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Comparative analysis of spinal extradural arteriovenous fistulas with or without intradural venous drainage: a systematic literature review

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Object. Spinal arteriovenous malformations (AVMs) are classified into types according to anatomical characteristics: dural arteriovenous fistulas (AVFs), intramedullary AVMs, perimedullary AVFs, and extradural AVFs. Spinal extradural AVFs are much rarer than other types of spinal AVMs, and the available literature on this clinical entity has been based only on case reports or small case series. To investigate the clinical characteristics of patients with spinal extradural AVFs, the authors systematically reviewed the associated literature in the MRI era.

Methods. The PubMed database was searched for all relevant English-language case reports and case series published from 1990 to 2011. The clinical differences between Type A with and Type B without intradural venous drainage were statistically compared, especially regarding clinical features and angiographic and MRI findings.

Results. Forty-five cases of spinal extradural AVFs were found. Type A spinal extradural AVFs were diagnosed in patients with a significantly older age (mean 63.5 years) as compared with Type B AVFs (mean 34.3 years, $p < 0.0001$). Most cases of Type A spinal extradural AVFs exhibited a diffuse high signal intensity of the spinal cord on T2-weighted MR images and no mass effect ($p < 0.0001$), and they commonly occurred in the thoracolumbar and lumbar regions ($p < 0.0001$). On the other hand, cases of Type B lesions exhibited a normal signal intensity of the cord with severe mass effect due to an enlarged extradural venous plexus, and they commonly occurred in the cervical and upper thoracic regions ($p < 0.0001$), frequently in patients with neurofibromatosis Type 1 ($p = 0.049$). Because Type B AVFs consisted of high-flow, multiple complex anastomoses between arteries and the epidural venous plexus, patients with these lesions tended to undergo multisession treatments, and the rate of partial AVF occlusion was significantly higher than for Type A AVFs ($p = 0.018$), although there was no difference in symptom outcomes between the 2 groups.

Conclusions. To the best of the authors' knowledge, a comparative analysis of the clinical differences in patients with extradural AVFs with or without intradural venous drainage has yet to be described in the literature. They concluded that in the diagnosis of spinal extradural AVF, evaluation of intradural venous drainage is important because the cause of myelopathy determines the treatment goals.
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Key Words • **spinal extradural arteriovenous fistula** • **intradural venous drainage** • **congestive myelopathy** • **compressive myelopathy**

Spinal arteriovenous malformations are classified into 4 major types according to anatomical characteristics: dural AVFs, intramedullary AVMs, perimedullary AVFs, and extradural AVFs.[14,18,24,26,28] Patients with dural AVFs generally present with slowly progressive myelopathy, whereas those with intramedullary AVMs or perimedullary AVFs commonly present with intramedullary and/or subarachnoid hemorrhage.[24] In dural AVFs, it is commonly accepted that increased medullary venous pressure by arterial blood reflux into the intradural veins is responsible for the progressive myelopathy;[11] therefore, interrupting these AVFs to block all abnormal pathways into intradural veins is the goal of treatment.[1] In intramedullary AVMs and perimedullary AVFs, hemorrhage may be caused by high-flow lesions; thus, the interruption of perimedullary AVFs, removal of the nidus, and treatment with the CyberKnife system have been reported.[18] Spinal extradural AVFs are defined as an abnormal direct connection between an artery or arteries and the extradural venous plexus within the spinal canal and/or intervertebral foramen. The mechanisms of myelopathy include venous hypertension,[3,4,6,7] mechanical compression,[5] and the vascular steal effect.[2]

Recently, it has been reported that spinal extradural AVFs can be divided into Types A and B according to the presence or absence of intradural venous drainage (Fig. 1).[22] Patients with Type A extradural AVFs generally present with venous congestive myelopathy due to the presence of intradural venous reflux,[7] whereas those with

Abbreviations used in this paper: AVF = arteriovenous fistula; AVM = arteriovenous malformation.

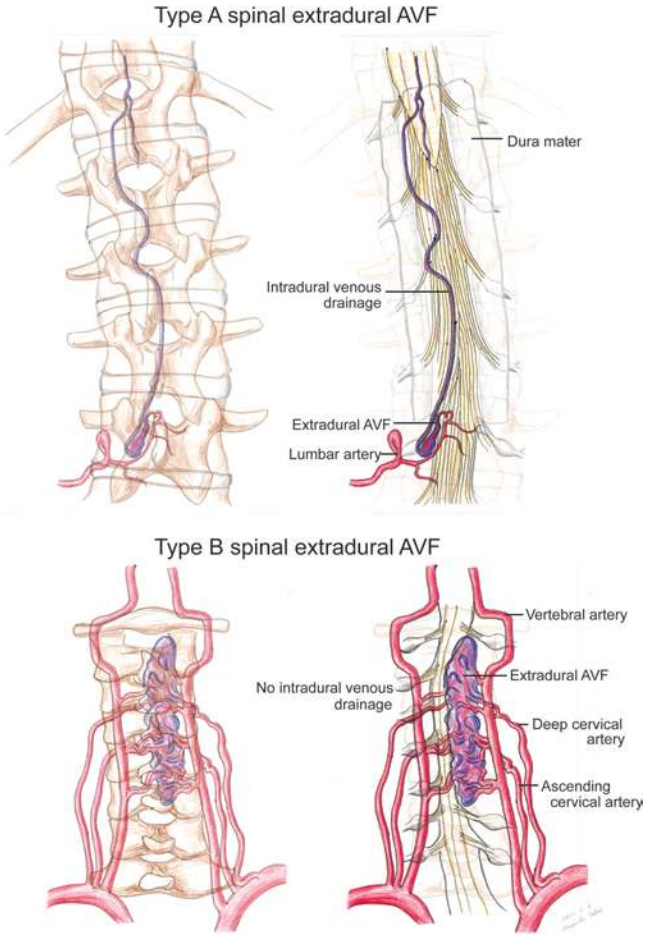

Fig. 1. Illustration showing the 2 different types of spinal extradural AVFs with or without intradural venous drainage. Printed with the permission of Keisuke Takai, 2012.

Type B lesions present with compressive myelopathy or radiculopathy due to compression of the thecal sac or root sleeves by an enlarged extradural venous plexus.

Because spinal extradural AVFs are much rarer than other types of spinal AVMs, the available literature on this clinical entity has been based only on case reports or small case series. The aim of this study was to systematically review these cases and investigate the clinical differences between patients with Type A and Type B spinal extradural AVFs for clinical features, neuroradiological findings, including angiography and MRI, treatment, and outcome.

Methods

To investigate the clinical characteristics of patients with spinal extradural AVFs, we systematically reviewed the associated literature in the MRI era. Two reviewers (K.T. and M.T.) searched the PubMed database for all relevant English-language case reports and case series published from 1990 to 2011 by using text word-based searches with the terms "spinal epidural arteriovenous fistula OR spinal epidural arteriovenous malformation OR spinal extradural arteriovenous fistula OR spinal extradural arteriovenous malformation AND ("1990"[Date - Publication]: "2011"[Date - Publication]) AND English[Language]." Since spinal extradural AVF is defined as a spontaneous abnormal direct connection between an artery or arteries and the extradural venous plexus within the spinal canal and/or intervertebral foramen,[7,14,22,26] case reports and case series on intradural, extraspinal, posttraumatic, and postoperative AVFs were excluded. Moreover, case reports and case series on spinal extradural AVFs with no clear description of angiographic or MRI findings were excluded.

The clinical course of and neuroradiographic images for patients with Type A and Type B spinal extradural AVFs were statistically compared for clinical presentations, angioarchitecture, MRI findings, treatment, and outcome. A Fisher exact test and Mann-Whitney U-test were used as indicated for statistical analysis of the data. The SPSS II for Windows software (SPSS Japan, Inc.) was used for statistical analysis. A p value < 0.05 was considered significant.

Results

Our systematic review revealed 45 cases of spinal extradural AVFs with a clear description of clinical course and neuroradiological findings.[2–10,12,13,15–17,19–23,25,27,29–32] These cases were divided into 2 groups: those with and those without intradural venous drainage, 22 and 23 cases respectively (Tables 1 and 2).

Several dissimilarities in the clinical features and neuroradiographic findings of the 2 groups were evident (Table 3). Type A spinal extradural AVFs with intradural venous drainage were diagnosed in significantly older patients (mean 63.5 years) as compared with Type B lesions (mean age 34.3 years; $p < 0.0001$, Fisher exact test). Most cases (20 [91%] of 22 cases) with Type A lesions exhibited a diffuse high signal intensity of the spinal cord on T2-weighted MR images ($p < 0.0001$, Fisher exact test) and no mass effect (20 [91%] of 22 cases), compared with cases with Type B lesions. Furthermore, most Type A cases (18 [82%] of 22 cases) appeared in the thoracolumbar and lumbar regions ($p < 0.0001$, Mann-Whitney U-test; Fig. 2). On the other hand, most cases (21 [91%] of 23 cases) with Type B spinal extradural AVFs without intradural venous drainage exhibited a normal signal intensity of the cord with severe mass effect due to an enlarged extradural venous plexus; they commonly occurred in the cervical and upper thoracic regions (18 [78%] of 23 cases), frequently in patients with neurofibromatosis Type 1 (5 [22%] of 23 cases; $p = 0.049$, Fisher exact test). Patients with Type B lesions tended to undergo multisession treatments, and the rate of partial AVF occlusion was significantly higher (5 [26%] of 19 cases) than in Type A AVFs ($p = 0.018$, Fisher exact test), although there was no difference in symptom outcomes between the 2 groups.

Discussion

In this study, we described the clinical differences between patients with Type A and Type B spinal epidural AVFs, especially regarding clinical features, neuroradio-

TABLE 1: Summary of clinical characteristics in patients with Type A spinal extradural AVFs with intradural venous drainage*

Authors & Year	Age (yrs), Sex	Presentation	Location of Extradural Veins	Feeders	Intradural Venous Drainage	Diffuse T2 Signal High on MRI	Mass Effect on MRI	Treatment (materials)	Outcome
Rangel-Castilla et al., 2011	80, M	myelopathy	L-5	L-5 LA	+	+	–	microsurgery, embolization (Onyx)	improved
	72, M	myelopathy	L2–3	L-2, L-3 LA	+	+	–	embolization (Onyx)	improved
	53, F	myelopathy	T-12	T-12 SA	+	+	–	embolization (Onyx)	same
	69, M	myelopathy	L1–2	L-1 LA	+	+	–	embolization (Onyx), microsurgery	improved
Clarke et al., 2009	65, M	myelopathy	L3–4	L-3 LA	+	+	–	microsurgery	improved
	70, M	myelopathy	L-4	L-4 LA	+	+	–	microsurgery, embolization (NBCA)	improved
	61, F	calf pain	L-3	L-3 LA	+	+	–	microsurgery	improved
	77, M	myelopathy	L-3	L-3 LA	+	–	–	microsurgery	improved
	53, F	myelopathy	L4–S1	L-4 LA	+	+	–	microsurgery 2 times	improved
	76, M	myelopathy	L4–5	L-4 LA	+	+	–	microsurgery	improved
Kawabori et al., 2009	65, F	radiculopathy	C5–6	C-5, -6 RA	+	–	+	embolization (NBCA)	improved
Silva et al., 2007	60, F	myelopathy	T-12	T-12 SA	+	+	–	embolization (G&L)	same
	68, M	myelopathy	L2–3	L-2, -3 LA	+	+	–	embolization (G&L)	improved
	69, M	myelopathy	T11–L1	T-11 IA, T-12 SA, L-1 LA	+	+	–	embolization (coils)	improved
Reul & Braun, 2007	68, F	myelopathy	L1–2	L-1 LA	+	+	–	embolization (NBCA)	improved
Krings et al., 2006	78, M	myelopathy	L3–4	L-3 LA	+	+	–	microsurgery	improved
Chul Suh et al., 2004	21, F	myelopathy	L1–3	L-1, -2, -3 LA	+	+	–	embolization (coils)	improved
Goyal et al., 1999	73, M	myelopathy	S-1	S-1 LSA	+	+	–	microsurgery	improved
	70, M	myelopathy	T-12	T-12 SA	+	+	–	microsurgery	improved
Pirouzmand et al., 1997	72, M	myelopathy	S-1	S-1 LSA	+	+	–	embolization (NBCA), microsurgery	improved
Cognard et al., 1995	17, F	back pain	T5–L5	L-5 LA	+	+	+	embolization (balloon)	improved
Arnaud et al., 1994	60, M	myelopathy	L2–4	L-3 LA	+	+	–	embolization (histoacryl)	improved

* Total occlusion was achieved after treatment in all cases. Abbreviations: G&L = Glubran and Lipiodol; IA = intercostal artery; LA = lumbar artery; LSA = lateral sacral artery; NBCA = *N*-butyl 2-cyanoacrylate polymer; RA = radicular artery; SA = subcostal artery; + = present; − = absent.

logical findings, treatment, and outcome (Table 3 and Fig. 2). To the best of our knowledge, a comparative analysis of the clinical differences in patients with extradural AVFs with or without intradural venous drainage has yet to be described in the literature. The characteristics of these 2 groups follow.

Type A: Extradural Spinal AVF With Intradural Venous Drainage

Type A extradural AVFs with intradural venous drainage are diagnosed in patients around the 6th decade of life and generally exhibit a diffuse high signal intensity change of the spinal cord on T2-weighted MR images; mass effect is rarely seen.[3,6,7,9,10,13,16,21–23,25] Venous congestion is presumed to be a primary cause of myelopathy in these patients, which is similar to cases of dural AVFs.[1,11] Therefore, these patients should be treated by interrupting the proximal site of intradural venous drainage as it enters the subarachnoid space, as in dural AVFs,[1,11] as well as extradural AVFs, to completely block venous reflux via direct microsurgery or endovascular embolization. These lesions are seen mainly in the thoracolumbar and lumbar regions, which is also similar to dural AVFs. The reason that Type A extradural AVFs are seen mainly in the lower spinal region may be attributable to a rich vascular network between the intradural and extradural venous systems in this region. Because the clinical characteristics of patients with Type A extradural AVFs are very similar to those of patients with dural AVFs in terms of age at diagnosis, location of the AVF, and MRI findings,[1,11,14,26] a relevant differential diagnosis of these lesions should be carefully made.

Type B: Extradural Spinal AVF Without Intradural Venous Drainage

Type B extradural AVFs without intradural venous drainage are diagnosed in patients around the 3rd decade of life, generally exhibit a normal signal intensity of the spinal cord on MR images, and cause severe mass effect due to an enlarged extradural venous plexus, sug-

TABLE 2: Summary of clinical characteristics in patients with Type B spinal extradural AVFs without intradural venous drainage*

Authors & Year	Age (yrs), Sex	Presentation	Location of Extradural Veins	Feeders	Intradural Venous Drainage	Diffuse T2 High on MRI	Mass Effect on MRI	Treatment (materials)	Occlusion of AVFs	Outcome
Rangel-Castilla et al., 2011	57, M	myelopathy	C2–T1	ACA	–	–	+	embolization (Onyx, coils)	total	improved
	37, M	radiculopathy	L4–5	L-3, -4, -5 LA	–	–	+	embolization (Onyx)	total	improved
	61, F	radiculopathy	L4–5	L-4 LA	–	–	+	embolization (Onyx)	total	improved
Wang et al., 2011	20, F	myelopathy	C3–7	VA, ACA	–	–	+	embolization (Onyx, coils)	total	improved
Kinoshita et al., 2009	23, F	myelopathy	T4–6	T-6	–	–	+	spontaneous regression		
Paolini et al., 2008	26, M	myelopathy, NF1	C1–5	VA, ECA, DCA	–	–	+	embolization (balloon), microsurgery, embolization (coils), microsurgery	total	improved
Marshman et al., 2007	62, M	claudication, NF1	L-3	L-3 LA	–	–	+	microsurgery, embolization (coils)	total	improved
Zhang et al., 2006	18, F	myelopathy	T-5	T-5 IA	–	–	+	microsurgery	total	improved
Tenjin et al., 2005	72, F	myelopathy	C-6	VA	–	–	+	embolization (coils)	total	improved
Chuang et al., 2003	4, F	epidural hematoma, back pain, myelopathy	C6–7	DCA	–	–	+	embolization (NBCA), microsurgery	total	improved
	4, M	back pain	C7–T3	SIA	–	–	+	spontaneous regression		
Alexander et al., 2002	30, M	myelopathy, KT syndrome	T3–5	ACA; T-2, -4, -5, -7 LA	–	–	+	embolization (NBCA), microsurgery	partial	improved
Kāhārā et al., 2002	38, M	neck pain, NF1	C2–4	VA	–	–	+	embolization (coils)	total	improved
Asai et al., 2001	24, M	myelopathy	C5–T2	ACA, DCA	–	+	+	embolization (NBCA), microsurgery	partial	improved
Taylor et al., 2001	41, F	radiculopathy	C1–T1	VA	–	–	+	embolization (coils)	total	improved
	44, F	radiculopathy	C2–7	VA	–	–	+	embolization (coils)	total	improved
Goyal et al., 1999	68, M	myelopathy	cervical	VA, ECA, ACA, DCA	–	–	+	embolization (coils) 2 times	partial	improved
	41, M	back pain, NF1	T8–9	T-8, -9 IA	–	–	+	embolization (coils) 2 times	partial	same
	13, F	back pain	T11–12	T-11 IA, T-12 SA	–	+	+	no treatment		
	17, F	myelopathy	T9–L1	T9–12 IA, L-1 LA	–	–	+	embolization (coils) 2 times	partial	same
Szajner et al., 1999	48, F	cervical instability, KT syndrome	C5–7	ACA, DCA	–	–	+	embolization (NBCA) 2 times	total	improved
Cluzel et al., 1994	25, F	radiculopathy, NF1	C2–T1	VA, ACA, DCA	–	–	+	embolization (balloon)	total	improved
Olivero et al., 1993	16, M	epidural hematoma, back pain, myelopathy	T-5	T-5 IA	–	–	+	microsurgery	total	improved

* ACA = ascending cervical artery; DCA = deep cervical artery; ECA = external carotid artery; KT syndrome = Klippel-Trenaunay syndrome; NF1 = neurofibromatosis Type 1; SIA = supreme intercostal artery; VA = vertebral artery.

TABLE 3: Summary of clinical characteristics in patients with spinal extradural AVFs*

Characteristic	Type A	Type B	p Value
total no. of patients	22	23	
mean age at diagnosis in yrs†	63.5	34.3	<0.0001‡
M/F	15/7	11/12	0.37
epidural hematoma at diagnosis	0	2	0.49
NF1	0	5	0.049‡
intradural venous drainage	22 (100)	0 (0)	<0.0001‡
diffuse high signal on T2WI	20 (91)	2 (9)	<0.0001‡
mass effect on MRI	2 (9)	23 (100)	<0.0001‡
single-session/multisession treatment	18/4	11/9	0.096
total/partial occlusion of AVFs	22/0	15/5	0.018‡
improved/same outcome	20/2	18/2	1.0

* Values represent the number of patients (%). Abbreviation: T2WI = T2-weighted imaging.
† Age range 17–80 years for Type A and 4–72 years for Type B.
‡ Significantly different (Fisher exact test).

gesting compressive myelopathy.[2,4,5,8,10,12,15,17,19,20,22,27,29–32] Therefore, patients with these lesions should be treated with decompression of the spinal cord by shrinking the enlarged extradural venous plexus to reduce mass effect, although no intradural procedure is required. These lesions, which are fed by vertebral, ascending cervical, and deep cervical arteries and exhibit high flow, are seen mainly in the cervical and upper thoracic regions.[4,5,8,10,12,20,22,27,29–31] In some cases, patients with these lesions present with acute epidural hematomas. Because Type B AVFs consist of high-flow, multiple complex anastomoses between these arteries and the epidural venous plexus, these lesions tend to require multisession treatments, including endovascular embolization with some kind of embolic material, direct microsurgical ligation of the lesions, and/or laminectomy.[2,4,5,10,17,20,27]

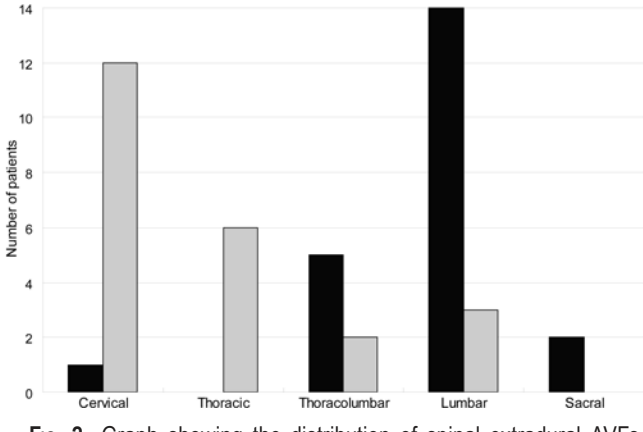

Fig. 2. Graph showing the distribution of spinal extradural AVFs. Thoracolumbar and lumbar lesions were more frequently observed in patients with Type A spinal extradural AVFs *(black bars)*, whereas cervical and upper thoracic lesions were more frequently observed in patients with Type B AVFs (*gray bars,* $p < 0.0001$, Mann-Whitney U-test).

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Takai. Acquisition of data: Takai. Analysis and interpretation of data: Takai. Drafting the article: Takai. Critically revising the article: Taniguchi. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of all authors: Takai. Statistical analysis: Takai. Study supervision: Takai.

References

1. Afshar JK, Doppman JL, Oldfield EH: Surgical interruption of intradural draining vein as curative treatment of spinal dural arteriovenous fistulas. **J Neurosurg 82:**196–200, 1995
2. Alexander MJ, Grossi PM, Spetzler RF, McDougall CG: Extradural thoracic arteriovenous malformation in a patient with Klippel-Trenaunay-Weber syndrome: case report. **Neurosurgery 51:**1275–1279, 2002
3. Arnaud O, Bille F, Pouget J, Serratrice G, Salamon G: Epidural arteriovenous fistula with perimedullary venous drainage: case report. **Neuroradiology 36:**490–491, 1994
4. Asai J, Hayashi T, Fujimoto T, Suzuki R: Exclusively epidural arteriovenous fistula in the cervical spine with spinal cord symptoms: case report. **Neurosurgery 48:**1372–1376, 2001
5. Chuang NA, Shroff MM, Willinsky RA, Drake JM, Dirks PB, Armstrong DC: Slow-flow spinal epidural AVF with venous ectasias: two pediatric case reports. **AJNR Am J Neuroradiol 24:**1901–1905, 2003
6. Chul Suh D, Gon Choi C, Bo Sung K, Kim KK, Chul Rhim S: Spinal osseous epidural arteriovenous fistula with multiple small arterial feeders converging to a round fistular nidus as a target of venous approach. **AJNR Am J Neuroradiol 25:** 69–73, 2004
7. Clarke MJ, Patrick TA, White JB, Cloft HJ, Krauss WE, Lindell EP, et al: Spinal extradural arteriovenous malformations with parenchymal drainage: venous drainage variability and implications in clinical manifestations. **Neurosurg Focus 26(1):**E5, 2009
8. Cluzel P, Pierot L, Leung A, Gaston A, Kieffer E, Chiras J: Vertebral arteriovenous fistulae in neurofibromatosis: report of two cases and review of the literature. **Neuroradiology 36:** 321–325, 1994
9. Cognard C, Semaan H, Bakchine S, Miaux Y, Thibault S, Sola Martinez MT, et al: Paraspinal arteriovenous fistula with perimedullary venous drainage. **AJNR Am J Neuroradiol 16:** 2044–2048, 1995
10. Goyal M, Willinsky R, Montanera W, terBrugge K: Paravertebral arteriovenous malformations with epidural drainage: clinical spectrum, imaging features, and results of treatment. **AJNR Am J Neuroradiol 20:**749–755, 1999
11. Jellema K, Tijssen CC, van Gijn J: Spinal dural arteriovenous fistulas: a congestive myelopathy that initially mimics a peripheral nerve disorder. **Brain 129:**3150–3164, 2006
12. Kāhārā V, Lehto U, Ryymin P, Helén P: Vertebral epidural arteriovenous fistula and radicular pain in neurofibromatosis type I. **Acta Neurochir (Wien) 144:**493–496, 2002
13. Kawabori M, Hida K, Yano S, Asano T, Iwasaki Y: Cervical epidural arteriovenous fistula with radiculopathy mimicking cervical spondylosis. **Neurol Med Chir (Tokyo) 49:**108–113, 2009
14. Kim LJ, Spetzler RF: Classification and surgical management of spinal arteriovenous lesions: arteriovenous fistulae and arteriovenous malformations. **Neurosurgery 59 (5 Suppl 3):** S195–S201, S3–S13, 2006
15. Kinoshita M, Asai A, Komeda S, Yoshimura K, Takeda J,

Uesaka T, et al: Spontaneous regression of a spinal extradural arteriovenous fistula after delivery by cesarean section. **Neurol Med Chir (Tokyo) 49:**313–315, 2009
16. Krings T, Mull M, Bostroem A, Otto J, Hans FJ, Thron A: Spinal epidural arteriovenous fistula with perimedullary drainage. Case report and pathomechanical considerations. **J Neurosurg Spine 5:**353–358, 2006
17. Marshman LA, David KM, Chawda SJ: Lumbar extradural arteriovenous malformation: case report and literature review. **Spine J 7:**374–379, 2007
18. Mourier KL, Gobin YP, George B, Lot G, Merland JJ: Intradural perimedullary arteriovenous fistulae: results of surgical and endovascular treatment in a series of 35 cases. **Neurosurgery 32:**885–891, 1993
19. Olivero WC, Hanigan WC, McCluney KW: Angiographic demonstration of a spinal epidural arteriovenous malformation. Case report. **J Neurosurg 79:**119–120, 1993
20. Paolini S, Colonnese C, Galasso V, Morace R, Tola S, Esposito V, et al: Extradural arteriovenous fistulas involving the vertebral artery in neurofibromatosis Type 1. Case report. **J Neurosurg Spine 8:**181–185, 2008
21. Pirouzmand F, Wallace MC, Willinsky R: Spinal epidural arteriovenous fistula with intramedullary reflux. Case report. **J Neurosurg 87:**633–635, 1997
22. Rangel-Castilla L, Holman PJ, Krishna C, Trask TW, Klucznik RP, Diaz OM: Spinal extradural arteriovenous fistulas: a clinical and radiological description of different types and their novel treatment with Onyx. Clinical article. **J Neurosurg Spine 15:**541–549, 2011
23. Reul J, Braun V: Spinal arteriovenous epidural fistula with acute paraplegia. Diagnosis and neurointerventional emergency treatment. A case report. **Interv Neuroradiol 13:**75–78, 2007
24. Rosenblum B, Oldfield EH, Doppman JL, Di Chiro G: Spinal arteriovenous malformations: a comparison of dural arteriovenous fistulas and intradural AVM's in 81 patients. **J Neurosurg 67:**795–802, 1987
25. Silva N Jr, Januel AC, Tall P, Cognard C: Spinal epidural arteriovenous fistulas associated with progressive myelopathy. Report of four cases. **J Neurosurg Spine 6:**552–558, 2007
26. Spetzler RF, Detwiler PW, Riina HA, Porter RW: Modified classification of spinal cord vascular lesions. **J Neurosurg 96 (2 Suppl):**145–156, 2002
27. Szajner M, Weill A, Piotin M, Moret J: Endovascular treatment of a cervical paraspinal arteriovenous malformation via arterial and venous approaches. **AJNR Am J Neuroradiol 20:** 1097–1099, 1999
28. Takai K, Kin T, Oyama H, Iijima A, Shojima M, Nishido H, et al: The use of 3D computer graphics in the diagnosis and treatment of spinal vascular malformations. Clinical article. **J Neurosurg Spine 15:**654–659, 2011
29. Taylor CG, Husami Y, Colquhoun IR, Byrne JV: Direct cervical vertebro-venous fistula with radiculopathy and MRI changes resolving after successful endovascular embolisation: a report of two cases. **Neuroradiology 43:**1118–1122, 2001
30. Tenjin H, Kimura S, Sugawa N: Coil embolization of vertebrovertebral arteriovenous fistula: a case report. **Surg Neurol 63:** 80–83, 2005
31. Wang Q, Song D, Chen G: Endovascular treatment of high-flow cervical direct vertebro-vertebral arteriovenous fistula with detachable coils and Onyx liquid embolic agent. **Acta Neurochir (Wien) 153:**347–352, 2011
32. Zhang H, He M, Mao B: Thoracic spine extradural arteriovenous fistula: case report and review of the literature. **Surg Neurol 66 (1 Suppl 1):**S18–S24, 2006

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