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ORIGINAL ARTICLE

Clinical Characteristics and Treatment Outcomes of Spinal Arteriovenous Malformations

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Abstract
Purpose Spinal arteriovenous malformations (SAVMs) are rare events. This study evaluated initial clinical presentations and treatment outcomes of SAVMs.
Methods In this study, 91 consecutive patients with SAVM between January 1993 and November 2014 were evaluated. Initial clinical presentations, radiological findings, treatment results, and follow-up outcomes were evaluated according to disease type and treatment modalities. Patient status was scored using the modified Rankin scale (mRS) and Aminoff–Logue Disability scale (ALS).
Results Of the SAVM patients 69 % were male and 31 % were female with a mean age of 49 years (range 11–82 years). At the time of initial imaging evaluation, myelopathy was the most common finding with main complaints of gait disturbance (69 out of 91, 76 %), sensory disturbances (61/91, 67 %), and bowel or bladder symptoms (51/91, 56 %). Among the 80 patients who received treatment 56 (62 %) underwent endovascular embolization and 24 (26 %) underwent surgery. Complete obliteration was achieved in 47 patients (84 %) after endovascular embolization and in 18 (75 %) after surgical ligation. At the time of final follow-up 67 patients (84 %) showed improvement of more than 1 point on the mRS, while 69 (86 %) showed significant improvement on the ALS after treatment.
Conclusion The SAVMs presented with diverse neurological deficits, including myelopathy. Endovascular or surgical treatment of SAVMs can result in good clinical outcomes in most patients.

Keywords Spine · Arteriovenous malformation · Myelopathy · Outcome · Embolization

Introduction

Spinal arteriovenous malformations (SAVM) can have a congenital or acquired abnormal shunt that drains into the perimedullary venous system [1, 2]. Spinal arteriovenous fistulas (AVF) and arteriovenous malformations (AVM) are very rare and complex neurosurgical lesions. Over the last few decades, the pathophysiology of SAVMs has become better understood with the development of spinal angiography [1, 3]. The shunted blood flow causes congestion in medullary veins, which can lead to low tissue perfusion with spinal cord edema and progressive loss of spinal cord function, if not treated properly [4]. Based on specific anatomical locations and pathophysiological features, SAVMs are much like their cerebral counterparts: shunts fed by arteries that normally supply neural tissue (e.g. intrinsic arteries of the spinal cord), whereas spinal dural AVFs are fed by radiculomeningeal arteries [2, 5–7].

Because initial presenting symptoms are unspecific and the course of the disease slowly progresses, clinicians must conduct a thorough neurological examination [3]. Approximately two thirds of patients show a combination of gait difficulty, sensory disturbance and sacral symptoms (e.g. micturition, defecation and sexual dysfunction) [3, 8]. More-

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over, outcome and prognosis depend on the neurological deficit present at the time of diagnosis [9]. Subarachnoid hemorrhage is another manifestation of SAVMs, particularly those located in the craniocervical junction and cervical spine [10]. Despite the unspecific clinical symptoms associated with their initial presentation, SAVMs show characteristic imaging results [11]. On magnetic resonance imaging (MRI) SAVMs are characterized by spinal cord enlargement in the involved area, especially in the lower thoracic region and conus, with T2 hyperintensity across multiple segments and by enlarged intradural vessels along the ventral or dorsal aspect of the spinal cord [11]. Successful treatment of spinal dural or extradural AVFs depends on occlusion of the shunting area or fistular nidus, which can be achieved through surgical or endovascular approaches [12–14]. Since Doppman et al. performed the first embolization of a spinal dural AVF in 1968 [15], endovascular embolization has become a first choice treatment modality. The purpose of the current retrospective study was to evaluate initial clinical presentations and outcomes of patients with SAVMs during the follow-up period after treatment.

Material and Methods

Patients

The local institutional review board approved the current study and only patients who provided written informed consent were included. Between January 1993 and November 2014, a total of 91 consecutive adult SAVM patients were admitted to our hospital. All SAVMS of the included patients had shunt flow through the whole spine and adequate initial radiological data, including spinal MRI and diagnostic spinal angiography. The three patients who did not have complete angiograms to make an exact diagnosis were excluded.

Patient information obtained included patient demographics, symptom onset time, duration of follow-up, imaging follow-up and functional outcome. Initial clinical presentations (symptoms and signs) were assessed in all patients and included pain, radiculopathy, myelopathy or hemorrhage. Pain complaints included the lower back, radicular and any other pain different from sensory changes, such as numbness. Radiculopathy was defined as radiating pain along a certain dermatome, weakness or numbness corresponding to a specific nerve root. Myelopathy was defined as a spinal cord symptom with complaints of gait disturbance, motor/sensory deficits or urinary/sphincter dysfunction with positive upper motor neuron signs, abnormal deep tendon reflex or Babinski signs. We evaluated the presence of functional disability using a modified Rankin Scale (mRS) and assessed functional scores of motor or micturition using the Aminoff–Logue Disability Scale (ALS) [3]. Scores were based on records of patient symptoms and neurological examinations, which were described by on-site neurologists not directly involved in treatment.

Imaging Diagnosis

Spinal MRI and spinal digital subtraction angiography (DSA) were obtained before treatment in all patients. MRI acquisition (1.5 or 3.0 T) varied among included patients with sequences of T1-weighted and T2-weighted axial and sagittal images as well as T1-weighted images with and without contrast enhancement. Angiographic findings of the segmental artery, including the lesion level, were reviewed. Spinal DSA (Artis Zee Biplane, Siemens, Forchheim, Germany) was performed to evaluate all possible feeding arteries and the anterior spinal artery. If available, three-dimensional (3D) rotational angiography was applied to provide 3D information about spinal angioanatomy and the locations of vessels relative to the spinal cord and surrounding structures [16]. Regarding the type of lesions, SAVMs were divided into nidus or fistula type according to the initial opinion about the existence of intervening nidus on spinal angiography made by the interventional neuroradiologists (D.C.S. and H.W.K.) [17]. The interval between the onset of initial symptoms and diagnosis of spinal AV lesions by angiography was calculated as the time of diagnosis in order to assess how much time it takes to reach a hospital diagnosis and how rapid the disease progresses.

The cause of myelopathy was evaluated using MRI and angiography by a site neuroradiologist at the time of consultation and reconfirmed by two other neuroradiologists (D.C.S. and P.J.E.). Venous reflux was considered as a cause of myelopathy when a retrograde drainage toward the perimedullary veins, fed by radiculomeningeal arteries, was noted on DSA, with diffuse T2 high signal change in the spinal cord on MRI. Mass effect was considered as a cause of myelopathy when a large aneurysm related to a spinal vascular lesion, compressed the spinal cord and resulted in a corresponding neurological deficit.

Treatment

Target lesions were fistula, especially in the single feeder of spinal dural AVFs, perinidal aneurysm associated with hemorrhage or mass effect and shunts related to reflux into perimedullary veins and leading to congestive venous myelopathy. Endovascular embolization of spinal dural AVFs was performed with a mixture of cyanoacrylate glue (*n*-BCA, Codman Neurovascular) and Lipiodol (Guerbet, Roissy, France). Concentrations of *n*-BCA used ranged

Table 1 Initial symptomatic presentation and clinical features of 91 patients with SAVMs

Variables	*n* (%) or mean ± SD
Age (years)	49.33 ± 19.09
Males	63 (69 %)
Location	
Cervical	22 (24 %)
Thoracic	46 (51 %)
Lumbar	19 (21 %)
Sacral	4 (4 %)
Treatment method	
Embolization	56 (62 %)
Operation	24 (26 %)
No treatment	11 (12 %)
Recurrence	4 (5 %)
Clinical follow-up period (months)	31.38 ± 44.09
Diabetes mellitus	10 (11 %)
Hypertension	24 (26 %)
Pain	61 (67 %)
Radiculopathy	19 (21 %)
Myelopathy	69 (76 %)
Hemorrhage	5 (6 %)

from 20 % to 30 %. Onyx (Ev3, Irvine, CA) alone or in combination with *n*-BCA was used in 5 patients.

Surgical ligation was considered if embolization failed or there was a common origin between the feeder and anterior or posterior spinal artery. The surgical approach and technique varied depending on the lesion location, type and clinical features. In most cases, a midline double or triple level laminectomy was performed at the predetermined level of the fistula or AV lesion, followed by resection of the nidus or division of the shunting vein to the perimedullary coronal venous plexus. The nidus or fistula was resected or coagulated whenever possible.

Technical Outcomes

Technical (procedural) outcomes after embolization were evaluated as complete, partial or no obliteration. Complete obliteration by embolization was confirmed by immediate postsurgical angiography when the target lesion was obliterated or when follow-up MRI showed improvement of spinal cord edema and/or disappearance of abnormal vessels around the spinal cord. Partial obliteration resulted in a residual nidus or fistula according to immediate postsurgical angiography. The technical outcome after surgery was confirmed by postsurgical angiography. The technical outcomes in patients without postsurgical angiography were determined by surgical records and when follow-up MRI showed improvement of spinal cord edema and/or disappearance of abnormal vessels around the spinal cord.

Clinical Outcomes

Clinical outcomes were evaluated and pretreatment as well as final clinical states were compared using the same symptom classification scales for initial evaluation during the follow-up period. Recurrence was reappearance of symptoms and signs due to recurred or aggravated residual lesions which required additional procedures [18].

Statistical Analysis

Data are reported as the mean ± standard deviation, median for continuous variables or the number of patients with sample population percentages for categorical variables. The normality of quantitative variables was evaluated using the Kolmogorov-Smirnov test. Patient age, sex, comorbidities and presence of pain, mass effect or radiculopathy were compared using analysis of variance for quantitative variables or the Kruskal-Wallis test for categorical variables. The nonparametric Wilcoxon signed rank test was used to compare functional scores in patients before and after treatment. In each group, the complete obliteration rate was compared using Fisher's exact test. All tests were two-sided. A $P < 0.05$ was considered statistically significant. Statistical analyses were performed using SPSS version 21.0 (SPSS, Chicago, IL).

Results

Patient Population and Clinical Features

Clinical features of patients with SAVMs are provided in Table 1. Prospective database registry analysis showed that 91 patients met the inclusion criteria. Clinical and radiological findings of these 91 patients were then retrospectively reviewed to identify the clinical features and diagnosis of SAVM. These patients consisted of 63 (69 %) males and 28 (31 %) females with a mean age of 49 years (range 11–82 years) at initial symptom onset and 19 patients were younger than 30 years old (Fig. 1). There was a significant difference in the mean age among patients with extradural (42.3 ± 15.0 years), dural (60.0 ± 12.4 years) and intradural (27.0 ± 13.2 years) SAVMs (analysis of variance, $P < 0.001$). Patients with dural AVF had the highest frequency of hypertension (Kruskal-Wallis test, $P = 0.027$). There was no significant difference in sex, history of diabetes mellitus or presence of pain, mass effect or radiculopathy among the three groups.

The SAVMs were located at the craniocervical junction or cervical spine in 22 patients and from the thoracic spine to the sacrum in 69 patients (Fig. 2). Of the patients 14 had extradural AVFs or AVMs (15 %) and 55 patients had du-

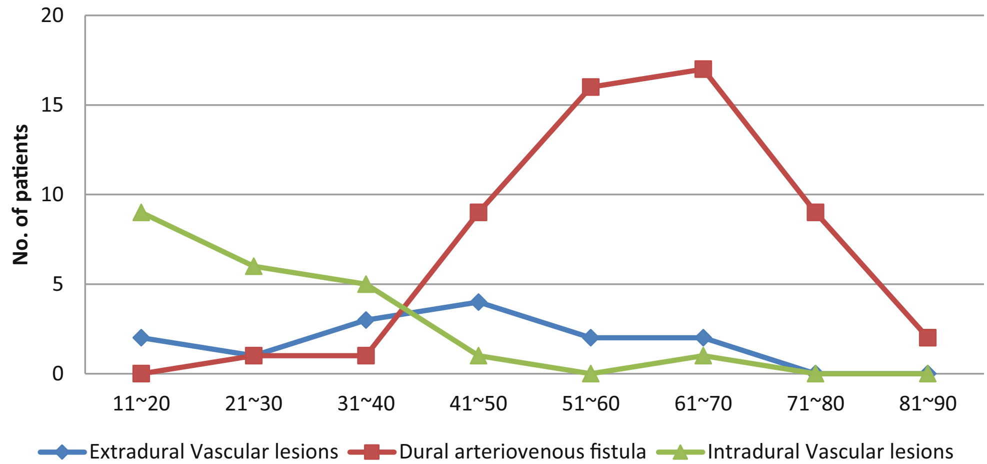

Fig. 1 Age distribution of 91 patients with spinal arteriovenous malformations

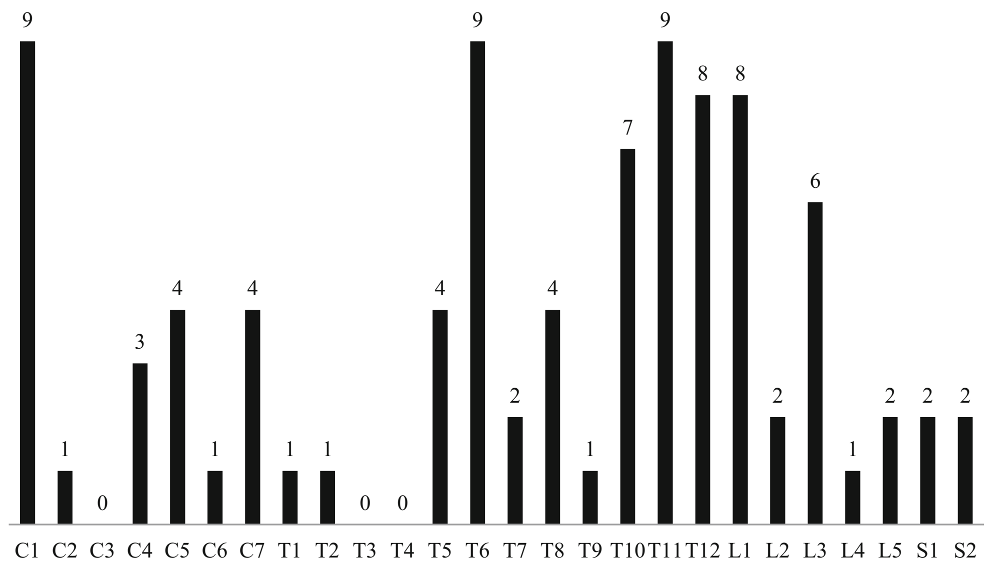

Fig. 2 Distribution and localization of spinal arteriovenous malformations in the 91 patients

ral AVFs (type I, intradural dorsal AVM 60 % Table 2). Of the 22 spinal cord lesions, 11 patients had AVMs, 7 patients had AVFs and 4 patients had metameric (intradural-extradural) AVMs. The seven perimedullary AVFs consisted of four small and three medium sized AVFs and nine AVMs, including five AVFs and four AVMs involved the conus medullaris.

The median interval between symptom onset and date of diagnosis was 5 months (range 1 day to 60 months) in all patients with SAVMs. In most patients, the symptomatic course was slow progression or stepwise worsening; however, 10 (11 %) patients experienced acute or subacute deterioration of neurological symptoms within 7 days. The subtype of lesions presenting with acute or subacute worsening included extradural ($n = 3$), dural ($n = 3$), and intradural ($n = 4$, including 1 metameric) AVMs. Among them, 5 patients presented with hemorrhage (Table 2).

At the time of initial imaging evaluation, myelopathy was the most common finding with main complaints of gait disturbance (69 out of 91, 76 %), sensory disturbances (61/91, 67 %) including pain and bowel or bladder symptoms (51/91, 56 %) and 5 patients presented with subarachnoid hemorrhage. Venous reflux leading to congestive venous myelopathy (58/91) or mass effect leading to cord compression by spinal aneurysm (11/91) was considered as the cause of myelopathy (69/91). At the time of diagnosis 78 patients (86 %) had mRS scores ≥2, 83 patients (91 %) had motor disability and 51 (56 %) had micturition function as measured by the modified ALS.

Treatment Outcome Evaluation

Of the 91 patients with SAVMs 80 received treatment. Among the 11 untreated patients, 8 refused treatment (including 4 with feeders from the anterior spinal artery) and 3 had a very tortuous aortic structure and a direct feeder could not be found. Embolization was the most common initial treatment modality to close the fistula (56/80, 70 %) and 47

Table 2 Clinical presentation in 91 patients with spinal arteriovenous malformations

Variables	Extradural (*n* = 14)	DAVF (*n* = 55)	Intradural vascular lesions (*n* = 22)				
			AVM (*n* = 11)		AVF (*n* = 7)		Metameric (*n* = 4)
			Compact (*n* = 6)	Diffuse (*n* = 5)	Small (*n* = 4)	Medium (*n* = 3)	
Mean age (years)	41 ± 16	60 ± 12	29 ± 5	20 ± 7	31 ± 12	43 ± 19	18 ± 6
No. of men, *n* (%)	8 (57)	42 (76)	6 (100)	3 (60)	1 (25)	1 (33)	2 (50)
Myelopathy, *n* (%)	5 (36)	47 (86)	6 (100)	2 (40)	3 (75)	2 (67)	4 (100)
Radiculopathy, *n* (%)	2 (14)	11 (20)	1 (17)	1 (20)	0	1 (33)	3 (75)
Pain, *n* (%)	11 (79)	33 (60)	5 (83)	2 (40)	3 (75)	3 (100)	4 (100)
Hemorrhage, *n* (%)	0	2 (4)	0	2 (40)	0	0	1 (25)
Initial ALS gait ≥1, *n* (%)	8 (57)	54 (98)	6 (100)	5 (100)	4 (100)	3 (100)	3 (75)
Initial ALS micturition ≥2, *n* (%)	4 (29)	14 (26)	2 (33)	0	2 (50)	1 (33)	1 (25)

DAVF dural arteriovenous fistula, *AVM* arteriovenous malformation, *AVF* arteriovenous fistula, *ALS* Aminoff–Logue scale

Table 3 Clinical outcomes following treatment in 80 patients with SAVMs

Parameter	Extradural vascular lesions (*n* = 12)			Dural vascular lesions (*n* = 50)			Spinal cord vascular lesions (*n* = 18)		
	Before	After	*P*-value*	Before	After	*P*-value*	Before	After	*P*-value*
mRS	2.25	1.08	0.003	3.26	2.04	0.000	2.94	1.5	0.001
ALS-gait	1.83	1	0.014	3.1	2	0.000	2.61	1.5	0.002
ALS-micturition	0.92	0.33	0.059*	1.18	0.64	0.000	0.72	0.44	0.102

mRS modified Rankin scale, *ALS* Aminoff–Logue scale
*Functional scores before and after treatment were compared by Wilcoxon signed rank test

(84 %) of these patients were treated with single embolization; however, 9 patients received repeated embolization amounting to a total of 19 procedures in order to address residual fistulae (partial embolization). A total of 24 patients underwent surgical ligation. Among them 14 (17.5 %) underwent surgical ligation for initial treatment because of failed embolization (10/14) or because the fistula originated from a segmental artery that also supplied the spinal cord (4/14). Among the 80 patients who underwent treatment, endovascular embolization was completed for 10 extradural, 34 dural and 12 intradural lesions and surgical ligation was completed in 2 extradural, 16 dural and 6 intradural lesions. In the 80 patients who underwent treatment, the initial technical outcome was complete in 65 (81 %), partial in 13 (16 %) and no obliteration was seen in 2 (3 %). Of the two patients with no obliteration, one refused further surgical ligation for spinal dural AVF with concomitant feeder and anterior spinal artery origination and the other had a diffuse type of SAVM that could not be treated due to an inaccessible nidus. Comparison between surgical ligation and embolization showed that complete obliteration was achieved in 47 patients out of 56 (84 %) who underwent endovascular embolization and in 18 out of 24 (75 %) who underwent surgical ligation. Furthermore, complete obliteration by any modality was achieved in 12 patients (100 %) with extradural, 43 patients (86 %) with dural and 10 patients (56 %) with intradural lesions. The mean follow-up period was 32.6 months (range 1–192 months) and 4 patients (5 %) had recurrences. Table 3 shows the comparison between preoperative and postoperative functional disability according to the mRS and ALS scores in the 91 patients with SAVMs. At the time of final follow-up, 67 patients (84 %) showed improvement by 1 point or more on the mRS and 69 patients (86 %) showed significant improvement on ALS scores after treatment. Table 4 shows a comparison of complete obliteration rate according to lesion type and treatment method. There was no significant difference in treatment outcome between the different types of treatment in each group.

Discussion

The clinical presentation of SAVM patients in the current study was extremely varied in terms of neurological symptoms, signs and outcomes [3]. The occurrence of SAVMs is rare and sometimes misdiagnosed because of nonspecific clinical symptoms at presentation [13, 19, 20]. Similar to previous reports of spinal vascular lesions, most of the patients in our series showed stepwise, progressive, neurological deterioration [3, 21]. The interval of time until diagnosis in our patients was comparable to that of other series [8, 22]. As with other studies, the majority of patients were men [8, 19, 22]. Our results also showed similar

Table 4 Comparison of complete obliteration rate by lesion type and treatment method in 80 patients with SAVMs

Parameter	Extradural (n = 12)			Dural (n = 50)			Intradural (n = 18)		
	Embo. (%)	Surgery (%)	P-value	Embo. (%)	Surgery (%)	P-value	Embo. (%)	Surgery (%)	P-value
Complete obliteration	100 (10/10)	100 (2/2)	1.00	91.2 (31/34)	75.0 (12/16)	0.19	50 (6/12)	66.7 (4/6)	0.64

Embo embolization
Data in parentheses represent the number of patients who underwent endovascular embolization/surgical ligation

demographics seen in several other large studies; however, our series included relatively young patients and 19 patients were younger than 30 years old (Fig. 1). In general, SAVMs are rare in young people [8, 22].

The SAVMs are most frequently located in the middle or lower thoracic and lumbar spinal regions [23, 24]. The most common symptoms in our series included myelopathy with main complaints of gait disturbance (69/91, 76 %), sensory disturbances (61/91, 67 %), including pain and bowel or bladder symptoms (51/91, 56 %), all of which were comparable with other reports [22, 25, 26]. Our study revealed that pain was the predominant symptom in extradural and extradural-intradural SAVMs, probably due to compression of nerve roots by enlarged, draining veins [27]. Even though pain was a common symptom of patients with SAVMs, the degree or pattern of pain was not evaluated in this study. Because the location and angioarchitecture of conus medullaris SAVMs are unique, both upper and lower motor neuron symptoms can occur [5]. In our series, both pain and gait disturbance were the most common in patients with conus medullaris SAVMs. Since the 1970s, several reports have shown that simply disconnecting the fistula and spinal venous drainage is an effective treatment strategy for most SAVMs [28–32]. With the development of minimally invasive techniques in the last two decades, interventional neuroradiology has become the first choice for treatment of SAVMs as an alternative to surgery [22, 25, 33]. During treatment, many factors are associated with spinal cord injury and restoration, including the spinal level involved, shunt velocity and volume and pattern of abnormal venous drainage [3, 18, 34]. Recently, several studies have discussed both endovascular treatment and surgical ligation treatment strategies [17, 22, 23, 26, 28, 35–40]. Van Dijk et al. reported that n-BCA embolization produced a cure rate of 25 % [38]; however, motor and bladder function ALS scores in their study were significantly improved in 35 patients who had long-term follow-up (both $P < 0.005$). Sherif et al. assessed 26 patients over a 15-year period (embolization 19/26 and surgical ligation 7/26) and showed a cure rate of 92.3 % [39]. After a mean clinical follow-up of 103.4 months in the current study, there was a statistically significant improvement in both mRS and ALS gait scores (both $P < 0.05$). Cho et al. previously classified SAVMs into three types: spinal dural AVFs, perimedullary AVFs and SAVMs [26]. Our results showed that the obliteration rate and favorable clinical outcome according to classification were 94 % and 91 % in spinal dural AVFs, 68 % and 95 % in perimedullary AVFs and 50 % and 58 % in spinal AVMs, respectively. A report by Gemmete et al. included 38 patients of which 29 were treated with an endovascular approach, 5 with an endovascular followed by a surgical approach and 4 with only a surgical approach [22]. In our study, clinical improvement of mRS and ALS gait and micturition scores were statistically significant (both $P < 0.05$); therefore, we provide additional evidence that correct treatment of SAVMs, including either embolization or surgery, results in good clinical outcomes.

In addition to improvement of gait, micturition disturbance after treatment was also improved, especially in spinal dural AVFs. In contrast, Jellema et al. reported improvement of gait disturbances and muscle strength after treatment with reduced disability [35]; however, micturition disturbance tended to remain unchanged. Moreover, Gemmete et al. showed that improvement in motor function after treatment was more likely to occur than improvement in micturition dysfunction [22].

There were several limitations to our study. Firstly, our study only included a single center even though we prospectively collected a relatively large number of patients; therefore, a multicenter registry analysis of this rare vascular disease and long-term follow-up may provide more information. Secondly, pain was not included in our mRS and ALS systems. Differentiating sensory disturbances, such as hyperesthesia, numbness or pain is sometimes subjective and grading of sensory disturbances is not routinely included in the evaluation of patients with SAVMs. Further practical scoring systems, which include pain and sensory changes, need to be developed.

Conclusion

Patients with SAVMs included in the present study showed diverse demographics and clinical features according to lesion location. We found that a multidisciplinary treatment approach that includes endovascular therapy and/or surgical ligation can result in good clinical outcomes. Our subgroup analysis contributes to a better prediction of positive outcomes in patients with SAVMs presenting with myelopathy and justifies the need for early intervention.

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Compliance with Ethical Guidelines

Conflict of Interests Ji E.P., Hae-Won K., Hairi L., Seung C.J., Danbi P., Dae C.S. state that they have no conflict of interests.

Ethical standards All investigations described in this article were carried out in accordance with national law and the Helsinki Declaration of 1975 (in its current revised form). Ethics approval was obtained from the local ethical review committee of Asan Medical Center. All included patients provided written informed consent.

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