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Spinal Extramedullary Arteriovenous Fistulas: A 15-Year Endovascular Treatment Experience in a Tertiary Care Hospital in Thailand

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ABSTRACT

Background: Spinal arteriovenous shunts are rare diseases. Different classifications have been proposed, but the most widely used are those classified by locations. Different locations (i.e., intramedullary and extramedullary) have different treatment outcomes and different posttreatment angiographical results. Our study presents the 15-year endovascular treatment outcomes of patients who had spinal extramedullary arteriovenous fistulas (AVFs) at Ramathibodi Hospital, which is a tertiary care hospital in Thailand.

Methods: A retrospective medical record and imaging review of all patients with spinal extramedullary AVFs, which were confirmed by a diagnostic spinal angiogram in our institute from January 2006 to December 2020, were performed. The angiographic complete obliteration rate in the first session of endovascular treatment, clinical outcomes of the patients, and complications of the procedures for all eligible patients were analyzed.

Results: Sixty-eight eligible patients were included in the study. The most common diagnosis was spinal dural AVF (45.6%). The most common presenting symptoms were weakness, numbness, and bowel–bladder involvement (70.6%, 67.6%, and 57.4%, respectively). Ninety-four percent had spinal cord edema in preoperative magnetic resonance imaging. All patients had pial venous reflux. Sixty-four patients (94.1%) received endovascular treatment as the first option. The complete obliteration rate in the first session of endovascular treatment was 75% and was high in all subgroups except for the perimedullary AVF group. The overall intraoperative complication of endovascular treatment was 9.4%. Follow-up imaging showed no residual AVF in 50 patients (87.7%). Most of the patients (57.4%) had improvement of neurological functions at 3- to 6-month follow-up.

Conclusion: Treatment results of spinal extramedullary AVFs were good in terms of angiographic aspects and clinical outcomes. This may have resulted from the locations of the AVFs, which mostly did not involve the spinal cord arterial supply, with the exception of perimedullary AVFs. Although perimedullary AVF is difficult to treat, it can be cured by careful catherization and embolization.

Minimally Invasive Surgery

Keywords: Spinal arteriovenous shunts, endovascular treatment, angiographic complete obliteration rate

INTRODUCTION

Spinal arteriovenous shunts (AVSs) are rare diseases, and they impact all age groups, from neonates to the elderly.[1] The neurological symptoms include progressive extremity weakness, sensory deficit, bowel or bladder dysfunction, and back or radicular pain. They resemble the other spinal diseases such as spinal cord compression,[2–4] and they therefore can easily be misdiagnosed. Other non-neurological symptoms, such as recurrent epitaxis or mucosal telangiectasia, can also be clinical presentations in hereditary hemorrhagic telangiectasia (HHT), which is an autosomal dominant genetic syndrome associated with perimedullary spinal arteriovenous fistula (AVF).[5] In the past, spinal AVSs were rarely detected and difficult to cure. With the new medical technology developed over the past few decades, such as high-resolution magnetic resonance imaging (MRI), spinal AVSs are easier to detect; however, the gold standard for diagnosis is still spinal angiography.[3,6–8] The treatment options for spinal AVSs are surgical disconnection and endovascular embolization.[1–4,9,10]

Different classifications have been proposed for spinal AVSs, but the most widely used are those that are based on an anatomic relationship with the spinal cord and surrounding spinal structures, and type of the shunts.[2,3,7,9–19] From literature reviews, spinal AVSs that are intramedullary (within the spinal cord tissue) are considered to have a poor neurological outcome, and

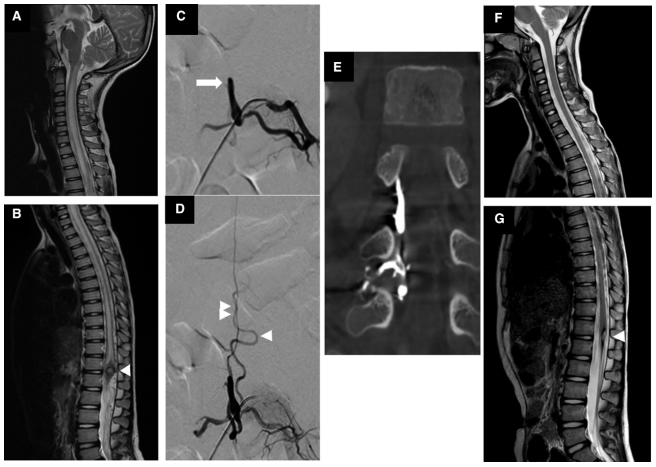

Figure 1. Example of spinal epidural arteriovenous fistula (AVF). (a–b) Pretreatment sagittal T2-weighted magnetic resonance image (MRI) of cervical and thoracolumbar spine shows hyperintense T2 cord signal change from craniocervical junction to conus medullaris with venous pouch at T12/L1 level (white arrowhead). (c) Early epidural venous pouch is fed by left L4 segmental artery (white arrow). (d) Epidural venous pouch drains into 2 radicular veins (white arrowhead). (e) Coronal reformatted image of flat panel computed tomography after transarterial glue embolization shows glue cast in venous pouch, confirming the position of venous pouch is in the epidural space. (f–g) Posttreatment sagittal T2-weighted MRI of cervical and thoracolumbar spine shows resolution of hyperintense T2 change of the spinal cord with hemosiderin deposit at the previously seen venous pouch (white arrowhead).

posttreatment angiographic complete obliteration of them is not common.[20] However, AVSs with extramedullary locations (outside the spinal cord tissue) have a better outcome with possible complete obliteration.

We propose the term "spinal extramedullary AVFs" to define AVFs that are located superficially on the spinal cord, from subpial to paraspinal spaces. These include paraspinal AVFs, epidural AVFs (Figure 1), spinal dural AVFs (Figure 2), perimedullary AVFs (Figure 3), radicular AVFs (Figure 4), and filum terminale AVFs (Figure 5).

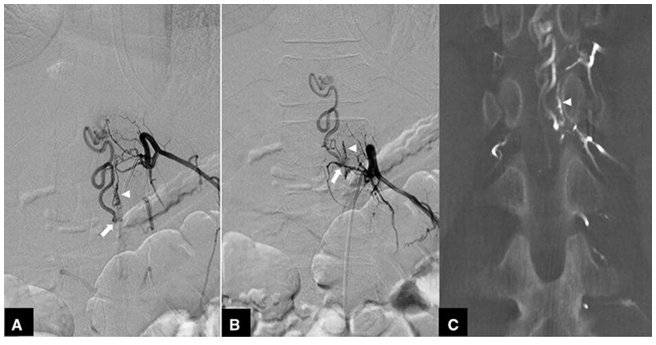

Figure 2. Example of a spinal dural arteriovenous fistula (AVF) at the T12 spinal level that is fed by 2 segmental arteries. (a) Left T11 segmental arterial injection shows the radiculomeningeal artery that runs along the dura (white arrowhead) before opening into the AVF (white arrow). (b) Left T12 segmental arterial injection shows the radiculomeningeal artery feeding the AVF (white arrow). (c) Coronal reformatted view of 3-dimensional rotational angiography before embolization shows the radiculomeningeal artery that runs along the dura.

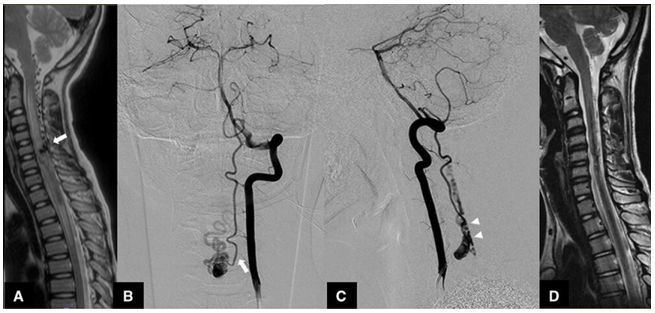

Figure 3. Example of perimedullary arteriovenous fistula (AVF) at the C5 spinal level. (a) Pretreatment sagittal T2-weighted magnetic resonance image (MRI) of the cervical spine shows a hyperintense T2 cord signal change from the craniocervical junction to the T4 level with a venous pouch at the C5 level (white arrow). (b) Anterior-posterior view of left vertebral artery injection shows an AVF that is fed by the left lateral spinal artery (white arrow). (c) Lateral view of the left vertebral artery injection shows an AVF draining into the posterior perimedullary vein (white arrowhead). (d) Posttreatment sagittal T2-weighted MRI of the cervical spine shows resolution of the hyperintense T2 cord signal change with hemosiderin deposition along the spinal cord at C2 to the T4 levels.

This study presents the 15-year endovascular treatment outcomes of all patients who had spinal extramedullary AVFs at Ramathibodi Hospital, which is a tertiary care hospital in Thailand.

METHODS

We performed a retrospective medical record and imaging review of all cases of the spinal extramedullary AVFs that were confirmed by a diagnostic spinal angiogram at Ramathibodi Hospital from January 2006 to December 2020. The medical records were reviewed, and patients who met the inclusion and exclusion criteria (Table 1) were included in the study. The MRI/magnetic resonance angiography (MRA) images and spinal angiogram were reviewed by 2 radiologists.

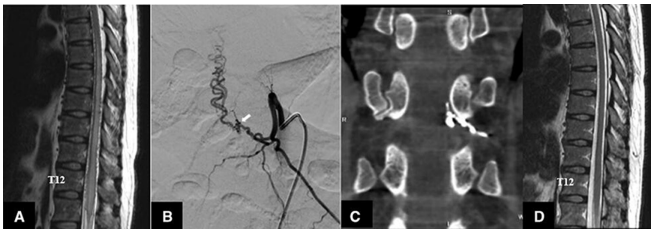

Figure 4. Example of radicular arteriovenous fistula (AVF) at the T11 spinal level. (a) Pretreatment sagittal T2-weighted magnetic resonance image (MRI) of the thoracolumbar spine shows hyperintense T2 cord signal change from T7 to the conus medullaris levels with dilated perimedullary veins. (b) Left T11 segmental arterial injection shows the AVF being fed by the radicular artery (white arrow). (c) Coronal reformatted image of flat panel computed tomography after transarterial glue embolization shows glue cast along the distal segment of left T11 radicular artery and the proximal segment of the radicular vein. (d) Posttreatment sagittal T2-weighted MRI of the thoracolumbar spine shows complete resolution of the hyperintense T2 cord signal change without visualization of the dilated perimedullar veins.

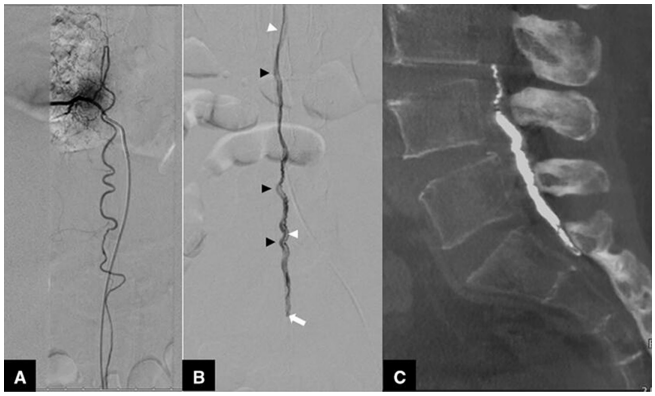

Figure 5. Example of filum terminale arteriovenous fistula (AVF). (a) Right T9 segmental arterial injection shows the radiculomedullary artery and contributing anterior spinal artery, which runs downward to the conus medullaris. (b) Filum terminale artery (white arrowhead) that is a caudal continuation of the anterior spinal artery feeding the AVF (white arrow), and the filum terminale vein runs upward along the filum terminale (black arrowhead). (c) Sagittal reformatted image of flat panel computed tomography after transarterial glue embolization shows glue cast in the filum terminale vein.

Data Collection

Patient demographic data, presenting symptoms, and clinical outcomes at 3–6 months follow-up were reviewed.

The preoperative MRI/MRA images and spinal angiogram were analyzed by 2 reviewers to reach a consensus about the presence of spinal cord edema; the presence of intramedullary or extramedullary hemorrhage; the location of AVFs; the number of AVFs; the number of arterial feeders; whether the AVF arterial feeder and spinal cord arterial supply originated from the same segmental level or not; the presence of pial venous reflux or venous pouch; the fistular characteristics and treatment outcome on immediate post-embolization control angiogram. The number of sessions and complications of endovascular treatment were also reviewed.

Data about surgical interventions were reviewed to see whether they were used as the main treatment due to failed endovascular treatment or in conjunction with endovascular treatment. The clinical outcome and spinal angiogram or MRI/MRA imags at 3–6 months after treatment were reviewed.

Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
• Diagnosis of the paraspinal AVF, spinal epidural AVF, spinal dural AVF, perimedullary AVF, radicular AVF, or filum terminale AVF	• Diagnosis of the intramedullary spinal cord AVM, SAMS, or VVF • Incomplete or absent spinal angiographic imaging

Abbreviations: AVF, arteriovenous fistula; AVM, arteriovenous malformation; SAMS, spinal arteriovenous metameric syndrome; VVF, vertebro-vertebral fistula.

Outcome Measures

The primary outcome was the angiographic complete obliteration rate of the spinal extramedullary AVFs in the first session of endovascular treatment. Angiographic complete obliteration was defined as no visible early venous drainage in the arterial phase of the immediate control spinal angiogram after treatment. The secondary outcomes were clinical outcomes of the patients and complications of the procedures.

Statistical Methods

STATA version 16.1 (StataCorp, Texas, United States) was used for statistical analysis. Categorical data were demonstrated as numbers and percentages. Continuous data were demonstrated as medians and ranges.

RESULTS

From January 2006 to December 2020, 122 patients were diagnosed with spinal AVSs. Forty-seven patients who were diagnosed as having a spinal intramedullary AVS (i.e., AVM or spinal arteriovenous metameric syndrome) and 7 patients who were diagnosed as having vertebro-vertebral fistula (VVF) were excluded.

Sixty-eight eligible patients were included in this study. The most common diagnosis for these spinal extramedullary AVFs was spinal dural AVF (45.6%). The second and third most common diagnoses were perimedullary AVFs and spinal epidural AVFs (25% and 23.5%, respectively).

Two patients in the perimedullary AVF group were diagnosed with HHT, which was confirmed by genetic testing. One patient had no neurological symptoms and had a family history of HHT with evidence of perimedullary AVF on his screening spinal MRIs. However, another patient had neurological deficits, presenting with weakness, sensory loss, and bowel–bladder symptoms.

The average age of these patients with spinal extramedullary AVFs was 57 years, with male predominance, as shown in Table 2. The most common symptoms were weakness and numbness (Table 3), and the most common finding in preoperative MRIs was spinal cord edema. Only 2 patients (2.9%) had hemorrhage. One patient had an intramedullary hemorrhage (hematomyelia) that was found in the perimedullary AVF group, and the other had an extramedullary hemorrhage that was found in the filum terminale AVF group (Table 4).

The most common location of these AVFs was found to be equal between the thoracic (44.1%) and

Table 2. Demographic data.

		Diagnosis				
Demographic	**Total (*N* = 68)**	**Spinal Epidural AVF (*n* = 16)**	**Spinal Dural AVF (*n* = 31)**	**Perimedullary AVF (*n* = 17)**	**Radicular AVF (*n* = 3)**	**Filum Terminale AVF (n = 1)**
Age, y, mean (range)	57 (43, 68)	65.5 (56.5, 73.5)	61 (54, 68)	27 (12, 43)	53 (40, 70)	53
Sex, *n* (%)						
Female	20 (29.4)	4 (25)	6 (19.4)	10 (58.8)	0	0
Male	48 (70.6)	12 (75)	25 (80.6)	7 (41.2)	3 (100)	1 (100)

Abbreviation: AVF, arteriovenous fistula.

lumbosacral (45.6%) regions. Spinal dural AVF was found mostly in the thoracic region (64.5%). Spinal epidural AVF was found mostly in the lumbosacral region (87.5%). Sixty patients (88.2%) had a single AVF. Most of the spinal epidural AVF and spinal dural AVF arterial supplies originated from different segmental arteries that supplied the spinal cord (93.8% and 80.6%, respectively). All 68 patients had pial venous reflux (Table 5).

Sixty-four patients (94.1%) received endovascular treatment as the first option, 3 patients (4.4%) received surgical treatment, and only 1 patient (1.5%) did not receive any treatment. All cases of endovascular treatment used n-Butyl cyanoacrylate (NBCA) as the embolic material. Endovascular treatment failed in 3 out of 64 patients (4.7%). Meanwhile, 1 patient was cured in the second session of endovascular treatment, 1 received no further treatment, and 1 underwent a surgical disconnection procedure but could not be cured. The complete obliteration rate in the first session of endovascular treatment was 75% (48 out of 64 patients) and was high in all subgroups except for the perimedullary AVF group (35.3%). Of the 13 patients (20.3%) with spinal extramedullary AVFs that were not completely obliterated in the first session of endovascular treatment, 4 underwent other sessions of endovascular treatment until they were cured, 2 underwent a surgical disconnection procedure, and 7 received no further treatment (Table 6).

Intraoperative complications of endovascular treatment were found in 6 patients (9.4%), including 3 patients in the spinal dural AVF group and 3 patients in the perimedullary AVF group. The complications included (1) occlusion of radiculopial artery and/or posterior spinal artery (PSA) from glue refluxation (2 patients), (2) occlusion of segmental artery from a blood clot, (3) injury of anterior spinal artery (ASA) while the microcatheter was being pulled out, and (4) dissection of the segmental artery during catheterization (2 patients) (Table 6). Although 2 patients had occlusion of the radiculopial artery, the immediate control angiogram showed complete obliteration of the AVF, and the clinical result showed improvement of the symptoms. Two patients underwent dissection of a segmental artery failed embolization; 1 received no further treatment, but clinical results at 3- to 6-month follow-up did not worsen. The other patient underwent a surgical disconnection procedure, and follow-up imaging at 3–6 months after treatment showed residual AVF. However, clinical results at 3- to 6-month follow-up showed improvement. In one patient in whom the ASA was injured, the immediate control angiogram showed incomplete obliteration of the AVF, and the patient was lost to follow-up. In the last patient, in whom the segmental artery was occluded from a blood clot, an intravenous antiplatelet drug (eptifibatide) was administered. The immediate control angiogram showed reopening of

Table 3. Presenting symptoms.

		Diagnosis				
Presenting Symptom	**Total (*N* = 68)**	**Spinal Epidural AVF (*n* = 16)**	**Spinal Dural AVF (*n* = 31)**	**Perimedullary AVF (*n* = 17)**	**Radicular AVF (*n* = 3)**	**Filum Terminale AVF (*n* = 1)**
Weakness	48 (70.6)	11 (68.8)	23 (74.2)	11 (64.7)	2 (66.7)	1 (100)
Numbness	46 (67.6)	11 (68.8)	20 (64.5)	12 (70.6)	2 (66.7)	1 (100)
Bowel and bladder involvement	39 (57.4)	6 (37.5)	21 (67.7)	11 (64.7)	1 (33.3)	0
Back pain	12 (17.6)	6 (37.5)	4 (12.9)	1 (5.9)	0	1 (100)
Radicular pain	13 (19.1)	5 (31.3)	6 (19.4)	2 (11.8)	0	0
Duration, mo, mean (range)	6 (1, 12)	6 (1, 12)	8.5 (3, 12)	0.75 (0.25, 7)	4 (1, 24)	0.25

Abbreviation: AVF, arteriovenous fistula.
Note: Data presented as *n* (%) unless otherwise specified.

Table 4. Preoperative MRI findings.

MRI Finding	Total (N = 68)	Diagnosis, n (%)				
		Spinal Epidural AVF (n = 16)	Spinal Dural AVF (n = 31)	Perimedullary AVF (n = 17)	Radicular AVF (n = 3)	Filum Terminale AVF (n = 1)
Spinal cord edema	64 (94.1)	15 (93.8)	30 (96.8)	16 (94.1)	2 (66.7)	1 (100)
Hemorrhage	2 (2.9)	0	0	1 (5.9)	0	1 (100)

Abbreviations: AVF, arteriovenous fistula; MRI, magnetic resonance imaging.

the occluded segmental artery and residual slow flow of the AVF. However, follow-up imaging after 3–6 months showed no residual AVF, and clinical results improved.

A surgical disconnection procedure was performed in 6 patient, 3 of whom underwent surgical disconnection as the primary treatment. Two patients underwent this procedure as the secondary treatment after incomplete obliteration by endovascular treatment in the first session, and 1 underwent it from the endovascular treatment failure group. A total of 5 out of 6 patients (83.3%) achieved complete cure. The single uncured patient was in the perimedullary AVF group (Table 6).

MRI/MRA imaging was the most common imaging modality that we used for follow-up after treatment (58.8%). Follow-up MRI/MRA images or spinal angiogram showed no residual AVF in 50 patients (87.7%) (Table 7). Out of 13 patients who had incomplete obliteration in the first session of endovascular treatment, 7did not receive any further treatment. Four of those 7 patients had follow-up imaging at 3–6 months that showed spontaneous complete obliteration of the AVF; 2 showed residual AVF, but there was an improvement of spinal cord congestion; and 1 was lost to follow-up. Clinical results at 3- to 6-month follow-up showed improvement in 38 patients (55.9%), complete recovery in 1 patient (1.5%), stability in 6 patients (8.8%), and worsening in 1 patient (1.5%). There were no follow-up clinical data in 22 patients (32.4%) (Table 7).

DISCUSSION

A great deal of literature exists about the classification of spinal AVS by location.[2,3,7,9,11–19] Most of this literature has reviewed only some common spinal AVSs (e.g., spinal dural AVFs) or rare cases (e.g., filum terminale AVFs). However, there is no literature that exclusively reviews a group of spinal extramedullary AVFs. Some literature has classified perimedullary AVFs into the spinal cord AVM group according to embryology and arterial supply. The difference between these 2 entities is the location of the AVF. Perimedullary AVFs are located superficially on the spinal cord, but spinal cord

Table 5. Characteristics of spinal extramedullary AVFs from spinal angiogram.

AVF Characteristic	Total (N = 68)	Diagnosis, n (%)				
		Spinal Epidural AVF (n = 16)	Spinal Dural AVF (n = 31)	Perimedullary AVF (n = 17)	Radicular AVF (n = 3)	Filum Terminale AVF (n = 1)
Location						
Cervical	7 (10.3)	1 (6.3)	2 (6.5)	4 (23.5)	0	0
Thoracic	30 (44.1)	1 (6.3)	20 (64.5)	7 (41.2)	2 (66.7)	0
Lumbosacral	31 (45.6)	14 (87.5)	9 (29)	6 (35.3)	1 (33.3)	1 (100)
Number of shunts						
Single	60 (88.2)	14 (87.5)	30 (96.8)	12 (70.6)	3 (100)	1 (100)
Multiple	8 (11.8)	2 (12.5)	1 (3.2)	5 (29.4)	0	0
Arterial feeder						
Single	39 (57.4)	10 (62.5)	21 (67.7)	5 (29.4)	3 (100)	0
Multiple	29 (42.6)	6 (37.5)	10 (32.3)	12 (70.6)	0	1 (100)
AVFs and spinal cord supplies						
Different segmental artery	43 (63.2)	15 (93.8)	25 (80.6)	0	3 (100)	0
Same segmental artery	25 (36.8)	1 (6.3)	6 (19.4)	17 (100)	0	1 (100)
Pial venous reflux						
No	0	0	0	0	0	0
Yes	68 (100)	16 (100)	31 (100)	17 (100)	3 (100)	1 (100)
Venous pouch						
No	55 (80.9)	15 (93.8)	31 (100)	5 (29.4)	3 (100)	1 (100)
Yes	13 (19.1)	1 (6.3)	0	12 (70.6)	0	0
Fistula						
Micro	59 (86.8)	16 (100)	31 (100)	8 (47.1)	3 (100)	1 (100)
Macro	9 (13.2)	0	0	9 (52.9)	0	0

Abbreviation: AVF, arteriovenous fistula.

Table 6. Treatment.

		Diagnosis, *n* (%)				
Treatment	**Total (*N* = 68)**	**Spinal Epidural AVF (*n* = 16)**	**Spinal Dural AVF (*n* = 31)**	**Perimedullary AVF (*n* = 17)**	**Radicular AVF (*n* = 3)**	**Filum Terminale AVF (*n* = 1)**
Endovascular, first treatment	64 (94.1)	16 (100)	28 (90.3)	16 (94.1)	3 (100)	1 (100)
Treatment failure	3 (4.7)	0	1 (3.6)	2 (11.8)	0	0
Complete obliteration in first session						
Yes	48 (75)	14 (87.5)	24 (85.7)	6 (35.3)	3 (100)	1 (100)
No	13 (20.3)	2 (12.5)	3 (10.7)	8 (47.1)	0	0
Complication	6 (9.4)	0	3 (10.7)	3 (17.6)	0	0
Surgery, first treatment	3 (4.4)	0	2 (6.5)	1 (5.9)	0	0
Surgery, total treatments	*n* = 6	*n* = 2	*n* = 2	*n* = 2	*n* = 0	*n* = 0
Complete cure (%)	5 (83.3)	2 (100)	2 (100)	1 (50)	0	0
No treatment	1 (1.5)	0	1 (3.2)	0	0	0

Abbreviation: AVF, arteriovenous fistula.

AVMs have intramedullary locations; nevertheless, both types of AVSs are fed by the ASA or PSA.[16,17] We decided to include perimedullary AVFs in the "spinal extramedullary AVF" group according to the superficial location; this is expected to have a better outcome. We decided not to include the VVF in our study because trauma is the most common cause of VVF cases in our institute; this is different from the other diseases in the "spinal extramedullary AVF" group.

Previous studies have shown that the most common spinal AVS is spinal dural AVF,[16,17,19] which was similar to our study. In our study, the mean age at the time of diagnosis, which in most cases was dural AVF, was 57 years; this was similar to previous studies.[21] Younger patients were more often found in the perimedullary AVF group because it had pathophysiology similar to spinal cord AVM. Men were affected more often than women for all groups of spinal extramedullary AVFs, with the exception of the perimedullary AVF group, which had no sex predilection.[22] This correlated with our results.

The most common presenting symptoms were weakness, numbness, and bowel–bladder involvement, which correlated with the previous studies.[3,22] Most of the spinal extramedullary AVF group had subacute to chronic clinical presentation, which was similar to our study.[3]

MRI is frequently the first imaging study used for workup of patients suspected of having spinal AVS. Spinal cord edema, which is the most common preoperative MRI finding, could be explained by the pial venous reflux from the AVS, causing spinal cord congestion.[22] The presence of dilated tubular or serpiginous vascular structures with flow voids had false negatives in about one-third of spinal AVSs.[7] Therefore, our study emphasized MRI findings of spinal cord edema more than flow void structures. Recent advances in MRA have improved the ability to confirm the diagnosis of spinal AVSs and have helped to locate lesions and arterial feeders at a specific spinal level, but spinal angiogram remains the gold standard.[3,8] In our study, the pretreatment MRA findings were not analyzed because we did not routinely perform MRA in the past.

Table 7. Follow-up at 3–6 months.

		Diagnosis, *n* (%)				
Follow-up	**Total**	**Spinal Epidural AVF**	**Spinal Dural AVF**	**Perimedullary AVF**	**Radicular AVF**	**Filum Terminale AVF**
Imaging modality	**(*N* = 68)**	**(*n* = 16)**	**(*n* = 31)**	**(*n* = 17)**	**(*n* = 3)**	**(*n* = 1)**
MRA	40 (58.8)	13 (81.3)	17 (54.8)	9 (52.9)	1 (33.3)	0
Spinal angiogram	17 (25)	2 (12.5)	6 (19.4)	7 (41.2)	1 (33.3)	1 (100)
NA	11 (16.2)	1 (6.3)	8 (25.8)	1 (5.9)	1 (33.3)	0
Imaging result	**(*n* = 57)**	**(*n* = 15)**	**(*n* = 23)**	**(*n* = 16)**	**(*n* = 2)**	**(*n* = 1)**
Cure	50 (87.7)	14 (93.3)	22 (95.7)	11 (68.8)	2 (100)	1 (100)
Improvement	6 (10.5)	1 (6.7)	1 (4.3)	4 (25)	0	0
Stability	1 (1.8)	0	0	1 (6.3)	0	0
Clinical result	**(*n* = 68)**	**(*n* = 16)**	**(*n* = 31)**	**(*n* = 17)**	**(*n* = 3)**	**(*n* = 1)**
Complete recovery	1 (1.5)	0	0	1 (5.9)	0	0
Improvement	38 (55.9)	7 (43.8)	17 (54.8)	12 (70.6)	2 (66.7)	0
Stability	6 (8.8)	3 (18.8)	2 (6.5)	1 (5.9)	0	0
Worsening	1 (1.5)	0	0	0	0	1 (100)
NA	22 (32.4)	6 (37.5)	12 (38.7)	3 (17.6)	1 (33.3)	0

Abbreviations: AVF, arteriovenous fistula; MRA, magnetic resonance angiography; NA, not available.

In many previous studies, the most common hemorrhage in perimedullary AVF was subarachnoid hemorrhage, but it was still rare. Hematomyelia has also been observed, just like in one patient in our study. Patsalides et al explained that it might be caused by rupture of the anterior spinal vein, which is subpial in location.[2] Krings et al found that thoracic microfistulous perimedullary AVFs are revealed mostly by hemorrhages,[16,17] which was the same finding as in our study. Subarachnoid hemorrhage was found in one case of the filum terminale AVF, but our reviewers suggested that the cause of the hemorrhage was coincidental spontaneous ASA dissection. There was no epidural hematoma in our study, which could be found in the spinal epidural AVF.[19]

At our institute, the routine protocol in the workup of the spinal AVSs in the spinal angiogram included (1) identifying the AVSs, (2) ruling out the possible collateral supply from another adjacent segmental artery by injection at the 2 to 3 adjacent segmental arteries above and below the AVS, (3) identifying the level of the artery of Adamkiewicz, and (4) identifying the angioarchitecture that had a higher chance of complications during treatment (i.e., ASA/PSA originating from same segmental level as the AVS supply). The 3-dimensional rotational spinal angiography was not performed routinely.

Compared with previous studies, the most common location of spinal dural AVFs, perimedullary AVFs, and radicular AVFs was at the thoracic level,[16,17,19] but spinal epidural AVFs were located at the lumbosacral level.[19] There is no previous literature illuminating the number of spinal cord and AVF arterial supplies originating from the same segmental artery. This finding needs extra caution during treatment because there is a possibility of ASA/PSA occlusion, leading to spinal cord infarction. Our study showed that most of the spinal dural AVF and spinal epidural AVF arterial supplies originated from different segmental arteries that supplied the spinal cord.

All patients in our study had pial venous reflux, although some showed no spinal cord edema in a preoperative MRI. The pial venous reflux, which was seen in the extradural AVF group (i.e., spinal epidural AVF and spinal dural AVF) could be explained by the AVF having venous reflux through the radicular vein and the perimedullary vein. Keisuke Takai et al categorized spinal extradural AVFs into 2 subtypes: (1) with intradural drainage (78.6%) and (2) without intradural drainage (21.4%).[18]

The intradural venous pouch in our study was defined as a dilated arterialized perimedullary vein, which could cause the mass effect on the spinal cord. It was commonly found in the perimedullary AVF group but could also be found in other spinal extramedullary AVFs if there was a high flow pial venous reflux.[2] The macrofistulas of the spinal AVF, which represented the high flow of the AVF, might lead to formation of a venous pouch. The perimedullary AVF group in our study showed the correlation between macrofistula and venous pouch (52.9% and 70.6%, respectively). However, microfistulas account for the majority of perimedullary AVFs.[17]

Sometimes we could not clearly differentiate the spinal dural AVF from the radicular AVF because the flat panel CT was not performed routinely. However, the principles and techniques of treatment for these 2 lesions are similar, targeting the shunting point without arterial reflux. From the previous studies, filum terminale AVF is rare but not unheard of.[23] Our study showed only one instance of this AVF. A typical finding of all filum terminale AVFs was the parallel feeder-drainer pattern,[23] as found in our study (Figure 5). In one patient with HHT, who presented with symptoms, there were multiple hole macrofistulas in the spinal angiogram, which are not typically found in HHT.[13,16,17]

The higher rates of angiographic obliteration after endovascular treatment are described for spinal dural AVFs[21] as in our study. In fact, several authors preconize embolization as the treatment of choice. However, the results for intradural AVSs (i.e., perimedullary AVFs) are more heterogenous.[3] The lower rates of angiographic complete obliteration in the first session of perimedullary AVF treatment might be caused by (1) the AVF and spinal cord supplies being in the same artery, which makes the treatment more challenging, and (2) most of the perimedullary AVFs having multiple arterial feeders, as shown in our study, which might decrease the rate of angiographic complete obliteration.

The complication rate of the spinal AVS treatment reported in the literature varies between 5% and 25%,[20] but there is no report about complication rates that reviews only the spinal extramedullary AVF group. In light of the complications identified in our study, we make 4 suggestions to reduce the complication rate. First, well-timed catheterizing of the vessel and/or connecting the diagnostic catheter with continuous saline flush would prevent vessel occlusion by blood clot. Second, a routine roadmap should be done to perform safe catheterization of the arterial feeder, which would decrease the chance for vasospasm or dissection. Third, performing proper superselective angiography to carefully check for spinal

cord feeders is highly recommended before NBCA injection, as segmental spinal angiography may not conceal spinal cord feeders. Fourth, NBCA injection should be done in a very short period of time, and only if the microcatheter is wedged, to avoid long unnecessary reflux of NBCA. The reflux of NBCA at microcatheter tip could cause glue migration to a nontargeted artery or arterial injury during the pulling out of the microcatheter.

At our institute, endovascular treatment is considered the first option for a spinal AVS, whether the lesion is in the extramedullary location or not. Some institutes have shown that surgical treatment was superior for treating spinal dural AVFs but was inferior for treating perimedullary AVFs.[4] However, in that series, 6 out of 7 cases of perimedullary AVFs were located on the ventral part of the spinal cord. Therefore, it was a challenge for the surgical treatment to approach and heal the lesions.

The modern treatment of spinal AVSs relies on a multidisciplinary approach. Even in high-volume surgical centers, almost half of spinal AVSs are preoperatively embolized or treated with embolization alone. The use of endovascular techniques to exclude high-risk features or obliterate arterial feeders that are not easily approached by microsurgery alone is of paramount importance. Radiosurgical treatment of spinal AVSs has not been extensively studied and thus is not recommended.[3,10]

In our series, there was no record of the follow-up clinical data for one-third of the patients, which impacted true results of the treatment. However, the available data showed functional improvement for more than half of patients.

Our study had limitations, as it was a retrospective descriptive study. There was selection bias because all patients with spinal AVSs underwent spinal angiography to evaluate the risks of the endovascular treatment before the decision was made about which treatment should be done. Therefore, there was no head-to-head comparison to the other treatment options. The other limitation was the missing clinical data in some cases. Some very old medical records of the patients were destroyed, and some patients were lost to follow-up.

CONCLUSION

Treatment results for spinal extramedullary AVFs were good in terms of angiographic aspects and clinical outcomes. This might have been the result of the AVFs being mostly in locations that did not involve spinal cord arterial supply, with the exception of perimedullary AVFs. Although perimedullary AVF is difficult to treat, it can be cured by careful catherization and embolization.

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