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Treatment outcomes of large and giant intracranial aneurysms according to various treatment modalities

Jai Ho Choi[1] · Kwan Sung Lee[1] · Bum-soo Kim[2] · Yong Sam Shin[1]

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Abstract

Purpose This study aimed to compare the treatment outcomes of large (15–25 mm) and giant (> 25 mm) intracranial aneurysms (IAs), according to different treatment modalities.

Methods In total, 112 patients with large and giant IAs treated with various treatment modalities between January 2009 and December 2018 were retrospectively reviewed. Clinical and radiological parameters were analyzed and correlated with the treatment modality.

Results A total of 141 procedures were performed on 112 patients. We initially treated 47 cases with coil embolization, 39 with flow diverter (FD), 13 with direct clipping, and 13 with parent artery occlusion (PAO). Recurrence (46.8%) and retreatment (31.9%) rates were significantly higher in the coiling group ($p < 0.001$). Complete occlusion rate (36.3%) was significantly lower in the coiling group ($p = 0.027$). PAO could achieve a high complete occlusion rate (90.9%) with low complication rate (12.5%). The total complication rate was 17%. In the multivariate logistic regression analysis, FD (OR 3.406, $p = 0.036$) and direct clipping (OR 5.732, $p = 0.017$) showed a significantly higher complication rate than coiling. The overall mortality rate was 8% (8/139 procedures). At the last follow-up (mean 30.6 ± 26.4 months), 70 of 96 patients (72.9%) showed complete or near-complete occlusion. Good functional outcome (mRS ≤ 2) was observed in 90 of 112 (80.3%) patients at the last follow-up (mean 33.2 ± 30.5 months).

Conclusions Good clinical and radiologic outcomes with acceptable complication and mortality rates can be achieved by various treatment modalities. The selection of appropriate modality should be individualized based on the angiographic findings and clinical symptoms.

Keywords Intracranial aneurysm · Coil · Flow diverter · Clip · Parent artery occlusion

Introduction

The treatment of large (15–25 mm) and giant (> 25 mm) intracranial aneurysms (IAs) is challenging for neurovascular neurosurgeons, because of its high rates of perioperative complication and recurrence [3, 13, 27, 33]. Treatment modalities of these aneurysms include surgical neck clipping, coil embolization, parent artery occlusion (PAO) with or without bypass surgery, and flow diverters (FD). Surgical neck clipping is a well-established traditional and definitive treatment modality. However, surgical neck clipping has technical difficulties because these aneurysms have complex anatomical configuration [28]. Thus, a lengthy learning curve should be required. In addition, it has a high postoperative complication rate [28, 33]. Coil embolization with or without adjunctive techniques such as stent or balloon-assisted and multiple catheter technique is relatively safe but has a high rate of recurrence and retreatment [13, 27, 30]. PAO is a simple technique and shows a high occlusion rate. However, this technique can be applied to limited cases because of its destructive nature, which potentially leads to severe ischemic complications [20, 29, 31]. Recently, FDs have become a mainstream treatment of complex aneurysms. FDs show a high occlusion rate compared

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✉ Yong Sam Shin
nsshin@catholic.ac.kr

[1] Department of Neurosurgery, Seoul St Mary's Hospital, College of Medicine, The Catholic University of Korea, 222 Banpodaero, Seochogu,, Seoul, Korea

[2] Department of Radiology, Seoul St Mary's Hospital, College of Medicine, The Catholic University of Korea, 222 Banpodaero, Seochogu, Seoul, Korea

with coil embolization with an acceptable complication rate [4, 5, 10]. However, the complication rate is significantly increased in large and giant IAs [14, 18, 23, 34].

Despite improvements in techniques and devices for open surgery and endovascular treatment (EVT), large and giant IAs are difficult to treat regardless of treatment modalities. Even though many researchers have investigated optimal modality for large and giant IAs, general consensus is not yet established, and it sometimes depends on the physician's preference. In this study, we reviewed our 10-year experience of consecutive patients treated with four different modalities for large and giant IAs and compared the clinical and angiographical outcomes among different treatment options.

Methods

Study population and decision for treatment option

A total of 3137 cases of ruptured and unruptured IAs were treated with open surgery and EVT in a single tertiary institute between January 2009 and December 2018. Of these cases, only those whose aneurysm size was more than 15 mm in the largest diameter were considered. Aneurysms smaller than 15 mm were excluded, leaving a total of 130 consecutive patients. Among them, 18 patients with vertebral artery dissecting aneurysm were excluded. Finally, a total of 112 patients with large and giant aneurysm were included in this study. We retrospectively reviewed the clinical and radiological characteristics from our prospectively collected aneurysm database that includes clinical information, radiological findings, treatment modalities, outcome, and complications.

The treatment option was decided by a multidisciplinary team composed of expert neurovascular neurosurgeons and a neurointerventionist. We performed diagnostic four-vessel digital subtraction angiography (DSA) along with ipsilateral external carotid artery angiography in all patients. Balloon test occlusion (BTO) was also conducted, if it was deemed necessary. After careful review of angiographic findings and discussion by the neurovascular team, treatment option was decided on an individual basis. We considered aneurysm location, configuration, endovascular accessibility to the aneurysm, BTO results, patient's medical and neurological condition, and predicted treatment risks. If there were no definite benefits regarding clinical outcome and perioperative complication among the modalities, coil embolization and FD were primarily chosen rather than direct neck clipping and PAO.

In South Korea, FD has been approved since 2014. Coil embolization was primarily performed before 2014. Thereafter, FD was considered as a primary treatment option for large and giant IAs. However, the indication of FD is very strict in our country. FD is only indicated to patients with unruptured aneurysm. Aneurysm diameter should be over 15 mm, and only one FD is allowed in a single procedure. Moreover, the use of any detachable coil combined with FD is not permitted [25]. Therefore, patients with subarachnoid hemorrhage (SAH) were inevitably treated with coil embolization, surgical neck clipping, or PAO. In cases with (1) distal bifurcation aneurysm (middle cerebral artery and anterior communicating artery) with relatively small aneurysm size, (2) incorporated fetal type posterior communicating artery, (3) difficult to access endovascularly due to vessel tortuosity, and (4) intracranial stenosis around the aneurysm, we primarily considered surgical neck clipping rather than endovascular treatment. PAO was selectively considered in cases with sufficient collateral flow and inaccessible to the distal vessel over the aneurysm to apply FD or stent.

Outcome assessment

Patients' clinical outcomes were measured by the modified Rankin Scale (mRS) at the last follow-up day. Good clinical outcome was defined as mRS ≤ 2. All procedure-related and perioperative events were registered in our database. The presence of postsurgical intracranial hemorrhage was evaluated by non-enhanced computed tomography (CT). We performed diffusion-weighted imaging and gradient echo imaging within 24 h after EVT to evaluate postprocedural hemorrhage or infarction.

Immediate postoperative angiographic results were evaluated by DSA after EVT and by indocyanine videoangiography or DSA after surgery. We could not assess immediate angiographic results after FD treatment because FD showed a delayed therapeutic effect. The first follow-up radiologic examinations were performed in an outpatient clinic 3 to 12 months after the operation. Additional imaging study was conducted according to the result of the first follow-up imaging study. The angiographic results of treatment were classified as follows: (1) complete occlusion, (2) near-complete occlusion (remnant neck), or (3) sac filling. The clinical outcome and angiographic results were retrospectively assessed by two observers (J.H.C and B.K.) who were blinded to the patients' baseline characteristics.

Statistical analysis

We performed a statistical analysis using SPSS version 24 (SPSS, Chicago, Illinois, USA). Categorical variables were analyzed by the chi-square test or Fisher's exact test. Continuous variables were compared using a t test, analysis of variance or Mann–Whitney U test. Multivariate logistic regression analysis to identify risk factors for procedure-related complications was performed after including variables with p value < 0.2 in the univariate analysis. Less than 0.05 of p value was regarded as statistically significant.

Results

Baseline patient clinical and angiographical characteristics

Clinical and angiographic characteristics of all patients treated in our institute are summarized in Table 1. Of the 112 patients, 23 (20.5%) were male, and the mean age was 55.9 years. The rate of incidentally detected lesions was 21.4% (24 of 112 patients). The most common presenting symptom was SAH (*n* = 23, 20.5%), followed by decreased visual acuity (*n* = 19, 16.9%), ophthalmoplegia (*n* = 18, 16.1%), headache (*n* = 15, 13.4%), ischemic symptom (*n* = 6, 5.3%), progressive brainstem sign (*n* = 5, 4.4%), and seizures (*n* = 2, 1.7%). The distal internal carotid artery (*n* = 63, 56.2%) was the most common site, followed by posterior circulation (*n* = 16, 14.3%), middle cerebral artery (*n* = 14, 12.5%), posterior communicating artery (*n* = 14, 12.5%), and anterior cerebral artery including anterior communicating artery (*n* = 5, 4.5%). The mean aneurysm size was 20.9 mm, and there were 22 cases (19.6%) with aneurysms of more than 25 mm in size. A total of 141 procedures were performed on 112 patients. Single-session treatments were performed on 88 patients. In contrast, 24 patients underwent multi-session treatments (20 patients with two sessions, three patients with three sessions, and one patient with four sessions).

Table 1 Baseline patient clinical and angiographical characteristics

Variables	Value (percentage)
Number of patients	112 (100)
Mean age ± SD (years)	55.9 ± 14.6
Male	23 (20.5)
Presenting symptom	
SAH	23 (20.5)
Infarction/TIA	6 (5.3)
Seizure	2 (1.7)
Progressive brainstem sign	5 (4.4)
Ophthalmoplegia	18 (16.1)
Decreased V/A	19 (16.9)
Headache	15 (13.4)
Incidental	24 (21.4)
Location	
Distal ICA	63 (56.2)
AcomA/A1	5 (4.5)
PcomA	14 (12.5)
MCA	14 (12.5)
Posterior circulation	16 (14.3)
Aneurysm size	
Mean size ± SD (mm)	20.9 ± 6.5
More than 25 mm	22 (19.6)
Initial treatment modality	
Coil embolization	47 (41.9))
Single catheter	11 (9.8)
Multiple catheter	11 (9.8)
Stent-assisted	21 (18.7)
Balloon-assisted	4 (3.6)
Flow diverter	39 (34.8)
Direct neck clipping	13 (11.6)
Parent artery occlusion	13 (11.6)
With bypass surgery	6
Number of treatments	141
Single-session treatment	88
Multi-session treatments	53
Two times	20
Three times	3
Four times	1
Mean follow-up period (months)	
Clinical follow-up	33.2 ± 30.5
Radiological follow-up	30.6 ± 26.4
Complete occlusion rate at last follow-up	48 out of 96 (50.0%)
mRS at last follow-up	
0	82 (73.2)
1–2	8 (7.1)
3–5	14 (12.5)
6	8 (7.1)

SD standard deviation, *SAH* subarachnoid hemorrhage, *TIA* transient ischemic attack, *V/A* visual acuity, *ICA* internal carotid artery, *AcomA* anterior communicating artery, *PcomA* posterior communicating artery, *MCA* middle cerebral artery

Clinical and radiological features and long-term outcome according to treatment modalities

Table 2 shows the details of the clinical and radiological features according to treatment modalities. Forty-seven patients were initially treated with coil embolization, 39 with FD, 13 with surgical neck clipping, and 13 with PAO. The mean size of aneurysms treated with coil embolization (17.9 mm) and surgical neck clipping (18.4 mm) was significantly smaller than that of those treated with FD (23.7 mm) and PAO (25.5 mm) ($p < 0.001$). The treatment modality was significantly different according to the presence of SAH ($p < 0.001$). Most patients with SAH were treated with coil embolization (*n* = 15) or surgical neck clipping (*n* = 7). Only one patient was treated with PAO, and FD was not used for treating SAH. However, the presence of SAH was not significantly associated with the recurrence ($p = 0.080$), retreatment ($p = 0.780$), the occurrence of complications ($p = 0.235$), and long-term radiologic results ($p = 0.731$) after treatment (Supplemental Table 1).

The aneurysm location was significantly different among the treatment modalities ($p < 0.001$). Of the 39 aneurysms treated with FD, 33 (84.6%) were located in the distal internal carotid artery. In the surgical neck clipping group, the rate of middle cerebral artery aneurysm (5 of 13 patients, 38.4%) was higher than that of aneurysms in other locations. Complete occlusion was achieved in 20 of 47 patients (42.5%) with coil embolization on postprocedural immediate DSA. In the surgical neck clipping group, 10 of 13 patients (76.9%) showed complete occlusion on postoperative immediate examination. No significant difference was found between the two groups ($p = 0.088$). The recurrence rate after the initial treatment was significantly higher in the coil embolization group (46.8%) than in other modalities group (15.3% in the surgical neck clipping group and 0% in the FD and PAO groups, $p < 0.001$). In addition, the retreatment rates of patients who

Table 2 Comparison of clinical and radiological features according to treatment modalities

	Coil embolization (*n* = 47)	Flow diverter (*n* = 39)	Surgical neck clipping (*n* = 13)	Parent artery occlusion (*n* = 13)	*p* value
Mean size ± SD (mm)	17.9 ± 2.8	23.7 ± 7.1	18.4 ± 3.6	25.5 ± 7.8	< 0.001
SAH	15 (31.9%)	0 (0%)	7 (53.8%)	1 (7.6%)	< 0.001
Location					< 0.001
Distal ICA	20 (42.5%)	33 (84.6%)	2 (15.3%)	8 (61.5%)	
AcomA/A1	4 (8.5%)	0 (0%)	1 (7.6%)	0 (0%)	
PcomA	10 (21.2%)	0 (0%)	4 (30.7%)	0 (0%)	
MCA	5 (10.6%)	3 (7.7%)	5 (38.4%)	1 (7.6%)	
Posterior circulation	8 (17.0%)	3 (7.7%)	1 (8.3%)	4 (30.7%)	
Immediate angiographic outcome					
Complete	20 (42.5%)*		10 (76.9%)*	6 (46.1%)	0.088*
Remnant neck	20 (42.5%)		2 (16.7%)		
Remnant sac	7 (15.0%)	39 (100%)	1 (7.6%)	7 (53.9%)	
Recurrence after initial treatment	22 (46.8%)	0	2 (15.3%)	0	<0.001
Retreatment after initial treatment	15 (31.9%)	6 (15.3%)	2 (15.3%)	0 (0%)	0.047

SAH subarachnoid hemorrhage

underwent surgical neck clipping (2 of 13 patients, 15.3%), FD (6 of 39 patients, 15.3%), and PAO (0 of 13 patients, 0%) were significantly lower than those of the coil embolization group (15 of 47 patients, 31.9%, $p = 0.047$).

Because 24 patients underwent additional treatments, a total of 141 procedures, including 62 cases of coil embolization, 48 cases of FD, 13 cases of surgical neck clipping, 16 cases of PAO, and two delayed balloon angioplasty following FD, were finally performed. Details of multi-session treatments are described in Table 3. The mean radiological follow-up period was 30.6 ± 26.4 months. Follow-up CT angiography, magnetic resonance angiography, and/or DSA were performed obtained in 96 patients, and the long-term complete or near-complete occlusion rate was 72.9% (70 of 96 patients). PAO showed the highest complete occlusion rate (10 of 13 patients, 90.9%) after a single-session treatment, followed by surgical neck clipping (7 of 11 patients, 77.8%), FD (17 of 33 patients, 56.6%), and coil embolization (8 of 31 patients, 36.3%) ($p < 0.027$). Good functional outcome (mRS ≤ 2) was achieved in 90 patients (80.3%) after a mean 33.2 ± 30.5 months of follow-up. Table 3 shows the clinical and radiological outcomes at the last follow-up according to different treatment modalities.

Complications based on treatment modalities

Details of the complication are summarized in Table 4. The total complication rate was the highest with surgical neck clipping (5 of 13 patients, 38.4%), followed by FD (9 of 48 patients, 18.7%), coil embolization (8 of 62 patients, 12.9%), and PAO (2 of 16 patients, 12.5%). The most common complication was cerebral infarction (11 of 141 procedures, 7.8%). Delayed aneurysmal ruptures occurred in three patients with coil embolization and in three patients with FD. There were two delayed in-stent stenosis after FD, leading to additional balloon angioplasty. In total, eight patients died at the last follow-up. The FD group showed higher mortality rate (4 of 48 procedures, 8.3%) than the other treatment groups, but no significance was found ($p = 0.702$). Overall moderate to severe morbidity (mRS of 3–5) and mortality rates (mRS of 6) were 12.5% and 7.1%, respectively. In the univariate analysis, procedure-related complication occurred more frequently in posterior circulation aneurysm rather than in anterior circulation aneurysms ($p = 0.031$). The results of the multivariate analysis showed that posterior circulation aneurysm (odds ratio (OR) 3.406, confidence interval (CI) 1.084–10.700, p=0.036) and treatment modality including FD (OR 5.732, CI 1.374–23.904, $p = 0.017$) and surgical clipping (OR 8.497, CI 1.096–65.889, $p = 0.041$) were significantly associated with procedure-related complication (Table 5).

Discussion

In this study, we achieved a high rate of complete or near-complete occlusion (72.9%) with 12.5% and 7.1% of morbidity and mortality rates for large and giant IAs using various treatment modalities. Large and giant IAs have a tragic natural history because of (1) particular pathological anatomy, including compression of the brainstem or cranial nerve, wide aneurysm neck, complex incorporated branching vessels, adherent surrounding perforators, and atherosclerotic changes of the

Table 3 Clinical and radiological outcome at last follow-up

	Radiological outcome				Clinical outcome (mRS)		
	Complete (n = 48)	Remnant neck (n = 22)	Sac filling (n = 26)	Follow-up los (n = 16)	0–2 (n = 91)	3–5 (n = 14)	6 (death) (n = 8)
Single-session treatment							
Coil embolization (n = 31)	8 (36.3%)*	6	8	9	24	7	
Flow diverter (n = 33)	17 (56.6%)*	9	4	3	28	3	2
Surgical neck clipping (n = 11)	7 (77.8%)*	2		2	9	1	1
Parent artery occlusion (n = 13)	10 (90.9%)*		1	2	10	2	1
Multi-session treatments							
Coil/coil (n = 6)	1	2	3		6		
Coil/PAO (n = 1)	1				1		
Coil/FD (n = 5)	2	1	2		4		1
FD/FD (n = 3)		1	2		2		1
FD/PAO (n = 1)		1			1		
Neck clipping/coil (n = 2)			2				2
FD/delayed balloon angioplasty (n = 2)	1		1		2		
Coil/coil/coil (n = 2)			2		2		
Coil/FD/PAO (n = 1)	1				1		
Coil/coil/coil/coil (n = 1)			1			1	

PAO parent artery occlusion, *FD* flow diverter

*p<0.027

aneurysm wall and parent vessel, and (2) related postoperative risks [3, 28]. Therefore, treatment goals are not only complete occlusion of the aneurysm but also prevention of hemorrhagic and thromboembolic complications [11].

Surgery is a traditional modality for treatment of all IAs. High complete and near-complete occlusion rates can be achieved by surgery even in large and giant aneurysms. Sughrue et al. reported that they achieved 87% of complete and near-complete occlusion rates for giant aneurysms [28]. However, surgical morbidity and mortality is sharply increased with treatment of very large and giant IAs [12, 28, 33]. Sheen et al. reported that morbidity and mortality rate at 6 months were 6% and 2% for a total of 69 large (> 10 mm) and giant aneurysms [24]. In a contemporary large surgical series reported by Sughrue et al., mortality rate at the perioperative period was 13% (18 out of 140 patients) and permanent neurologic morbidity occurred in 13 patients [28]. In the surgical neck clipping group, we could achieve a high complete occlusion rate (77.8%), but complications occurred most frequently among the four treatment groups. Even though the complication rate was high (5 of 13 patients, 38.4%) in this study, most (4 of 5 patients, 80%) of the patients fully recovered over time.

Table 4 Complications based on treatment modalities

	Coil embolization	Flow diverter	Surgical neck clipping	Parent artery occlusion	p value
Total number of procedures	62	48	13	16	
Complications	8 (12.9%)	9 (18.7%)	5 (38.4%)	2 (12.5%)	0.155
Infarction	3	2	4	2	
Procedural rupture		1	1		
Remote ICH	1				
Delayed rupture	3	3			
Aggravated mass effect	1	1			
Delayed in-stent stenosis		2			
Mortality after final treatment	2 (3.2%)	4 (8.3%)	1 (7.7%)	1 (6.3%)	0.702

ICH intracranial hemorrhage

Table 5 Uni- and multivariate analyses of procedure-related complications

Characteristics	Complication		Univariate	Multivariate	Odds ratio	95% confidence interval
	Yes (n = 24)	No (n = 115)				
Clinical features						
Age (mean ± SD)	58.83 ± 10.98	56.05 ± 15.81	0.414			
Female	20 (83.3%)	88 (76.5%)	0.466			
Radiologic features						
Size in mm (mean ± SD)	22.65 ± 6.44	20.51 ± 6.09	0.123	0.316	0.959	0.882–1.041
Aneurysm location			0.031	0.036	3.406	1.084–10.700
Anterior circulation	16 (66.7%)	98 (85.2%)				
Posterior circulation	8 (33.3%)	17 (14.8%)				
Treatment modality			0.155			
Coil	8 (33.3%)	54 (47%)		Ref.		
FD	9 (37.5%)	39 (33.9%)		0.017	5.732	1.374–23.904
PAO	2 (8.3%)	14 (12.2%)		0.073	3.857	0.881–16.883
Surgical clip	5 (20.8%)	8 (7.0%)		0.041	8.497	1.096–65.889

Coil embolization has been developed as an alternative and has become one of the treatments of all IAs with the advent of endovascular devices [19]. However, coil embolization of large and giant IAs has several different aspects compared with that of small IAs. Adjunctive devices, such as stent or balloon, are often needed because these aneurysms usually have a wide neck [30]. Most aneurysms are recanalized over time due to coil compaction and coil migration into the aneurysm sac, resulting in luminal growing [13, 27, 30]. Gao et al. reported 29.6% of overall recanalization rate [11] and Chalouhi et al. showed 37% of retreatment rate after coiling for large and giant aneurysms [9]. In this study, the recurrence (46.8%) and retreatment (31.9%) rates were also very high similar to previous studies. The advantage of coil embolization can be a relatively safe procedure compared to other modalities [30] and our study also showed lowest complication rate.

Recent meta-analysis by Brinjikji et al. in 2013 showed a high complete occlusion rate in large (74%) and giant (76%) aneurysms treated with FD [7]. In a large Japanese series of FD for large and giant UIAs, complete occlusion was achieved in 63 out of 91 aneurysms (69.2%). They used multiple overlapping or telescoping FDs in 23 patients and inserted additional detachable coils in 34 aneurysms (34%) [22]. Although FD had a higher complete or near-complete occlusion rate than coil embolization, complication and mortality rates were not negligible. We experienced two cases with early delayed aneurysmal rupture within 1-month post procedure and one late delayed aneurysmal rupture. All early delayed rupture cases were located in the distal internal carotid artery, and the patient finally died. To avoid this fatal complication, several techniques including adjunctive coil insertion and strict blood pressure (BP) control have been suggested [16, 23, 26]. Erez et al. reported that pipeline embolization device with partially dense coil packing showed high complete occlusion rate (23 of 27 patients, 85.2%) without delayed rupture at 1-year follow-up [21]. Oishi et al. reported two delayed aneurysm rupture, but all developed carotid cavernous fistulas. They put adjunctive coils when the aneurysm was expected with a high risk of delayed rupture, which was located in the subarachnoid space with the jet flow with a narrow neck, irregular shape, and more than 15 mm [22]. However, as previously mentioned, additional coil insertion with FD is not allowed in our country. After we experienced two early delayed rupture cases in 2014, strict BP control to reduce direct hemodynamic strain on the aneurysm wall and steroid therapy to avoid thrombus-related inflammation and autolysis to the aneurysm wall have been routinely conducted [8, 15]. Thereafter, early delayed aneurysmal rupture did not develop. In this study, symptomatic ischemic complications occurred in two patients, but all fully recovered at the last follow-up. Asymptomatic delayed in-stent stenosis developed in two patients, and they underwent additional balloon angioplasty. One aneurysm completely disappeared, and another aneurysm showed small sac filling on final angiography.

PAO showed the highest complete occlusion rate (90.0%) and the lowest complication rate (12.5%) in this study. Similar to our study, Nishi et al. reported that high complete occlusion rate (90.5%, n = 248) with low morbidity (5.8%) and mortality (0.7%) rate was achieved in their study [20]. PAO can be a definitive and useful modality because (1) it is a simple technique and (2) it shows a high complete occlusion rate and low recurrence rate compared with other modalities [20, 30]. However, patients treated with PAO were often exposed to inherent ischemic complications because of its destructive nature [20]. Thus, a tolerance test should be performed prior to performing PAO [1, 17, 31]. Additional risks associated with the revascularization technique (especially high flow bypass) can occur when the patient is intolerable to the test [20, 28]. In this study, six patents underwent bypass surgery before PAO. We performed 5 low flow bypass surgeries (4 superficial temporal artery-middle cerebral artery anastomoses and 1 occipital artery-posterior inferior cerebellar artery anastomosis) and 1 high flow bypass surgery with radial artery graft. Among them, graft failure occurred in 1 patient who developed Wallenberg syndrome.

Coil embolization is a low-risk procedure and can offer short-term protection against hemorrhage [30]. However, recanalization frequently occurs with time and, thus, it may not be a definitive treatment [11, 30]. In addition, recent study regarding comparison of coil embolization and FD showed that FD provides higher aneurysm occlusion with no additional morbidity and similar clinical outcomes [9]. They concluded that FD might be a preferred treatment modality for large and giant UIAs [9]. Since the pipeline embolization device was approved by the Food and Drug Administration (FDA), the use of FD for complex IAs has significantly increased. Several investigators have suggested the safety and efficacy of FD for the treatment of IAs regardless of its size, location, and complexity [5, 7, 32, 35]. Although FD has become a mainstay treatment of any kinds of IAs, the results of large and giant IAs were relatively unfavorable because of high thromboembolic and symptomatic hemorrhagic complication rates similar to our results [2, 6, 14]. However, with the advent of new technology including phospholipid choline coating technique, development of a low-profile FD compatible with a small-caliber microcatheter, and evolution of new antiplatelet drugs, thromboembolic complication of FD can be reduced in the future. Fatal hemorrhagic complication may be reduced by adjunctive coil packing and postprocedural strict BP control and steroid therapy. Accordingly, FD will be more widely used for treating large and giant IAs. Surgery is still a useful and effective treatment modality when FD is not available due to medical problems such as vessel tortuosity and severe atherosclerotic change or socioeconomic problems. Because FD has some disadvantages, a surgical option with an appropriate indication would be valid and collaboration between surgery and EVT is still needed [24]. PAO can be a good and powerful alternative when abundant collateral flow exists and access to the distal vessel over the aneurysm to apply FD is not possible.

This study had some limitations. First, this was a single-center experience and not a population-based study. In addition, the number of patients treated with surgical neck clipping and PAO was relatively small. Therefore, our results may not be enough to draw definite conclusions. Second, although we collected the data prospectively, clinical and radiologic data were analyzed retrospectively. Third, clinical and radiologic follow-up protocols were not standardized. Moreover, there was a relatively high follow-up loss rate (16 of 112 patients, 14.2%) in our study. Among them, 11 patients (seven with initial high Hunt-Hess grade and four with morbidity or mortality) showed poor clinical outcome (mRS $\geq$ 4) after treatment, and their family did not want any follow-up radiologic examinations.

To date, there is no general consensus as to which treatment modality is optimal for large and giant IAs, and each modality has its advantages and disadvantages. The most important point for achieving complete occlusion and reducing complications is to select an appropriate treatment modality based on the angiographic features and clinical conditions of each patient.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards

Informed consent For this type of study, formal consent is not required

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