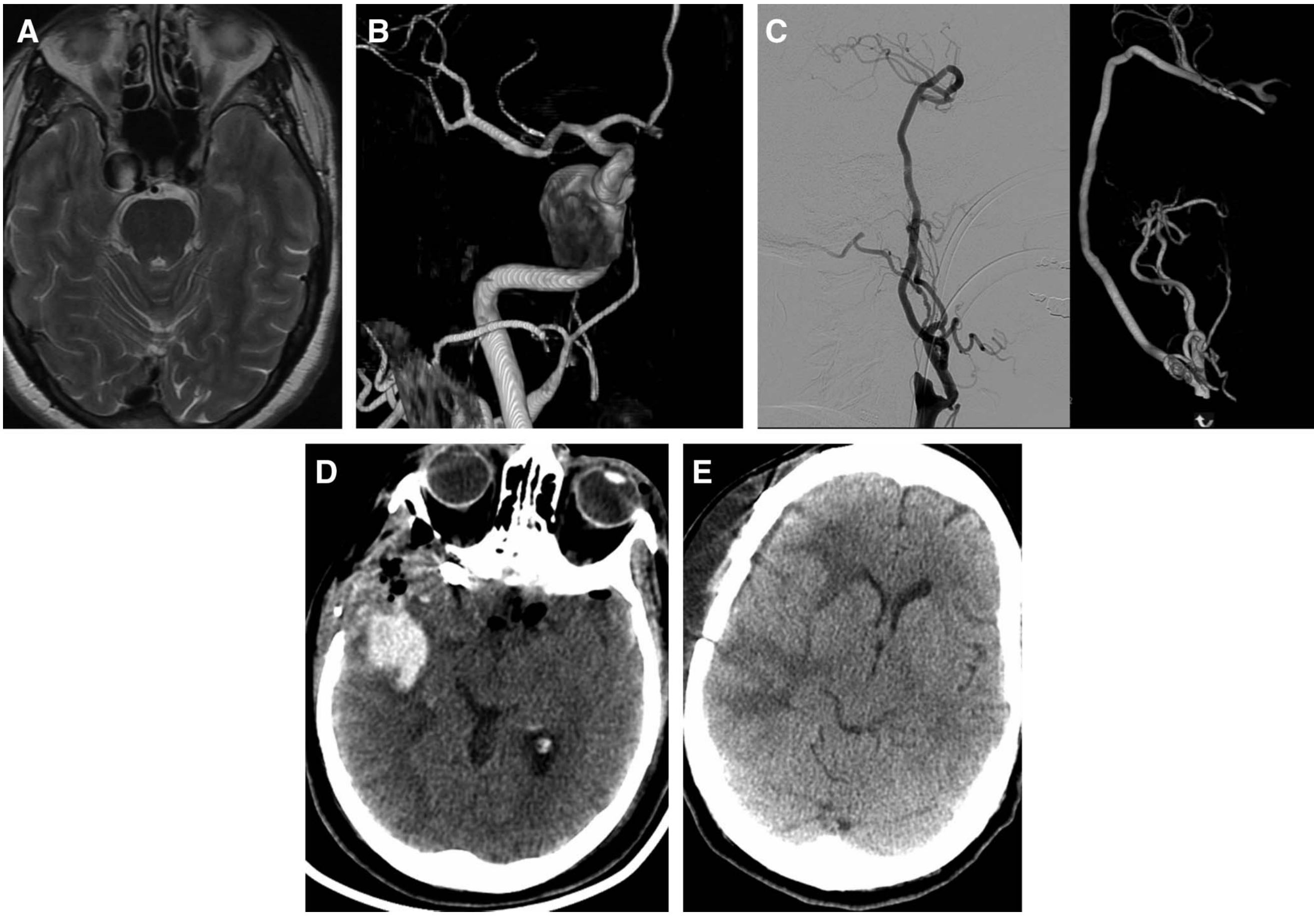

FIGURE 4. **A**, *magnetic resonance imaging scan and* (**B**) *cerebral angiogram of a 69-year-old woman showing a large cavernous internal carotid artery aneurysm.* **C**, *postoperative angiogram showing radial artery graph bypass from cervical external carotid artery to M2 middle cerebral artery and complete exclusion of the aneurysm from the circulation.* **D**, *postoperative computed tomography scan showing an intraparenchymal hemorrhage.* **E**, *the hematoma was evacuated surgically.*

endovascular over microsurgical treatment and, among endovascular cases, an increased (partly as a result of availability beginning in 2011) use of PEDs over Neuroform/Enterprise stents. Given the relative technical ease of endovascular treatment, the reasonable rates of durable occlusion and morbidity, and the increasing availability of neuroendovascular-trained personnel, we anticipate that this shift will continue to trend further in that direction.

There are several major limitations to this study. It is retrospective in nature and in no way represents a prospective comparative analysis of these 4 modalities of treatment. Because of the different skill sets of the 4 members of our cerebrovascular team, there is inherent selection bias. Naturally, providers tend toward methods at which they are highly skilled and that they are comfortable performing. The follow-up outcomes lack formal neuropsychometric testing, which might parse out more significant differences in functional outcome among the treatment groups despite the generally excellent clinical results. The follow-up duration is short, particularly for the PED group (6 months). Our PED experience presented here occurred during our "learning curve" of the first several cases by each of the providers. The 2 cases of delayed PED migration are an indication of this learning curve, and delayed PED migration is unlikely to occur at the same frequency in the future. The remaining 3 treatment modalities are well beyond the learning curve for the treating providers and thus may represent an inherent advantage compared with PED treatment regarding procedural complication rates.

CONCLUSION

For unruptured cavernous and paraclinoid ICA aneurysms, these 4 treatment methods can produce radiographic and clinical outcomes well within accepted tolerances of morbidity. Currently, we prefer flow-diverting stents over stent-assisted coiling and microsurgical techniques for large and giant broad-based aneurysms in these locations. Nonetheless, in our experience, there remains a subset of patients who will continue to require microsurgical treatment because of medication compliance concerns, anatomic limitations, the need for long-term obliteration in young patients, and patient preference for immediate obliteration. As flow-diverter technologies continue to evolve, we anticipate that the subset of patients undergoing microsurgical treatment will continue to diminish. However, for the foreseeable future, it is unlikely that the surgical subset of patients will disappear completely, especially in certain cases of ruptured and complex or recurrent aneurysms. As a result, microsurgical skills should remain highly valued.

Disclosures

Dr Kim is a shareholder in Spi Surgical, Inc, a consultant for Aesculap, Inc, and a principal investigator for an NIH/NINDS grant 1RO3NS078539-01. Drs Kim, Levitt, and Ghodke share a research grant by Volcano, Inc. Dr Hallam is a shareholder in Viket Medical. Dr Ghodke is a shareholder in Viket Medical. Dr Sekhar is a shareholder in Spi Surgical, Inc, and Viket Medical. The other authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this study.

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COMMENTS

The authors present a series of 102 patients treated for 109 unruptured aneurysms occurring at the cavernous and paraclinoid internal carotid artery proximal to the posterior communicating artery. The 4 methods of treatment were stent-assisted coiling (41 patients), Pipeline Embolization Device (PED; 24 patients), microsurgical clipping (24 patients), and trapping/bypass (20 patients). The authors document the complication types and rates in each group. Rates of obliteration were also documented in each group. It is difficult to make any meaningful direct comparison of results of 1 group with another because the study patients were selected for treatment with a predetermined algorithm based on patient age and comorbidities, angioarchitecture of the aneurysm, and need/risk of anticoagulation. In addition, the fact that there were 4 separate practitioners (2 dually trained neurosurgeons and 2 interventional neuroradiologists) implies some variation in technique even within a particular treatment paradigm. Nevertheless, a few findings are worthy of mention. As expected, the average hospital stay was significantly shorter in the 2 endovascularly treated groups (2.6 and 2 days) compared with the surgically treated patients (5.6 and 10 days). Cranial nerve palsies were very common in the clipping (29%) and bypass (35%) groups compared with the PED group (13%). Intracerebral hemorrhage was seen in 2%, 4%, 8%, and 10% of patients in the stent/coil, PED, clipping, and bypass groups, respectively. Infarcts were seen in 2.5%, 8%, 4%, and 15% of patients in the same respective groups. Significant residuals after treatment were seen in 10%, 5%, 4%, and 0% of patients in the same respective groups. The data illustrate the utility in having combined expertise in all modalities of treatment for these complex proximal internal carotid artery aneurysms in a single center. It is clear that the inexorable trend toward endovascular treatment will continue, but the technical skills required for microsurgical treatment should not be lost in the process.

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The authors describe their institutional experience with the treatment of unruptured cavernous and paraclinoid internal carotid artery aneurysms. One hundred nine aneurysms were treated in 102 patients at a comprehensive center by both endovascular and open surgical techniques. As expected, the length of stay was significantly shorter for patients treated by endovascular means, and these patients had fewer cranial nerve palsies. However, the obliteration rate was better in the surgical clipping and bypass groups vs the stent/coil group. The long-term follow-up is still pending in the Pipeline Embolization Device patients. The majority of patients were treated with stent-assisted coiling, with the other 3 groups relatively evenly split. The long-term outcomes for all groups were similar. This article demonstrates the importance of treating aneurysms at high-volume centers that offer all treatment options by experienced surgeons and that have the dedicated infrastructure to care for these patients postoperatively. The authors report their outcomes in a system in which the treatment choice was made by a group of surgeons who could offer any possible treatment option and chose the best option for the individual patient. Not only does this comprehensive approach lead to better patient outcomes, but it is really what all patients deserve when being counseled about their surgical and nonsurgical options. We agree with the authors that when possible, these aneurysms are best managed endovascularly. However, this is not always achievable in patients with very tortuous anatomy and impossible access. Therefore, it is important to realize how effective clipping and, when necessary, bypass can be for these aneurysms in carefully selected patients and in experienced hands.

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CME Questions:

1. With respect to the treatment of complex unruptured paraclinoid aneurysms, which treatment modality has the highest rate of aneurysmal obliteration?
   A. Stent/coil
   B. Pipeline endovascular device
   C. Clipping
   D. Bypass/trapping

2. What is the most common adverse event associated with pipeline treatment of unruptured cavernous and paraclinoid aneurysms?
   A. Cranial nerve palsies
   B. Ischemic stroke
   C. Intraparenchymal hematoma
   D. GI hemorrhage secondary to antiplatelets
   E. Device deployment failure

3. In treating unruptured paraclinoid aneurysms, which procedure has the highest rate of peri- and post-procedural ischemic and hemorrhagic strokes?
   A. Standalone coil embolization
   B. Stent-assisted coil embolization
   C. Pipeline treatment
   D. Microsurgical clipping
   E. Bypass and trapping