



Original Article

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Microsurgery Versus Endovascular Treatment - Which Is Adequate for Initial Treatment of Spinal Dural Arteriovenous Fistula: A Case Series

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Objective: Considering the adverse natural history of spinal dural arteriovenous fistula (sDAVF), clinical outcomes may be worsened if the initial occlusive trial does not achieve complete fistula occlusion. We aimed to analyze the initial success rate of microsurgery and embolization and confirm the effects of initial treatment success on the clinical outcomes of sDAVF patients. In addition, we investigated the factors associated with initial treatment failure.

Methods: A total of 38 patients treated for sDAVF at a single institution over a 14-year period were retrospectively reviewed. Clinical outcomes according to the initial treatment modality were quantitatively analyzed. Demographic characteristics and angioarchitecture data were evaluated to identify factors associated with initial treatment failure.

Results: In the study population, 34 patients underwent embolization as the initial treatment, and complete occlusion of the fistula was achieved in 13 patients (38%). However, all patients who underwent microsurgery showed complete fistula occlusion. Among patients with initial treatment success, gait and micturition were improved with statistical significance ($p < 0.001$ each). However, in cases of initial treatment failure, only mild improvements in gait and micturition were observed, which were not statistically significant ($p = 0.097$ and $p = 0.375$, respectively). A narrow feeding artery diameter ($p = 0.007$) and embolization of the artery only ($p = 0.002$) were identified as factors associated with initial treatment failure.

Conclusion: To achieve symptomatic improvement and prevent neurological deterioration due to recurrence, the initial definite occlusion of the fistula is important. Despite advances in endovascular techniques, microsurgical occlusion is still superior in terms of initial complete obliteration.

Keywords: Arteriovenous fistula, Embolization, Microsurgery



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INTRODUCTION

Spinal dural arteriovenous fistula (sDAVF) is a rare disease, and diagnosis is difficult as the clinical presentation is nonspecific, the lesion is small and complex, and the angioarchitecture is diverse.¹⁻³ The appropriate diagnosis and treatment of sDAVF are important because venous hypertension and chronic ischemia due to arterialization of the recipient vein can cause my-

elopathy or paraplegia. Treatment of sDAVF requires obliteration of the arteriovenous fistula either by microsurgical occlusion or endovascular embolization. The endovascular treatment of sDAVF is preferred because of the technical developments in this procedure and the higher degree of safety attributed to its noninvasive characteristics.^{4,5} However, poorer outcomes have been reported using this approach compared with microsurgery.⁶⁻¹³ Moreover, recent studies have indicated that the pro-

portion of sDAVF patients undergoing microsurgical treatment has been increasing.¹⁴ Some studies suggest that clinical outcomes may improve if additional treatment is performed after an incomplete initial therapy.^{15,16} However, treatment failure has been identified as a factor associated with poor prognosis in cases of sDAVF.^{16,17} Therefore, initial conclusive treatment is important as this disease can progress with severe deficits and can recur aggressively even after symptoms have been reduced or resolved after an initial therapy.⁷

Several studies have analyzed the clinical outcomes of patients with sDAVF according to the treatment modality.^{2,7-9} However, due to its low incidence, studies of the effects of initial treatment success on sDAVF patient outcomes or possible prognostic indicators are limited. Therefore, in our present study, we analyzed and compared not only the outcomes of endovascular treatment and microsurgical treatment in cases of sDAVF but also the effects of initial treatment success on patient outcomes through quantitative analysis. In addition, we investigated the factors associated with initial treatment failure.

MATERIALS AND METHODS

We performed a retrospective analysis of a consecutive series of sDAVF patients treated at our institution from January 2004 to June 2017. The data supporting the findings of this study are available from the corresponding author upon reasonable request. The analyses were approved by the Institutional Review Board of Asan Medical Center (Protocol No. AMC-IRB-2018-0795). This study was a retrospective analysis of the medical records, and there was no risk to the patients. Consent was not obtained due to the retrospective nature of the study.

1. Clinical Data

The clinical variables of the patients including age, sex, and initial neurologic status, duration of symptoms were assessed using the electronic medical record. The classification scale for gait disturbance and micturition used by the Aminoff-Logue scale (ALS) score of disability was applied to analyze the clinical status before and after treatment. Based on the medical records of the patients, the ALS scores were retrospectively calculated by a neurosurgeon not directly involved in the treatments.

2. Radiologic Features

All of the patients underwent a diagnostic workup via magnetic resonance imaging (MRI) of the whole spine and consecutive selective spinal angiography, which confirmed the pres-

ence of sDAVF in all cases. The angiographic features of the arteriovenous fistula (AVF) (feeder location, number of feeders, feeder diameter—in the case of multiple feeders, we calculated and analyzed the average value of each feeder diameter, location of the most proximal site of the radiculomedullary vein [RMV], presence of collateral flow to the fistula, venous drainage flow direction) were recorded.

3. Treatments

For all the patients included in this study, the decision to treat was made after diagnosis by angiography. Endovascular treatment was conducted using either N-butyl cyanoacrylate (NBCA; Histoacryl; B. Braun, Tuttlingen, Germany) and/or Lipiodol or Onyx (ev3, Irvine, CA, USA). In most patients, NBCA was administered in a mixture with lipiodol (33 patients). One patient was treated with onyx.

Microsurgery was performed after failed embolization for obliteration of the fistula or if embolization was considered not feasible. Of the 4 patients who underwent microsurgery as the initial treatment, 3 of them showed a relationship between the feeder and anterior spinal artery (ASA) on preoperative spinal angiography, and arterial selection was regarded as difficult during diagnostic angiography for 1 patient. The microsurgery procedure consisted of laminectomy at the level of the fistula and disconnection of the fistula followed by cauterization. Indocyanine green (ICG) angiography was used to identify the fistula before treatment and to confirm fistula obliteration after disconnection.

4. Follow-up

The treatment results were confirmed by angiography and MRI. All patients underwent posttreatment spinal angiography to confirm definite fistula occlusion immediately after treatment. Definite fistula occlusion on postoperative angiography and the absence of or decreased cord swelling and engorged pial vessels on MRI were defined as fistula closure without recurrence. The imaging was repeated when there was a clinical suspicion of recurrent disease. Treatment failure was defined as the presence of a persistent AVF or occurrence of a new fistula at follow-up when compared with the status at posttreatment angiography. However, in the patients receiving embolization treatment, even if the sDAVF was partially occluded at follow-up, we classified it as successful occlusion if the feeder pattern remained unchanged (i.e., no occurrence of a new fistula on angiography, decreased cord swelling and engorged pial vessels on MRI, and the patient's symptoms remained improved). Successful occlusion of the fistula with the initial treatment was de-

defined as initial treatment success. Secondary treatment success was defined as successful occlusion of the fistula after additional treatment for a recurrent or residual lesion.

Successful occlusion of the fistula with the initial treatment was defined as initial treatment success. Secondary treatment success was defined as successful occlusion of the fistula after additional treatment for a recurrent or residual lesion. Patients were classified into the initial treatment success group and initial treatment failure group to analyze factors affecting treatment failure. Microsurgery cases were excluded from factor analysis related to the initial treatment success because this initial treatment was 100% successful. Factor analysis was performed for patients who underwent embolization as the initial treatment. In addition, all events during the operations were recorded, and any complications associated with the microsurgery procedure were documented.

5. Statistical Analysis

Statistical analyses were performed using the commercially

available IBM SPSS Statistics ver. 21.0 (IBM Co., Armonk, NY, USA). The chi-square test was performed to assess categorical variables, and the Mann-Whitney test was used to evaluate continuous variables. The clinical outcomes of the groups were compared using the Wilcoxon signed-rank test. Patients who underwent embolization as the initial treatment were divided into 2 groups, and logistic regression was performed to evaluate the odds ratio (OR) and 95% confidence interval (CI) of potential prognostic indicators. The statistical significance level was set at $p < 0.05$.

RESULTS

We initially reviewed the records of 53 cases of spinal AVF evaluated by spinal angiography at our hospital during the study period. Classification according to the angioarchitecture revealed that the study population was composed of 41 patients with sDAVF (78.8%), 5 patients with epidural AVF (9.4%), and 7 patients with perimedullary AVF (13.2%).¹ Of the 41 patients di-

Table 1. Baseline demographics and characteristics of 38 patients with sDAVF

Variable	Initial treatment success (n = 17)	Initial treatment failure (n = 21)	p-value
Demographics and clinical characteristics			
Sex, male:female	12:5	19:2	0.207
Age (yr)	59 ± 12	62 ± 12	0.628
Neurologic status (Aminoff-Logue scale score)			
Gait	2.62 ± 1.49	2.76 ± 1.53	0.791
Micturition	1.5 ± 1.18	1.53 ± 1.50	0.880
Initial treatment modality, microsurgery:embolization	4:13	0:21	0.028*
Follow-up period (mo)	32 ± 26	27 ± 29	0.378
Angiographic characteristics			
Location of the feeding artery			
Cervical	2	3	0.832
Upper thoracic	3 (above T6)	3	
Lower thoracic	7 (below T7)	11	
Lumbar	5	4	
No. of feeders	1.35 ± 0.6	1.40 ± 0.6	0.914
Feeder diameter (mm)	1.1 ± 0.26	0.79 ± 0.23	0.004*
Presence of collateral flow	3 (17.6)	8 (38.1)	0.281
Location of the proximal site of the RMV, dorsal:ventral	14:3	19:2	0.650
Venous drainage flow direction, upward:downward:mixed	4:1:12	1:6:14	0.899
Relationship between the feeder and ASA	3 (17.6)	2 (9.5)	0.647

Values are presented as number, mean ± standard deviation, or number (%).

RMV, radiculomedullary vein; ASA, anterior spinal artery.

agnosed with sDAVF, 3 patients refused treatment. The remaining 38 patients who underwent treatment were enrolled in the present study. The initial clinical and angiographic data for the 38 patients with sDAVF are shown in Table 1. This cohort was composed of 30 males and 8 females with a median age of 61.2 years. There were 5 cervical lesions and 33 thoracolumbar lesions. All patients with cervical lesions, except one with subarachnoid hemorrhage (SAH) who only had headache and neck pain, and all patients with thoracolumbar lesions had myelopathy.

In the initial neurological evaluation, the values were similar between the 2 groups. There were 4 patients who underwent microsurgery and 13 patients who underwent embolization in the initial treatment success group. However, in the initial treatment failure group, all patients underwent embolization, and there was a statistically significant difference in the initial treatment modality between the 2 groups ($p=0.028$). The lower thoracic region (below T7) was the most common site of the feeding artery. The diameter of the feeding artery was significantly smaller in the initial treatment failure group (0.79 mm) than in the initial treatment success group (1.1 mm) ($p=0.004$). A total of 8 patients (38%) in the initial treatment failure group

and 3 patients (17%) in the initial treatment success group exhibited collateral flow.

In present study, the duration from onset to treatment in the initial success group ranged from 0 to 96 months (average, 26 months). If patients were symptomatic for less than 24 months before treatment, gait function improved by 1.7 grades at last follow-up, while in those with longer duration of preoperative symptoms, gait function improved by 1.1 grades at last follow-up ($p=0.48$).

1. Radiologic Outcomes

Among the 38 patients with sDAVF, 34 patients underwent embolization, and 4 patients underwent microsurgical ligation as the initial treatment. Among the patients who underwent initial embolization, treatment failure occurred in 8 patients, and partial occlusion resulting in a residual fistula occurred in 10 patients. The causes of treatment failure in the study population included difficulty in advancing the catheter due to the severe tortuosity of the feeding artery (6 of 8) and the ASA originating with or adjacent to the feeding artery (2 of 8). Complete occlusion was achieved in 16 patients; however, 5 of them sub-

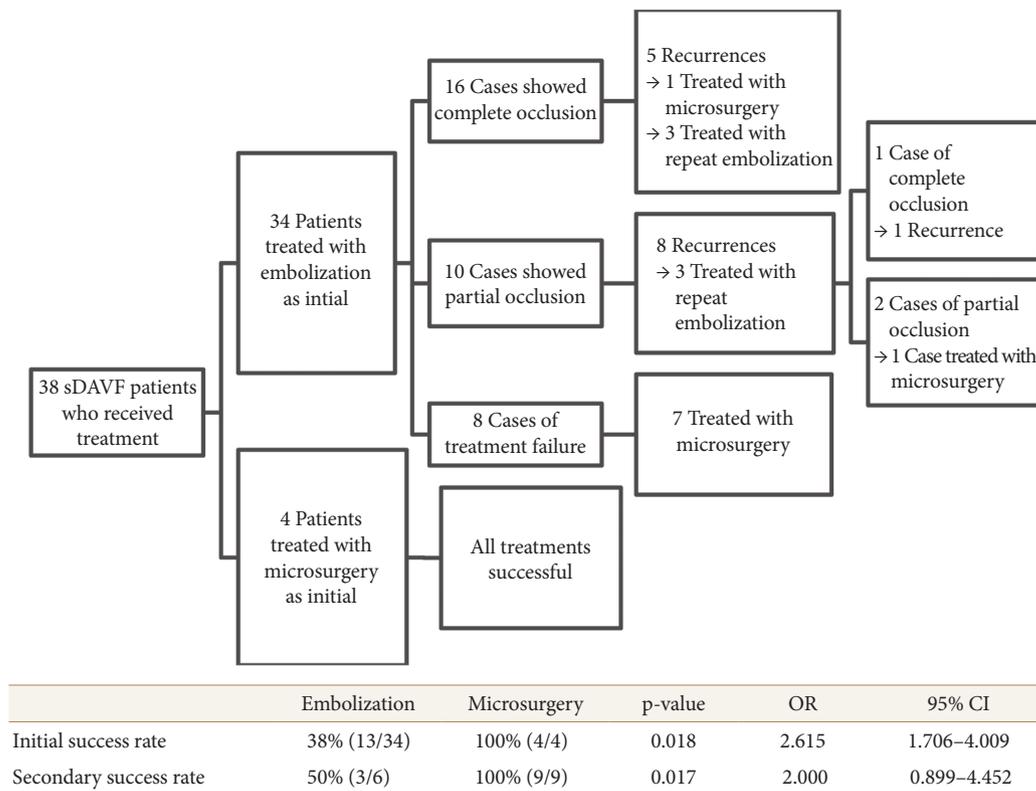


Fig. 1. Flow diagram of the treatment modalities and treatment success rates in the current case series. Statistically significant difference. sDAVF, spinal dural arteriovenous fistula; OR, odds ratio; CI, confidence interval. $p < 0.05$, chi-square test.

sequently had recurrence in the follow-up period. Among the patients with initial treatment failure including recurrence, 6 patients underwent embolization as the secondary treatment; however, this was only successful in 3 cases. In addition, 9 patients underwent microsurgery as the secondary treatment with subsequent complete occlusion of the fistula. They took a minimum of 7 days, a maximum of 27 days, and an average of 13 days to undergo surgery after embolization failure. One patient who recurred after embolization as the secondary treatment showed complete occlusion after microsurgical treatment as the tertiary treatment. Among the patients treated with embolization, 5 of the 8 patients with partial occlusion were followed up without further treatment as there was no further neurological deterioration and the MRI scans and angiography showed no changes during the follow-up period.

None of the 4 patients who underwent microsurgery as the initial treatment for sDAVF showed any follow-up evidence of persistent arteriovenous shunting. Hence, the initial success rate for endovascular treatment in our current study cohort was 38%, and the secondary success rate was 50%. In comparison, the initial and secondary success rates for microsurgical treatment were both 100% (Fig. 1).

2. Clinical Outcomes

Neurological improvements in both gait and micturition were

determined by clinical outcome analysis using ALS scores. Subgroup analysis was performed according to the treatment modality (microsurgery vs. endovascular) and the initial treatment outcome (initial treatment success vs. initial treatment failure). In quantitative terms, the mean ALS gait score showed significant improvement in the final follow-up after treatment in all subgroups (microsurgery group: $p=0.001$, embolization group: $p=0.005$, initial treatment success group: $p<0.001$) except for the initial treatment failure group ($p=0.097$). In addition, the

Table 2. Pre- and final ALS score in the initial treatment success (n = 17) and initial treatment failure (n = 21) groups

Variable	Aminoff-Logue score			Group comparison [†]
	Pretreatment	Last follow-up	p-value	
Gait				0.002
Initial success group	2.62 ± 1.49	1.21 ± 1.06	<0.001*	
Initial failure group	2.76 ± 1.53	2.15 ± 1.77	0.097	
Micturition				0.124
Initial success group	1.5 ± 1.18	0.71 ± 0.80	<0.001*	
Initial failure group	1.53 ± 1.50	1.23 ± 1.64	0.375	

Values are presented as mean ± standard deviation. * $p<0.05$, statistically significant difference (as determined by the Wilcoxon signed-rank test). [†]Comparison between the groups. An improvement in gait but not micturition was significantly different between the 2 groups.

Table 3. Prognostic indicator analysis

Variable	Univariate analysis			Multivariate analysis		
	p-value	Odds ratio	95% CI	p-value	Odds ratio	95% CI
Sex, male:female	0.405	0.482	0.087–2.680	-	-	-
Age	0.263	1.033	0.976–1.093	-	-	-
Neurologic status				-	-	-
Gait	0.566	1.144	0.722–1.813	-	-	-
Micturition	0.457	1.239	0.705–2.177	-	-	-
Location of the feeding artery	0.696	0.861	0.407–1.821	-	-	-
No. of feeders	0.639	0.779	0.275–2.206	-	-	-
Feeder diameter	0.020*	0.015	0.000–0.511	-	-	-
Presence of collateral flow	0.114	4.278	0.706–25.919	-	-	-
Location of the proximal site of the RMV (dorsal: ventral)	0.877	1.182	0.142–9.827	-	-	-
Venous drainage flow direction (upward: downward: mixed)	0.552	1.400	0.462–4.238	-	-	-
Relationship between the feeder and ASA	0.999	Not estimated	Not estimated	-	-	-
Embolization site (artery, artery+vein)	0.008*	19.250	2.183–169.786	0.023*	14.034	1.448–136.003

CI, confidence interval; RMV, radiculomedullary vein; ASA, anterior spinal artery.

* $p<0.05$, statistically significant difference.

mean ALS micturition score was significantly improved after treatment in each subgroup (microsurgery group: $p=0.015$, embolization group: $p=0.007$, initial treatment success group: $p<0.001$) except for the initial treatment failure group ($p=0.375$) (Table 2). In addition, when we analyzed the degree of symptom improvement between subgroups (initial treatment success vs. initial treatment failure), there were statistically significant gait improvements in the initial treatment success group ($p=0.002$). In terms of micturition, the comparison indicated no significant differences in the degree of symptom improvement between the groups ($p=0.124$).

3. Prognostic Factors

We conducted prognostic factor analysis related to the initial treatment success of 34 patients who underwent embolization as the initial treatment (Table 3). Patients were first classified into 2 groups depending on this outcome. In univariate analysis, the diameter of the feeding artery ($p=0.020$; OR, 0.015; 95%

CI, 0.000–0.511) and embolization of the artery only ($p=0.008$; OR, 19.250; 95% CI, 2.183–169.786) were identified as factors associated with initial treatment failure. In multivariate analysis, no variable other than embolization of the artery only ($p=0.023$; OR, 14.0342; 95% CI, 1.448–136.003) was identified as statistically significant. There was no association between initial treatment success or failure and the age, sex, initial neurologic status, level of the fistula, number of feeders, dorsal or ventral location of the RMV, presence of collateral flow, venous drainage flow direction, or relationship between the feeder and ASA.

4. Complications

There were no surgical complications in the microsurgery group. In the embolization group, unintentional complications including arterial tear or endothelial injury occurred in 4 patients, and a fatal complication caused by posterior spinal artery (PSA) territory infarction occurred in 1 patient.



Fig. 2. Recurrence after initial complete obliteration of the fistula. (A) Pretreatment T2-weighted sagittal magnetic resonance image showing the flow voids of the enlarged pial vessels and the increased signal intensity of the spinal cord. (B) Reconstructed spinal angiography showing spinal dural arteriovenous fistula (sDAVF) filling from the right T7 pedicle (arrow) and suggesting the minor feeding of the sDAVF from the right T6 radicular artery (arrowhead). (C) The patient showed mild symptomatic improvements after the intervention; however, the symptoms worsened after 1 year. A sagittal T2-weighted magnetic resonance image taken at 24-month posttreatment indicated persistent increased signal intensity as well as enlarged pial vessels. (D) 3-dimensional reconstruction images showing complete occlusion of the feeder at the previous embolization site (right T7) and a recurred DAVF fed by the right T6 spinal artery.

5. Case Illustration

1) Case 1

A 46-year-old man was presented at our clinic with a history of progressive hypoesthesia, paraparesis, and urinary and fecal incontinence. The patient was diagnosed with sDAVF and undergone embolization at another hospital 2 years previously with similar symptoms (Fig. 2). The patient showed mild symptomatic improvements after the previous intervention; however, his symptoms worsened at 1-year posttreatment. The patient was recommended for an annual follow-up at the hospital where the initial treatment was given; however, his symptoms continued to progress, and he visited our hospital for further evaluation and treatment.

There was a questionable component at T6 associated with the fistula on the pretreatment DSA from the previous institution (Fig. 2B). Selective spinal angiography at our hospital showed the recurrent fistula at the right T6 (Fig. 2D). We attempted another embolization procedure for the recurrent lesion but decided to perform surgical ligation because of inaccessibility with the microcatheter. The patient underwent a T6–7 laminotomy for obliteration of the sDAVF. A midline durotomy was performed, and the right T6 artery was identified with a clear fis-

tula point (Fig. 3). Successful obliteration of the fistula was achieved using ICG and an MV Doppler. Postoperative spinal angiography performed 7 days later revealed no residual sDAVF (Fig. 4). Periodic follow-ups at our outpatient clinic for 6 months indicated that the patient showed signs of hypoesthesia and gait improvements; however, urinary and fecal incontinence improvements were somewhat marginal.

2) Case 2

A 62-year-old man visited the Emergency Department with headache and neck pain. A brain computed tomography (CT) scan revealed SAH, and angiography showed sDAVF at the craniocervical junction. The main feeder was the ASA originating from the left vertebral artery. Another fistula was observed from the left C2 segmental artery (Fig. 5).

We tried embolization as the first treatment. The feeding artery from the left C2 segmental artery was completely blocked but the feeding artery from the ASA was partially occluded. After embolization, the patient's neurological findings indicated severe paralysis of the left upper and lower limbs and sensory disturbance of touch and position sensations on the left side of his body from the neck downward.

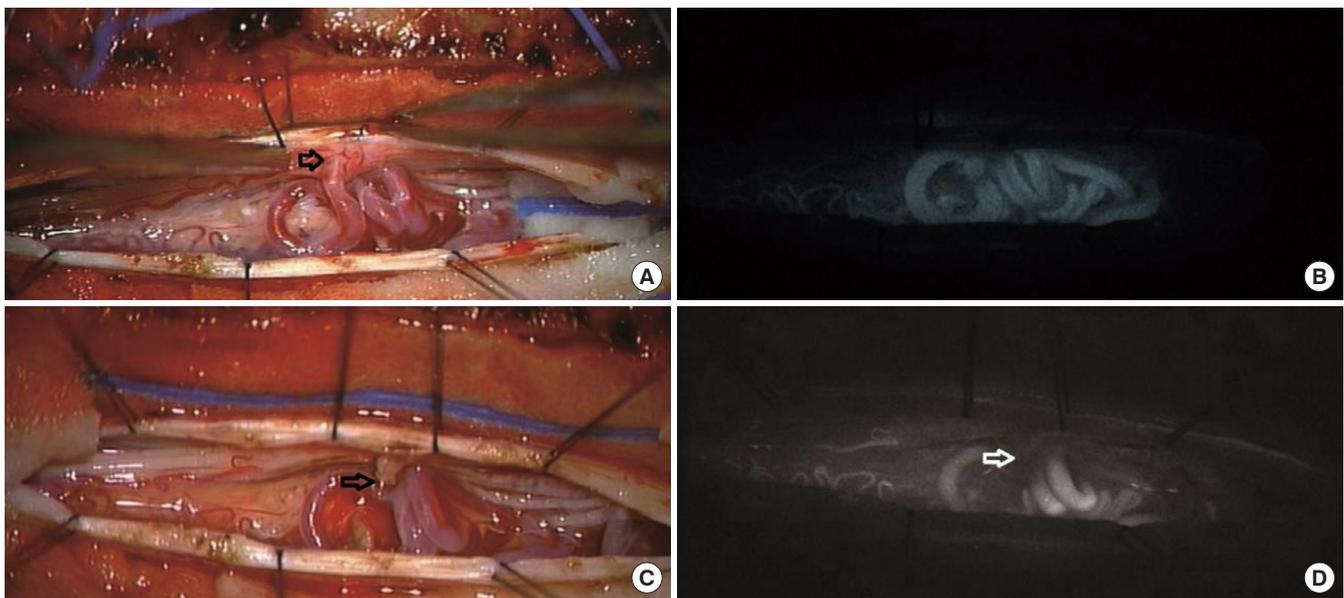


Fig. 3. Intraoperative photographs. (A) Dilated arteries and arterialized perimedullary veins along the spinal cord. The fistula point could be identified at the dorsolateral portion of the dura mater as the feeding artery enters the intradural space (arrow). (B) Indocyanine green (ICG) angiography revealed the gradual filling of the dilated perimedullary vein, indicating the presence of spinal dural arteriovenous fistula at that level. (C) Bipolar coagulation and disconnection of the fistulous point (arrow) were performed, resulting in the immediate darkening of the blood in the draining vein. (D) ICG angiography revealed that the previously injected dye remained in the dilated perimedullary vein and that the feeding artery was no longer in contrast (arrow). This confirmed the successful obliteration of the fistula. Persistent dye filling in the dilated veins indicated existing venous hypertension.²⁰



Fig. 4. (A) DSA showing no further filling of the fistula from the radiculomedullary junction of the right T6 vertebral level of the thoracic cord. (B) Posttreatment (4 months) sagittal T2-weighted magnetic resonance image showing markedly decreased cord swelling without the engorgement of pial vessels.

T2-weighted MRI images showed high signal intensity areas in the left upper cervical PSA from the C1 to the C4 levels that were consistent with spinal cord infarction (Fig. 6).

He received comprehensive rehabilitation treatment. His left limb strength was restored to grade 4 and he was able to walk without assistance on his own. About 2 years later, he underwent surgical treatment for sDAVF recurrence and was diag-

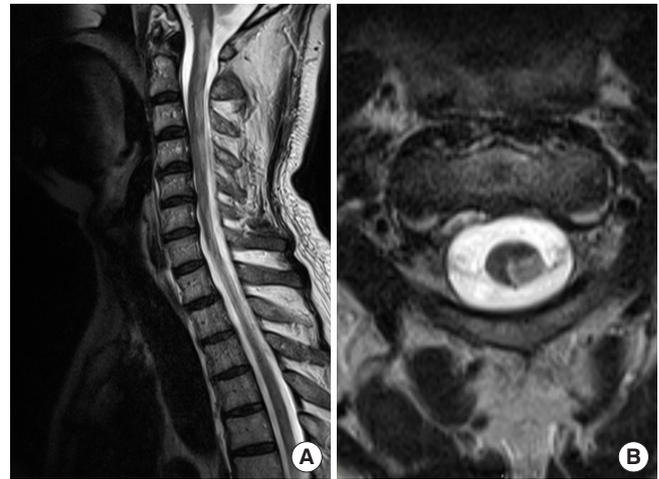


Fig. 6. T2-weighted magnetic resonance imaging sagittal (A) and axial (B) images show high signal intensity areas in the left upper cervical posterior spinal artery from C1 to C4 level.

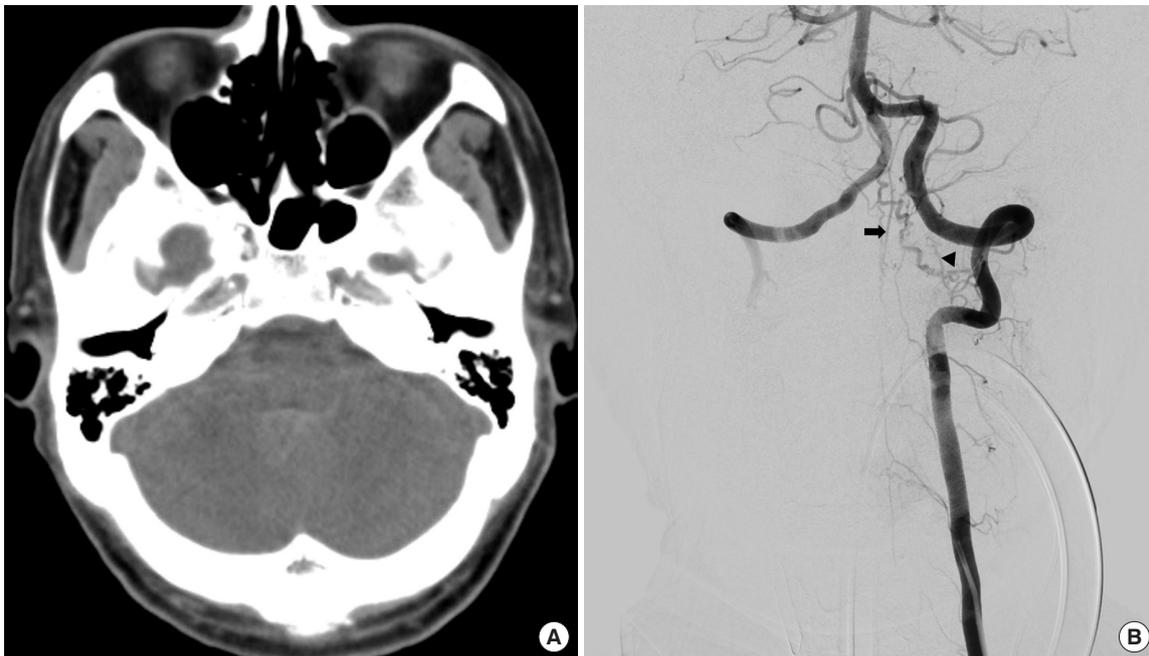


Fig. 5. (A) A brain computed tomography scan shows the subarachnoid hemorrhage in the perimedullary cistern and intraventricular hemorrhage in the 4th ventricle. (B) Angiography shows the subarachnoid hemorrhage. Anterior spinal artery (arrow) and left C2 segmental artery (arrowhead) form the feeding artery of the fistula.

nosed with complete obliteration.

DISCUSSION

1. Treatment of Choice for sDAVF

The choice between endovascular and surgical interventions for sDAVF remains somewhat controversial in the current literature. In a meta-analysis of spinal AVF cases published by Steinmetz et al.² in 2004, the treatment success rate for the endovascular treatment group was 46%; however, another meta-analysis published in 2015 reported a 72.2% success rate.¹¹ In our current study, the total success rate was 69%. However, the surgical success rates reported in several studies have been consistently high.⁶⁻¹³ The surgical success rate in our case series was 100%.

Consistently, the results of other studies have indicated that initial embolization has limitations for successful treatment and that additional treatment is frequently needed.^{2,3,10} Some studies suggest that even though additional treatment may be needed after an incomplete initial therapy, patient outcome would improve.^{15,16} However, it is also well established that occlusion may be temporary as sDAVF can have a high rate of recurrence, and recanalization of the fistula can lead to secondary clinical deterioration; thus, early definitive treatment is important.^{7,18} A previous study revealed that a shorter duration of symptoms was linked to better clinical outcomes.¹⁹ In our study, the duration from onset to treatment in the initial success group ranged from 0 to 96 months (average, 26 months).

Although this was not statistically significant, patients with shorter duration of symptoms before treatment had better clinical outcomes. If patients were symptomatic for less than 24 months before treatment, gait function improved by 1.7 grades at last follow-up, while in those with longer duration of preoperative symptoms, gait function improved by 1.1 grades at last follow-up ($p = 0.48$).

In our current study, quantitative analysis of the clinical symptoms of sDAVF demonstrated the importance of initial treatment success in improving the patients' neurologic status.

Other studies have described surgery for AVF as a definitive treatment with stable long-term results and low levels of procedure-related morbidity.^{2,20} Endovascular techniques have continued to improve in recent years. However, advances in intraoperative microscopy and the use of ICG have augmented the ability to resolve this type of lesion surgically.^{20,21} In addition, minimally invasive spine surgery has been developed, which can produce similarly excellent results and allow faster patient

discharges.¹¹ Moreover, surgery is an effective intervention when the segmental feeding artery also supplies a spinal cord artery—a relative contraindication for endovascular treatment.⁶ Indeed, our current case series included a case of inadvertent occlusion causing PSA territory infarction.

The development of 3-dimensional rotational angiography has facilitated the examination of the angioarchitecture in sDAVF patients prior to treatment. This method may also be helpful in choosing the right working angle and feeder prior to embolization and assist with the decision to change the treatment modality if embolization is likely to fail or incomplete occlusion is possible. In our present study, the treatment decision for 3 of the 4 sDAVF patients who underwent microsurgery as the initial intervention was attributed to the relationship between the feeding artery and ASA on diagnostic angiography. In the remaining initial microsurgery case, the selection of the feeding artery was regarded as difficult. Owing to sound decision-making in this case, the patient achieved neurological recovery without recurrence after only one operation. Although embolization materials or other endovascular devices have undergone considerable advances over the years, endovascular treatment may not be curative. Typically, in sDAVF cases with enhanced angioarchitecture complexity on diagnostic angiography, no endovascular attempts are made, and patients would be immediately referred for microsurgical treatment.^{6,11,22-24}

2. Prognostic Indicators of Initial Treatment Success

Initial treatment success and recanalization in spinal AVF are related to the complexity of the angioarchitecture and rich collateral networks.^{3,6,9,23} In our current study cohort, 6 of 8 cases of failed embolization were attributed to the severe tortuosity of the feeding artery, thus making surgery a favorable option for these patients. We also found a statistically significant association between a narrow feeding artery diameter and initial treatment success ($p = 0.020$). In our present study, 5 of 16 patients with complete occlusion at initial embolization developed subsequent recurrence. If the glue penetrates only the feeding artery and does not penetrate the draining vein, recanalization occurs through the newly opened or existing collateral vessel.³

Discontinuous and uneven glue distribution between the arterial and venous segments tends to cause the fistula to recur.^{6,23} Furthermore, our prognostic factor analysis revealed a statistically significant association between initial treatment success and venous occlusion of the embolization material ($p = 0.008$). The development of the collateral network was also greater in the initial treatment failure group (38%) than in the initial treat-

ment success group (15%), which could be caused by an additional supply from anywhere from the segmental artery or a dural collateral with low flow at pretreatment that could not be determined as a feeder or was not visible. However, this limited flow could change over time to a feeder after embolization.²⁵

However, this was not statistically significant ($p=0.114$; OR, 4.278; 95% CI, 0.706–25.919). There was no correlation between the venous drainage flow direction and treatment outcome ($p=0.696$; OR, 0.861; 95% CI, 0.407–1.821). The association between fistula location and treatment success remains a subject of controversy in the current literature.^{6,23,26} As indicated by a previous study, an ASA arising from the same level could limit the ability to embolize.¹⁵ However, no statistically significant association was found between the ASA and treatment failure in our current case series ($p=0.999$); most of the patients with sDAVF and ASA of the same origin underwent microsurgery.

3. Limitations

There were some limitations in our current study. First, it was a retrospective design. Second, the patient population was small. However, in terms of rare disease entities, our study sample size was comparable to that of many other studies. Third, the number of patients who underwent microsurgery as the initial treatment was significantly lower, and the success rate of microsurgery was 100%, thus limiting treatment failure analysis. Fourth, the angioarchitecture of the spinal vessels in our cases was very small and complex and thus did not allow for the quantitative analysis of tortuosity. Further studies are required to address these limitations.

CONCLUSION

Although the natural course of sDAVF is progressive, it can be considered as a treatable and curable disease due to advances in imaging diagnosis and treatment techniques. Endovascular treatment is the preferred intervention for sDAVF because it is safer and less invasive than surgery. However, there is a higher tendency for recurrence, which can be accompanied by neurological deterioration. Therefore, the success of the initial treatment of sDAVF is essential for improving the patient's symptoms. A detailed pretreatment evaluation and proper decision-making for each individual sDAVF patient are important, and endovascular therapy should be attempted if it is likely that a single embolization session could treat sDAVF. Despite the continued development of endovascular techniques, microsurgical occlusion still produces superior outcomes, especially in terms

of initial complete obliteration.

CONFLICT OF INTEREST

The authors have nothing to disclose.

REFERENCES

1. Spetzler RF, Detwiler PW, Riina HA, et al. Modified classification of spinal cord vascular lesions. *J Neurosurg* 2002;96(2 Suppl):145-56.
2. Steinmetz MP, Chow MM, Krishnaney AA, et al. Outcome after the treatment of spinal dural arteriovenous fistulae: a contemporary single-institution series and meta-analysis. *Neurosurgery* 2004;55:77-87; discussion 87-8.
3. Jellema K, Sluzewski M, van Rooij WJ, et al. Embolization of spinal dural arteriovenous fistulas: importance of occlusion of the draining vein. *J Neurosurg Spine* 2005;2:580-3.
4. Wakao N, Imagama S, Ito Z, et al. Clinical outcome of treatments for spinal dural arteriovenous fistulas: results of multivariate analysis and review of the literature. *Spine (Phila Pa. 1976)* 2012;37:482-8.
5. Kirsch M, Berg-Dammer E, Musahl C, et al. Endovascular management of spinal dural arteriovenous fistulas in 78 patients. *Neuroradiology* 2013;55:337-43.
6. Blackburn SL, Kadkhodayan Y, Ray WZ, et al. Onyx is associated with poor venous penetration in the treatment of spinal dural arteriovenous fistulas. *J Neurointerv Surg* 2014;6: 536-40.
7. Schick U, Hassler W. Treatment and outcome of spinal dural arteriovenous fistulas. *Eur Spine J* 2003;12:350-5.
8. Qi X, Lv L, Han K, et al. Analysis of the embolization spinal dural arteriovenous fistula and surgical treatments on 52 cases of the patients. *Int J Clin Exp Med* 2014;7:3062-71.
9. Singh B, Behari S, Jaiswal AK, et al. Spinal arteriovenous malformations: is surgery indicated? *Asian J Neurosurg* 2016; 11:134-42.
10. Van Dijk JM, TerBrugge KG, Willinsky RA, et al. Multidisciplinary management of spinal dural arteriovenous fistulas: clinical presentation and long-term follow-up in 49 patients. *Stroke* 2002;33:1578-83.
11. Bakker NA, Uyttenboogaart M, Luijckx GJ, et al. Recurrence rates after surgical or endovascular treatment of spinal dural arteriovenous fistulas: a meta-analysis. *Neurosurgery* 2015; 77:137-44; discussion 44.
12. Narvid J, Hetts SW, Larsen D, et al. Spinal dural arteriove-

- nous fistulae: clinical features and long-term results. *Neurosurgery* 2008;62:159-66; discussion 66-7.
13. Gokhale S, Khan SA, McDonagh DL, et al. Comparison of surgical and endovascular approach in management of spinal dural arteriovenous fistulas: a single center experience of 27 patients. *Surg Neurol Int* 2014;5:7.
 14. Ma Y, Chen S, Peng C, et al. Clinical outcomes and prognostic factors in patients with spinal dural arteriovenous fistulas: a prospective cohort study in two Chinese centres. *BMJ Open* 2018;8:e019800.
 15. Koch MJ, Stapleton CJ, Agarwalla PK, et al. Open and endovascular treatment of spinal dural arteriovenous fistulas: a 10-year experience. *J Neurosurg Spine* 2017;26:519-23.
 16. Lee J, Lim YM, Suh DC, et al. Clinical presentation, imaging findings, and prognosis of spinal dural arteriovenous fistula. *J Clin Neurosci* 2016;26:105-9.
 17. Andres RH, Barth A, Guzman R, et al. Endovascular and surgical treatment of spinal dural arteriovenous fistulas. *Neuroradiology* 2008;50:869-76.
 18. Guillevin R, Vallee JN, Cormier E, et al. N-butyl 2-cyanoacrylate embolization of spinal dural arteriovenous fistulae: CT evaluation, technical features, and outcome prognosis in 26 cases. *AJNR Am J Neuroradiol* 2005;26:929-35.
 19. Shinoyama M, Endo T, Takahashi T, et al. Long-term outcome of cervical and thoracolumbar dural arteriovenous fistulas with emphasis on sensory disturbance and neuropathic pain. *World Neurosurg* 2010;73:401-8.
 20. Hanel RA, Nakaji P, Spetzler RF. Use of microscope-integrated near-infrared indocyanine green videoangiography in the surgical treatment of spinal dural arteriovenous fistulae. *Neurosurgery* 2010;66:978-84; discussion 84-5.
 21. Yi S. The failure of operation for spinal dural arteriovenous fistula demonstrated by intraoperative indocyanine green video-angiography. *Cureus* 2014;6:e205.
 22. Hessler C, Regelsberger J, Grzyska U, et al. Therapeutic clues in spinal dural arteriovenous fistulas - a 30 year experience of 156 cases. *Cent Eur Neurosurg* 2010;71:8-12.
 23. Su IC, terBrugge KG, Willinsky RA, et al. Factors determining the success of endovascular treatments among patients with spinal dural arteriovenous fistulas. *Neuroradiology* 2013;55:1389-95.
 24. Trivelato FP, Rezende MTS, Ulhoa AC, et al. Dual-lumen balloon to increase onyx venous penetration in the treatment of spinal dural arteriovenous fistulas. *J Neuroradiol* 2018;45:142-6.
 25. Krings T, Geibprasert S. Spinal dural arteriovenous fistulas. *AJNR Am J Neuroradiol* 2009;30:639-48.
 26. Cenzato M, Debernardi A, Stefini R, et al. Spinal dural arteriovenous fistulas: outcome and prognostic factors. *Neurosurg Focus* 2012;32:E11.