Comparison of Clinical and Radiologic Outcomes of Diverse Endovascular Treatments in Vertebral Artery Dissecting Aneurysm Involving the Origin of PICA

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■ OBJECTIVE: **To determine clinical and radiologic outcomes of vertebral artery dissecting aneurysms involving posterior inferior cerebellar artery according to different types of endovascular treatment.**

■ METHODS: **This study included 18 vertebral artery dissecting aneurysms (6 ruptured and 12 unruptured) involving posterior inferior cerebellar artery treated from January 2009 to December 2016. Treatments were multiple stenting, stent-assisted coil embolization, vertebral artery trapping with vertebral artery—posterior inferior cerebellar artery stenting, and Pipeline embolization. Clinical and radiologic information were obtained from retrospective chart review and radiologic review.**

■ RESULTS: **Subarachnoid hemorrhage was diagnosed initially in 6 of 18 patients, and infarction was diagnosed initially in 2 patients. Multiple stenting was performed in 4 patients, including 1 (25%) who had cerebellar infarction and 1 (25%) who had recurrence. Stent-assisted coil embolization was performed in 8 patients, including 1 (12.5%) who had postoperative cerebellar infarction and 2 (25%) who had recurrence. Vertebral artery trapping with vertebral artery—posterior inferior cerebellar artery stenting was performed in 4 patients, including 1 (25%) who had postoperative cerebellar infarction. There was no recurrence (0%). Pipeline embolization was performed in 2 patients, including 1 (50%) who had recurrence. There was no postoperative infarction (0%). No subarachnoid hemorrhage occurred during follow-up. Deterioration in modified Rankin Scale score was found only in the stent-assisted coil embolization group (1/8; 12.5%).**

■ CONCLUSIONS: **Vertebral artery trapping with vertebral artery—posterior inferior cerebellar artery stenting showed the lowest rate of aneurysm recurrence with high rate of minor infarction and favorable neurologic outcome. Stent-assisted coil embolization showed high recurrence rates with possible fatal disabling infarction.**

INTRODUCTION

Vertebral artery (VA) dissection is the most common arterial dissection in intracranial arteries. Arterial dissection is initiated by sudden disruption of internal elastic lamina and media. Circulating blood accumulation in the arterial wall occurs following wall disruption and promotes intramural hematoma formation.[1] Some types of VA dissection can heal spontaneously with excellent prognosis, whereas others may progress to stroke.[2] Stroke can manifest as brainstem involvement, cerebellar infarction, or subarachnoid hemorrhage (SAH).[3] Stroke in posterior fossa owing to brainstem involvement may lead to high mortality and morbidity with various neurologic deficits, such as eye movement disturbance and Terson syndrome.[4] Endovascular surgery can be performed on lesions that may progress to stroke. Optimal treatment of VA dissection is complete occlusion of the dissecting segment with surgical or endovascular trapping. However, when vertebral artery dissecting aneurysm (VADA) involves the posterior

Key words
- Endovascular procedure
- PICA
- Vertebral artery dissection

Abbreviations and Acronyms
mRS: Modified Rankin Scale
MS: Multiple stenting
PED: Pipeline embolization device embolization
PICA: Posterior inferior cerebellar artery
SAC: Stent-assisted coil embolization
SAH: Subarachnoid hemorrhage
VA: Vertebral artery
VADA: Vertebral artery dissecting aneurysm
VTVPS: Vertebral artery trapping with vertebral artery—posterior inferior cerebellar artery stenting

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inferior cerebellar artery (PICA), there is a high risk of PICA infarction accompanied by VA trapping.[5] Reconstruction therapy is indicated for patients with VADAs involving the origin of the PICA.[6] Diverse surgical methods combined with endovascular treatment have been used to preserve PICA vascularization after trapping, including occipital artery—PICA anastomosis, PICA-PICA anastomosis, and PICA transposition.[7,8] Kanematsu et al. reported proximal occlusion of VA with occipital artery—PICA anastomosis and clip ligation of PICA origin in ruptured VADAs to prevent aneurysmal recurrence and rupture resulting from retrograde flow from contralateral VA.[9] Recently, endovascular treatment alone has shown good results owing to development of methods such as vertebral artery trapping with vertebral artery—posterior inferior cerebellar artery stenting (VTVPS), multiple stenting (MS), flow-diverting stent implantation, and stent-assisted coil embolization (SAC).[10-13] The studies have concluded that there are favorable outcomes with the these endovascular treatment methods. However, no study has compared outcomes among various treatment modalities. Therefore, the aim of this study was to evaluate postoperative stroke risk and recurrence rate of VADA involving the PICA after different endovascular treatment modalities.

MATERIALS AND METHODS

Patients

From January 2009 to December 2016, intracranial VADA was diagnosed in 190 patients in a single institution. VADAs involving the PICA were diagnosed based on the following characteristics: (1) typical pearl-and-string sign or circumferential irregular lumen widening on three-dimensional reconstruction digital subtraction angiography, (2) intramural hematoma or double lumen sign on time-of-flight magnetic resonance angiography, and (3) pathologic dissecting aneurysm walls extending to the origin of PICA. Of 190 patients with VADAs, 20 (10.5%) had PICA involvement. One patient who underwent surgical treatment and 1 patient who was lost to follow-up were excluded. Therefore, 18 patients were included in this study. All clinical data, including initial stroke presentation, age, sex, angiographic type of dissecting aneurysm, and risk factors (diabetes mellitus, hypertension, dyslipidemia, smoking), of patients were collected retrospectively.

Endovascular Procedures

All patients included in this study underwent endovascular treatment at initial diagnosis or during the follow-up period owing to progression of VADA. Four types of endovascular treatments were performed: 1) MS, 2) SAC, 3) VTVPS, and 4) flow-diverting stent with Pipeline embolization device (PED) (Medtronic, Minneapolis, Minnesota). Ruptured long-segment fusiform VADAs were mostly treated with VTVPS to obtain immediate obliteration of aneurysms. MS or PED was performed when contralateral VA was hypoplastic or when patients presented with infarction on posterior fossa to avoid additional ischemic stroke. VADAs with saccular types tended to be treated with SAC. All procedures were performed under general anesthesia with right femoral artery puncture. For unruptured elective cases, aspirin 100 mg and clopidogrel 75 mg daily were given for 7 days before treatment; for ruptured emergency cases, aspirin 300 mg and clopidogrel 300 mg were given via a Levin tube immediately after the procedure. For MS cases, a 5-, 6-, or 7-F Envoy catheter (Codman Neurovascular, Raynham, Massachusetts, USA) or sheath (6-F Shuttle Select; Cook, Inc., Bloomington, Indiana, USA) was introduced into the parent artery. A Prowler Select Plus microcatheter (Codman Neurovascular) for the Enterprise stent (Codman Neurovascular) was introduced and placed in the basilar artery. The Enterprise stent was then deployed over the dissecting segment via the Prowler microcatheter. Double or triple stent deployment was performed. For SAC cases, the same kind of guiding catheter and microcatheter were introduced with an additional secondary microcatheter (Excelsior; Stryker Neurovascular, Fremont, California, USA) introduced into the aneurysmal sac for coil deployment. Initial stent deployment was followed by bridging the aneurysmal dilated lesion and coil embolization. Intravenous heparin (3000 U) was injected after the first coil detachment. For VTVPS, an Envoy catheter or sheath was introduced into the ipsilateral VA (V2 segment). A Prowler Select Plus microcatheter was placed from VA to PICA for stenting, and an Excelsior microcatheter was placed through the dissected segment for VA occlusion with coil embolization. The Enterprise stent was deployed from PICA to VA, distal to PICA, and coil embolization was performed for parent artery occlusion. Intravenous heparin (3000 U) was injected after the first coil detachment. For flow-diverting stent with PED, an Envoy guiding catheter was introduced through the ipsilateral VA (V3 segment), and a Marksman microcatheter (Medtronic) was introduced and positioned in the basilar artery for PED deployment. PED was deployed with a standard push and pull technique until the best wall apposition was obtained. Intravenous heparin was given during the procedure.

Clinical and Radiologic Follow-Up

All patients underwent magnetic resonance imaging diffusion-weighted examination on postoperative day 1 to evaluate postprocedural infarction. Additional magnetic resonance imaging diffusion-weighted imaging was performed if new neurologic symptoms developed during the follow-up period. Time-of-flight magnetic resonance angiography was performed to evaluate recurrence of the aneurysm after 6, 12, and 24 months. Additional magnetic resonance angiography examinations were performed every 2 years after 24 months. Recurrence of the aneurysm was defined as a remnant of blood inflow into the aneurysmal sac after the endovascular procedure on follow-up time-of-flight magnetic resonance angiography. Modified Rankin Scale (mRS) score was checked on initial visit and at each follow-up appointment at the outpatient clinic. Any stroke episode during the follow-up period, either infarction or hemorrhage, was also recorded. Dual antiplatelet medication was maintained for at least 6 months. It was reduced by stages in the outpatient clinic.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Version 20 (IBM Corp., Armonk, New York, USA). Baseline characteristics and clinical outcomes between different treatment modality groups were analyzed. Kruskal-Wallis test was used for numerical variables, whereas Fisher exact test was used for nominal variables. Statistical significance was considered at P value <0.05.

Table 1. Characteristics of Patients, Aneurysms, Treatment Modalities, and Clinical Outcomes

Patient	Age (Years)/Sex	Risk Factors	Angiographic Type	Aneurysm Length/ Width (mm)	Initial Stroke	Treatment Modality	Stroke on Follow-Up	Recurrence (Months)	Initial mRS Score	Final mRS Score	Follow-Up (Months)
1	38/F	None	Fusiform dilatation	14.9/4.0	Medulla infarction	SAC	None	None	1	1	39
2	55/M	None	Fusiform dilatation	16.8/7.5	SAH	VTVPS	None	None	1	0	97
3	55/M	None	Fusiform dilatation	7.3/3.9	None	SAC	None	None	0	0	92
4	53/M	DM, HTN	Saccular	5.6/4.8	None	SAC	None	13	1	0	13
5	37/M	None	Fusiform dilatation	23.1/8.5	None	PED	None	15	0	0	9
6	37/M	None	Saccular	7.9/5.4	None	SAC	None	None	0	0	7
7	64/F	None	Fusiform dilatation	13.1/8.4	Cerebellum infarction	MS	Cerebellar infarction	22 (VA occlusion)	2	1	48
8	49/F	None	Fusiform dilatation	7.1/5.7	None	MS	None	None	0	0	15
9	M/53	HTN	Fusiform dilatation	10.2/15.4	None	MS	None	13	1	0	14
10	M/49	None	Fusiform dilatation	24.7/9.5	SAH	VTVPS	Cerebellar infarction	None	5	3	72
11	73/M	HTN	Pearl and string	11.1/8.2	SAH	SAC	Cerebellar infarction	None	2	6	0
12	37/M	None	Fusiform dilatation	35.6/6.1	SAH	MS	None	None	1	0	62
13	49/M	None	Fusiform dilatation	25.1/7.6	SAH	VTVPS	None	None	2	2	12
14	39/M	HTN	Fusiform dilatation	6.8/5.5	SAH	SAC	None	5, retreated with SAC	1	0	50
15	50/M	None	Pearl and string	20.9/6.5	None	VTVPS	None	None	1	0	72
16	58/F	HTN	Saccular	5.0/4.6	None	SAC	None	None	1	0	5
17	59/F	HTN	Saccular	10.9/7.3	None	SAC	None	None	1	0	49
18	57/M	None	Fusiform dilatation	7.1/6.2	None	PED	None	None	1	0	5

mRS, modified Rankin Scale; F, female; SAC, stent-assisted coil embolization; M, male; SAH, subarachnoid hemorrhage; VTVPS, vertebral artery trapping with vertebral artery—posterior inferior cerebellar artery stenting; DM, diabetes mellitus; HTN, hypertension; PED, Pipeline embolization device; MS, multiple stenting; VA, vertebral artery.

Table 2. Baseline Characteristics of Each Treatment Modality Group

Variables	MS (n = 4)	SAC (n = 8)	VTVPS (n = 4)	PED (n = 2)	P Value
Age, years	50.6 ± 11.4	51.5 ± 12.6	50.8 ± 2.9	47 ± 14.1	0.929*
Male sex	2 (50%)	5 (62.5%)	4 (100%)	2 (100%)	0.44
Right VA lesion	4 (100%)	4 (50%)	3 (75%)	2 (100%)	0.249
Follow-up, months	34.7 ± 24.0	31.9 ± 31.6	63.2 ± 36.1	7.0 ± 2.8	0.145*
Aneurysm length, mm	16.6 ± 12.9	8.6 ± 3.3	21.9 ± 3.9	15.3 ± 10.9	0.048*
Aneurysm width, mm	8.9 ± 4.5	5.4 ± 1.5	7.8 ± 1.3	7.4 ± 1.6	0.067*
Initial SAH	1 (25%)	2 (25%)	3 (75%)	0 (0%)	0.335
Initial infarction	1 (25%)	1 (12.5%)	0 (0%)	0 (0%)	1.000
Dissecting aneurysm type					
Fusiform dilatation	4 (33.3%)	3 (25%)	3 (25%)	2 (16.7%)	
Pearl and string	0 (0%)	1 (50%)	1 (50%)	0 (0%)	
Saccular	0 (0%)	4 (100%)	0 (0%)	0 (0%)	

Values are presented as mean ± SD or number (%).

MS, multiple stenting; SAC, stent-assisted coil embolization; VTVPS, vertebral artery trapping with vertebral artery—posterior inferior cerebellar artery stenting; PED, Pipeline embolization device; VA, vertebral artery; SAH, subarachnoid hemorrhage.

*Kruskal-Wallis test.

RESULTS

Baseline Patient Characteristics

Mean age of patients was 50.6 ± 10.2 years. Six patients presented with SAH. Infarction was initially diagnosed in 2 patients, 1 medullary infarction and 1 cerebellar infarction. Ten patients did not have a stroke on initial visit. Mean aneurysm length and width were 13.8 ± 8.4 mm and 6.9 ± 2.7 mm, respectively. The mean follow-up period was 36.7 ± 32.7 months. Three cerebellar infarctions occurred during the follow-up period. No SAH occurred. Clinical information of treated patients is summarized in Table 1.

Table 2 shows baseline characteristics of each treatment modality group. There was no significant difference in age, proportion of right-sided lesions, or sex between groups. Follow-up period was the shortest in the PED group (7.0 ± 2.8 months) and the longest in the VTVPS group (63.2 ± 36.1 months). However, the difference in follow-up period among groups was not statistically significant owing to the small number of participants. The length of the dissecting aneurysm was the largest in the VTVPS group (21.9 ± 3.9 mm), followed by MS (16.6 ± 12.9 mm), PED (15.3 ± 10.9 mm), and SAC (8.6 ± 3.3 mm) groups ($P < 0.048$). The proportion of patients with an initial diagnosis of SAH was the largest in the VTVPS group (3 of 4; 75%), followed by MS and SAC groups (1 of 4; 25%). No PED treatment was performed in patients with SAH. The proportion of patients who had infarction initially was the highest in the MS group (1 of 4; 25%), followed by SAC group (1 of 8; 12.5%). No VTVPS or PED was performed in patients with infarction. These data were not significantly different owing to small number of participants.

Selected Treatment Modality According to Angiographic Type

VADAs were classified into 3 types according to angiographic findings: 1) fusiform dilatation, 2) pearl and string, and 3) saccular. Fusiform dilatation type was defined as conferential irregular lumen widening, pearl-and-string type was defined as coexistence of tapered narrowing and widening of lumen, and saccular type was defined as aneurysm with neck and dome appearance (Figure 1). Fusiform dilatation VADAs were mostly treated with MS (4 of 12; 33.3%), followed by SAC (3 of 12; 25%), VTVPS (3 of 12; 25%), and PED (2 of 12; 16.7%). Two pearl-and-string VADAs were treated with SAC (1 of 2; 50%) and VTVPS (1 of 2; 50%). All saccular VADAs were treated with SAC (4 of 4; 100%).

Comparison of Outcomes of Treatment Modalities

Table 3 shows the incidence of postoperative stroke, recurrence, and mRS score alteration. The rate of postoperative infarction was highest in MS and VTVPS groups (1 of 4; 25%), followed by SAC group (1 of 8; 12.5%). No infarction occurred in the PED group during follow-up. All infarctions developed in the cerebellum. No SAH occurred during follow-up. Recurrence of aneurysm was seen in 1 (25%) of 4 patients treated with MS, 2 (25%) of 8 patients treated with SAC, and 1 (50%) of 2 patients treated with PED. No recurrence was seen in the VTVPS group. Deterioration in mRS score occurred in 1 patient in the SAC group. The patient progressed to severe PICA infarction postoperatively, leading to death on postoperative day 1. Other patients did not show any deterioration of mRS score.

DISCUSSION

VADA is a common pathologic lesion that occurs in the vertebrobasilar system. The lesion can be easily treated with VA trapping when the origin of the PICA is not involved. When VADA is located proximal to the PICA, total occlusion of the pathologic lesion can be performed with preservation of PICA flow by blood

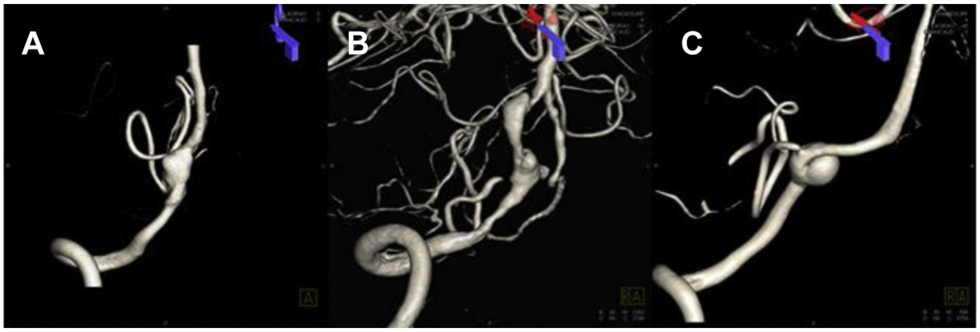

Figure 1. Angiographic types of dissecting aneurysm. (**A**) Fusiform dilatation. (**B**) Pearl and string. (**C**) Saccular.

flow from the opposite VA through the vertebrobasilar junction unless the contralateral VA is not hypoplastic. When VADA is located distal to the PICA, occlusion of the lesion distal to the PICA can preserve PICA flow from an ipsilateral VA. However, mortality and morbidity of treatment will increase when VADA incorporates the origin of the PICA. Aihara et al.[6] reported the high risk of medullary infarction with VA trapping when the origin of the PICA is involved, suggesting the need for additional reconstructive techniques. Shi et al.[14] reviewed the progress of various treatments when VADA involves the PICA. However, each treatment modality was not compared owing to the limitations of a review article. Although various studies have presented endovascular techniques and outcomes of managing VADA involving the PICA, no study has compared different treatment modalities. In our study, we compared each treatment modality performed in a single institution with long-term follow-up (36.1 ±32.6 months) results for various clinical outcomes. Selecting an appropriate treatment modality in each case is the most important consideration when managing VADA involving the PICA. In our study of 18 patients, MS, SAC, VTVPS, and PED were treatment options.

Multiple Stenting

In contrast to VA trapping, MS can preserve the parent arterial blood flow. PICA flow can also be preserved even if the origin of the PICA is involved in the dissecting segment. Stent deployment can also benefit the healing process by attaching the destroyed intimal flap to tunica media, thereby restoring blood flow of small perforators.[15] We previously reported MS as a possible treatment option for nonhemorrhagic vertebrobasilar dissection with PICA involvement.[16] Park et al.[17] reported outcomes of stent-only therapy for vertebrobasilar dissecting aneurysms unsuitable for destructive techniques. They found that MS groups showed better angiographic improvement (17 of 17) compared with single stenting groups (7 of 9). Ahn et al.[18] compared single stenting with MS for VADA in 9 patients and found that MS had an excellent prognosis with a high rate of complete occlusion (3 of 4 patients) compared with single stenting (none of 5 patients), with no postprocedural stroke. Recently, double stenting with LVIS Blue stent (MicroVention, Inc., Aliso Viejo, California, USA) and Enterprise stent technique showed successful obliteration of dissecting aneurysm while preserving VA patency with vessel wall remodeling as an alternative technique to flow diverters.[19] In our cases, 3 unruptured VADAs and 1 ruptured VADA involving the PICA were treated with MS. One patient with an unruptured lesion presented with cerebellar infarction preoperatively. Double stenting was performed for 3 unruptured lesions, and triple stenting was performed for 1 ruptured lesion. Three of 4 patients achieved complete occlusion, whereas 1 patient did not (patient 9). One cerebellar infarction occurred postoperatively after 22 months with parent artery occlusion in a patient receiving double stenting of unruptured aneurysm who

Table 3. Clinical Outcome, Stroke, and Recurrence of Aneurysm During Follow-Up Period

Variables	MS (n = 4)	SAC (n = 8)	VTVPS (n = 4)	PED (n = 2)
Infarction	1 (25%)	1 (12.5%)	1 (25%)	0 (0%)
SAH	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Recurrence	1 (25%)	2 (25%)	0 (0%)	1 (50%)
mRS score deterioration	0 (0%)	1 (12.5%)	0 (0%)	0 (0%)

Values are presented as number (%).
MS, multiple stenting; SAC, stent-assisted coil embolization; VTVPS, vertebral artery trapping with vertebral artery—posterior inferior cerebellar artery stenting; PED, Pipeline embolization device; SAH, subarachnoid hemorrhage; mRS, modified Rankin Scale.

had presented with cerebellar infarction initially (patient 7). All aneurysms treated with MS were fusiform dilatation type. Our results showed a 25% recurrence rate and a 25% postoperative infarction rate without any SAH during follow-up.

Stent-Assisted Coil Embolization

SAC can be a reasonable treatment choice in VADA when the origin of the PICA is not involved. However, a few limitations exist when the PICA is involved. Obtaining complete occlusion of the aneurysmal sac is difficult owing to the risk of PICA occlusion. Incomplete occlusion of the lesion might lead to aneurysm recurrence. The recurrence of VADA after SAC may occur in acute stage if complete obliteration of the dissected cavity is not obtained.[20] SAC might be a good option when the dissecting aneurysm is of the saccular type, when the PICA originates from the opposite side to the aneurysmal dilated vessel wall, or when the involved dissecting segment is very short. Lylyk et al.[21] reported the first case of SAC in VADA in 1998. They also reported outcomes of 7 cases treated with SAC, resulting in 5 total occlusions and 2 residual necks.[21] Lv et al.[22] reported outcomes of 7 patients with VADA involving the PICA treated with SAC.[22] Five complete occlusions and 2 incomplete occlusions of aneurysms were obtained without any neurologic deficit.[22] In our study, 8 patients with VADA involving the PICA underwent SAC. One cerebellar

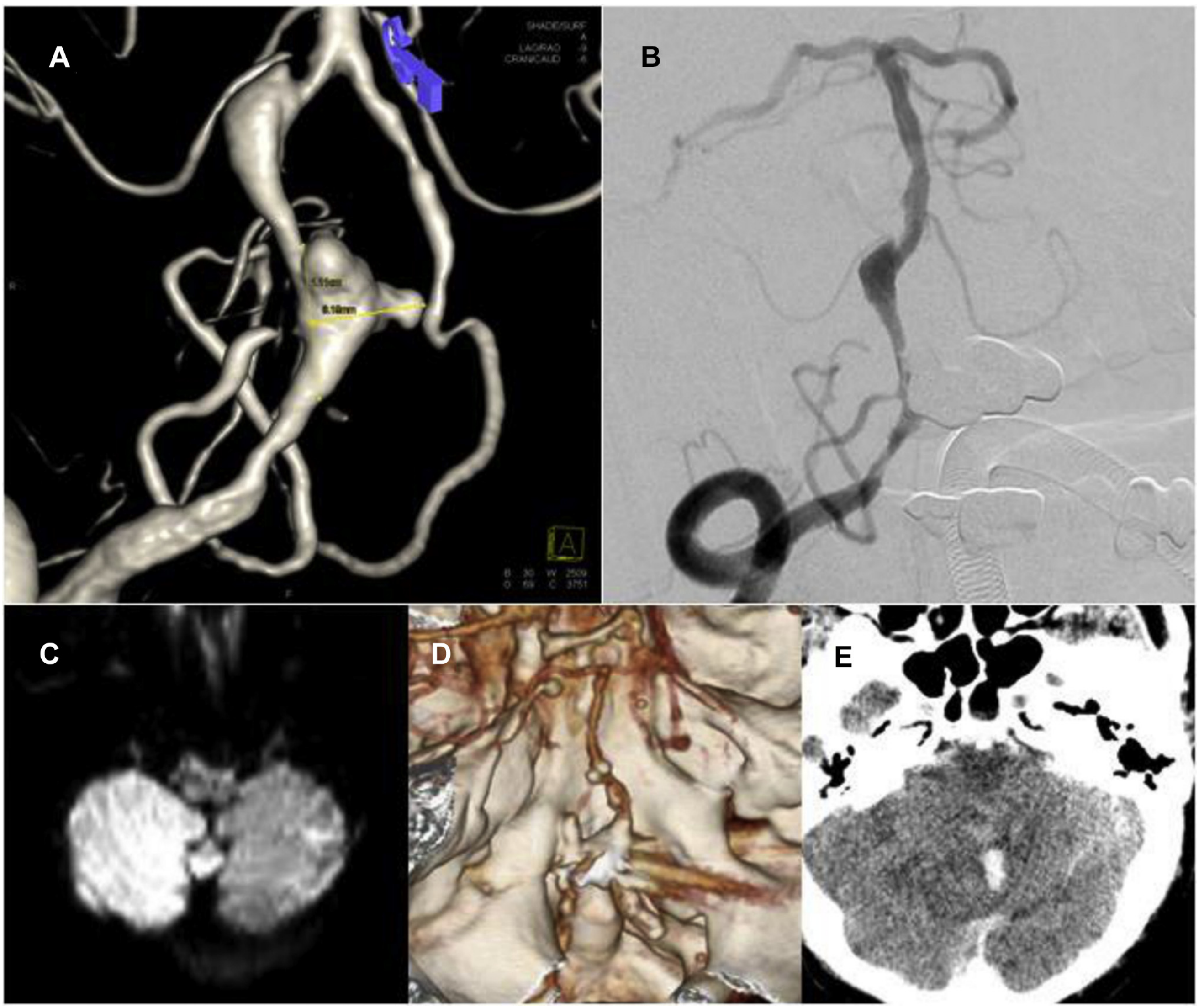

Figure 2. Postoperative infarction in a 73-year-old man who presented with Hunt and Hess grade 2 subarachnoid hemorrhage (patient 11 in Table 1). (**A**) Preoperative three-dimensional reconstruction digital subtraction angiography shows pearl-and-string type of dissecting aneurysm with involvement of posterior inferior cerebellar artery (PICA) origin. (**B**) Stent-assisted coil embolization was performed with PICA flow preservation. After 3 hours, the patient progressed to a stuporous level of consciousness. (**C** and **D**) Diffusion-weighted magnetic resonance angiography and computed tomography angiography show right cerebellar infarction with PICA occlusion. (**E**) Brain computed tomography on postoperative day 1 shows brainstem infarction due to cerebellar edema. The patient died on postoperative day 1.

infarction occurred postoperatively, and 2 remnant inflow lesions occurred during follow-up.

The case with postoperative cerebellar infarction was initially diagnosed as Hunt and Hess grade II SAH with pearl-and-string type aneurysm (patient 11) (Figure 2). The length of dissecting segment was large (11.1 mm) compared with the average length of aneurysms treated with SAC (8.6 mm). PICA origin was involved in the dissecting segment. However, aneurysmal dilatation was medially directed, whereas PICA origin was located opposite to the dilatation site. Therefore, SAC was successfully performed with well-maintained PICA flow. However, the patient progressed to a stuporous level of consciousness after 3 hours. Follow-up computed tomography angiography and MRA diffusion showed occlusion of the ipsilateral PICA with a large volume of acute infarction in the ipsilateral cerebellum. We recommended decompressive suboccipital craniectomy to the patient's legal guardians. However, they refused because of the advanced age and poor general condition of the patient. The patient died of posterior fossa edema and brainstem compression the following day.

In previous studies, dissecting aneurysms in posterior circulation showed a higher recurrence rate than dissecting aneurysms in anterior circulation (33% vs. 6%), whereas dissecting aneurysms showed a higher recurrence rate compared with saccular aneurysms (18% vs. 8.3%—14%).[23] PICA involvement is another major cause of recurrence after SAC.[5] Consequently, VADA with PICA involvement has a very high risk of recurrence compared with saccular aneurysms in anterior circulation after SAC. Multiple stent deployment can be helpful when immediate complete occlusion is not achieved.[5] However, all our cases obtained immediate complete occlusion of the aneurysm with single stent and coil embolization. In our study, 2 aneurysm recurrences occurred during follow-up. One was an unruptured saccular type (patient 4) (Figure 3), and the other was a ruptured fusiform dilatation type (patient 14). Patient 4 was simply observed, whereas patient 14 underwent retreatment after 5 months with stent-on-stent technique and additional coil embolization. Our results of treatment of VADA with PICA involvement with SAC showed 12.5% postoperative infarction, which progressed to death, and 25% recurrence rate without any SAH during follow-up.

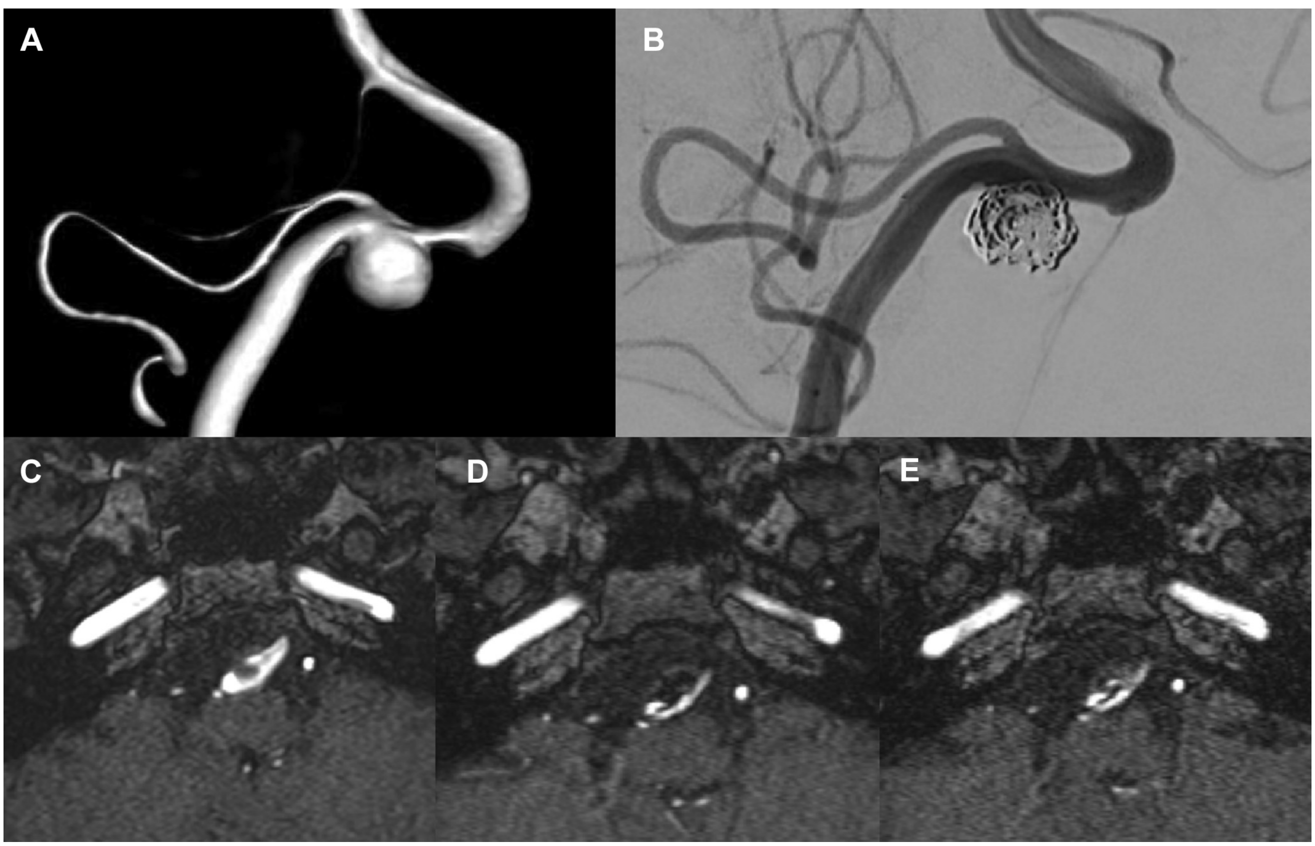

Figure 3. Recurrence of aneurysm in a 53-year-old man (patient 4 in Table 1). Right V4 dissecting aneurysm involving the posterior inferior cerebellar artery was diagnosed. (**A**) Three-dimensional reconstruction digital subtraction angiography shows saccular aneurysm with distal vertebral artery luminal narrowing. (**B**) Stent-assisted coil embolization was performed. (**C**) Preoperative time-of-flight magnetic resonance angiography shows intramural hematoma with blood flow into aneurysm sac. (**D**) Postoperative time-of-flight magnetic resonance angiography performed after 1 month shows complete occlusion of aneurysm sac without inflow. (**E**) After 13 months, remnant inflow appeared on time-of-flight magnetic resonance angiography.

Vertebral Artery Trapping with Vertebral Artery—Posterior Inferior Cerebellar Artery Stenting

VA trapping is a novel therapy for treating VADA, especially for ruptured cases because of its low chance of recurrence and rebleeding. However, a few limitations exist, including contralateral hypoplastic VA, bilateral lesion, and PICA involvement. When treating lesions with PICA involvement, reconstruction of PICA flow is needed. Iihara et al.[7] reported a combination therapy of internal trapping of the parent artery with surgical occipital artery—PICA bypass in 1 patient with ruptured VADA with PICA involvement and 2 patients with unruptured VADA with PICA involvement without recurrence or ischemic symptoms. However, surgical bypass in the posterior circulation may require a lengthy operative time. Furthermore, various surgical complications, such as lower cranial nerve palsy and anastomosis failure, can develop. As an alternative method, VA occlusion with VA-to-PICA stenting for preserving PICA flow can be used.[10] We treated 4 patients with VADA with PICA involvement with VTVPS (3 ruptured aneurysms and 1 unruptured aneurysm). During follow-up, 1 postoperative infarction occurred, and there was no recurrence. Postoperative infarction occurred in 1 case of ruptured fusiform dilatation—type VADA (patient 10) (Figure 4). During the procedure, ipsilateral PICA flow was patent when a VA-PICA stent was deployed. However, PICA occlusion developed after trapping the ipsilateral VA with coil embolization. Postoperative diffusion-weighted magnetic resonance imaging showed cerebellar infarction. Follow-up angiography performed after 24 months showed total restoration of PICA flow with improvement of symptoms. The

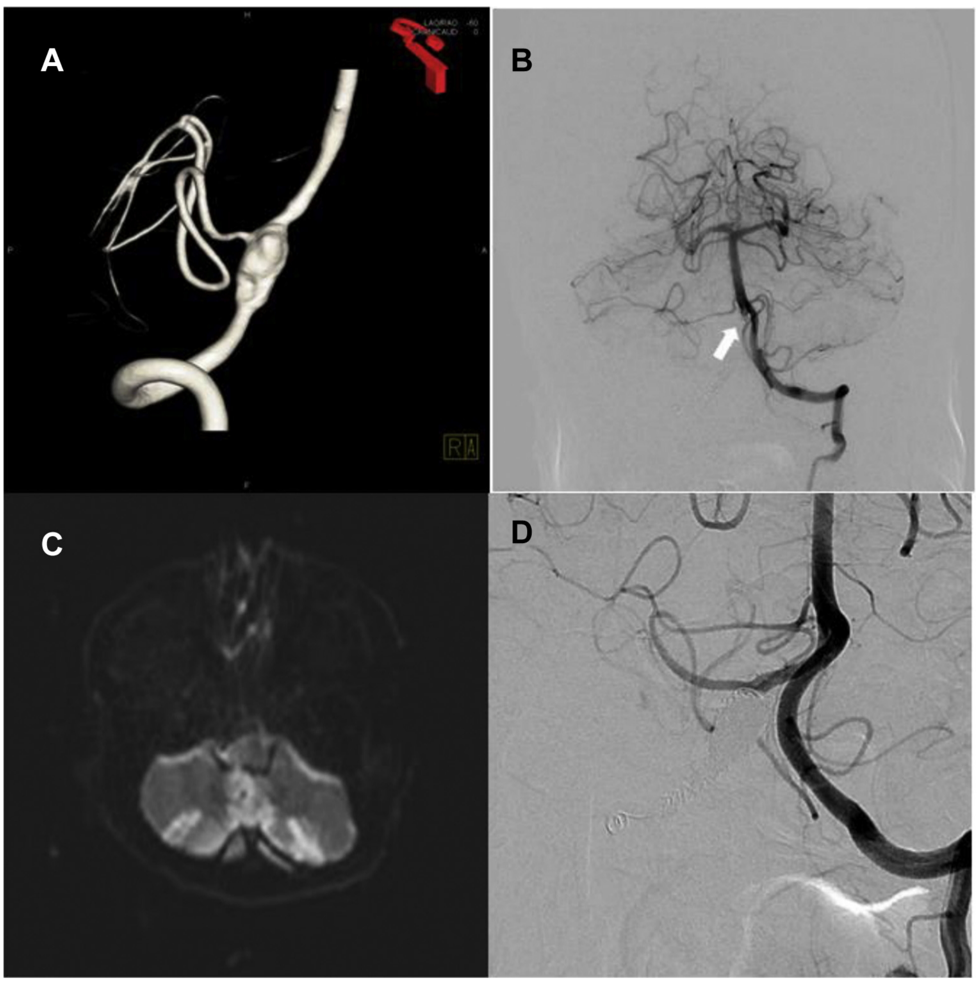

Figure 4. Postoperative infarction in a 49-year-old man who presented with subarachnoid hemorrhage (patient 10 in Table 1). (**A**) Preoperative three-dimensional reconstruction digital subtraction angiography shows fusiform dissecting aneurysm in right V4 with involvement of posterior inferior cerebellar artery (PICA) origin. (**B**) Right vertebral artery occlusion with VA-PICA stenting was performed, and postoperative angiography showed total occlusion of right vertebral artery and occlusion of PICA (*arrow*). (**C**) Diffusion-weighted magnetic resonance imaging performed on postoperative day 1 shows acute infarction on posterior inferior aspect of the cerebellum. (**D**) Follow-up angiography performed after 24 months shows restoration of right PICA flow.

other 3 patients had excellent outcomes without postoperative stroke or recurrence. Figure 5 shows a VADA involving the PICA that was successfully treated with VTVPS. The postoperative infarction rate was 25%, and the recurrence rate was 0%. There was no SAH on follow-up.

Pipeline Embolization Device (Flow Diverter)

Flow diversion is emerging as a method for treating VADAs. PED preserved perforators from the parent artery, and therefore may be adequate to treat VADA with PICA involvement. Compared with a non−flow-diverting stent, PED accelerates endoluminal remodeling by supporting neointimal overgrowth. Therefore, rapid thrombus formation can be achieved to inhibit aneurysmal growth. Yeung et al. reported favorable outcomes of 4 VADA cases treated with PED, all resulting in complete occlusion without postoperative stroke or recurrence.[24] We treated 2 VADAs involving the PICA. Results showed 1 remnant inflow without stroke during follow-up. The patient with the remnant inflow lesion underwent digital subtraction angiography after 15 months. Although the inflow lesion was still shown, its size was reduced. However, the number of patients treated with PED was too small and the follow-up period was too short to compare with other treatment modalities. Further study with a larger number of patients and longer follow-up period is needed.

There were 3 postoperative infarctions among 18 patients. Deterioration of mRS score was found in only 1 patient, who was treated with SAC. Another 2 patients with infarction who were treated by MS and VTVPS, respectively, did not demonstrate any neurologic deficit at the end of follow-up. However, a patient treated with SAC had PICA infarction and died. When treated with MS, VTVPS, or PED, the patency of PICA flow might be well maintained immediately postoperatively. Even if PICA occlusion occurs, the occlusion might progress slowly, earning sufficient time for the development of collateral vessels. However, SAC has a risk of compromising the PICA, which can result in rapid suppression of PICA flow and severe PICA infarction.

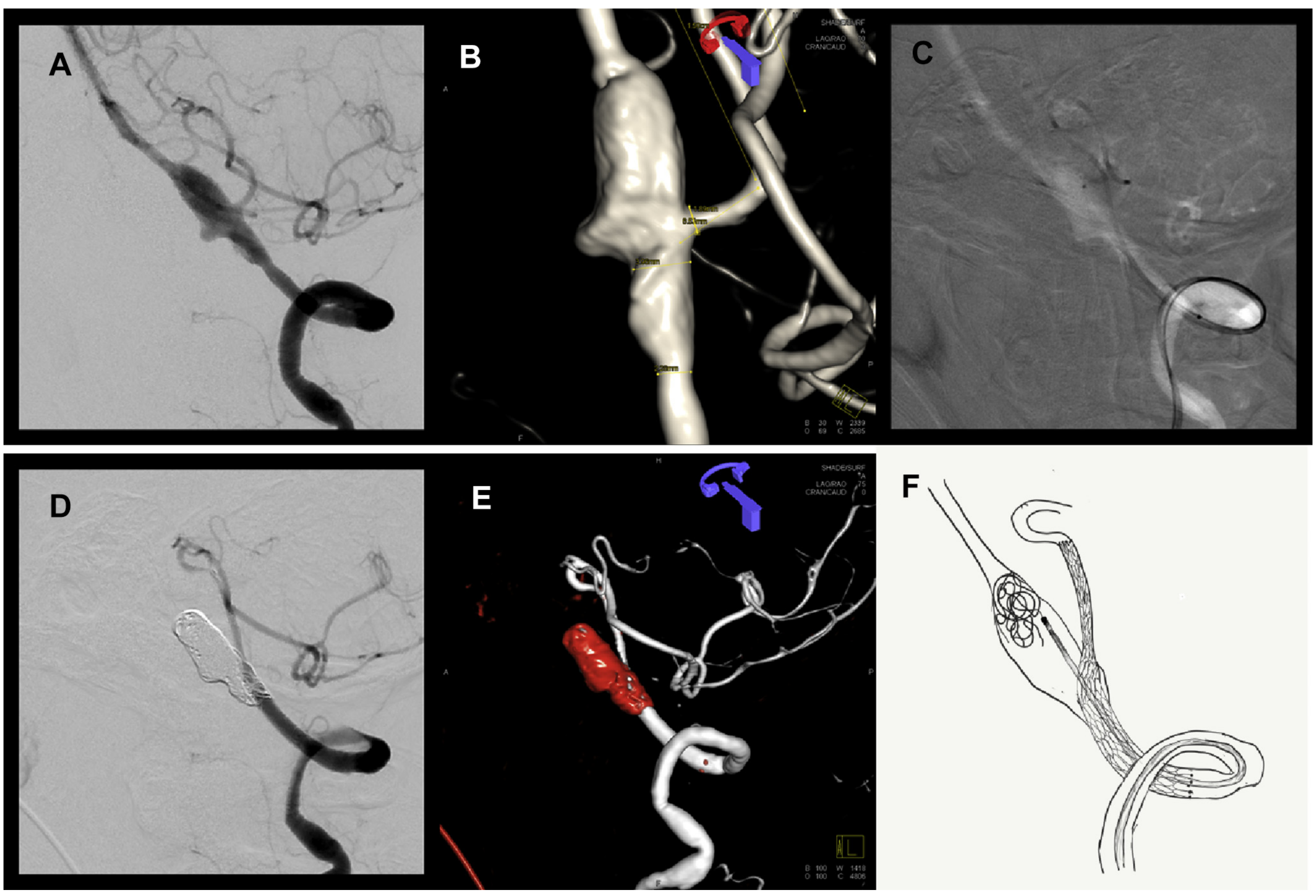

Figure 5. A 55-year-old man presented with subarachnoid hemorrhage (patient 2 in Table 1). (**A** and **B**) Preoperative angiography shows fusiform dilatation type of vertebral artery dissecting aneurysm involving the origin of the left posterior inferior cerebellar artery (PICA). Left PICA selection was done with a Prowler Select Plus microcatheter, and aneurysm selection was done with an Excelsior 1018 microcatheter. An Enterprise stent was deployed from cranial loop of left PICA to left V4, and vertebral artery (VA) trapping was performed with detachable and pushable coils. (**C**−**E**) Postoperative angiography shows complete occlusion of distal VA with preservation of PICA flow. (**F**) Illustration of VA-to-PICA stent placement with coil embolization.

Study Limitations

The retrospective review study design and small number of cases from a single institution are limitations of this study. These may lead to statistical bias.

CONCLUSIONS

The present study shows outcomes of diverse treatment modalities in treating PICA involved VADAs. Various characteristics of VADA should be considered when selecting the appropriate treatment modality. In our treatment strategy, patients who were treated by VTVPS were mostly patients with SAH who presented with long dissecting segment length. Patients with hypoplastic contralateral VA and patients with ischemic stroke were mostly treated with MS and PED to reduce the risk of additional stroke. Saccular aneurysms with short dissecting segments tended to be treated with SAC. Of all treatment modalities, VTVPS showed the lowest rate of recurrence and a high rate of minor ischemic stroke without neurologic deficit. MS showed a high rate of recurrence and minor ischemic stroke without neurologic deficit. SAC showed a high rate of recurrence and low rate of ischemic stroke. However, it was accompanied by the possibility of fatal disabling stroke. PED showed the lowest rate of infarction and the highest rate of recurrence. Further study is needed to verify these results.

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