

3D DCE-MRA in spinal vascular malformations

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Research Article

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Abstract

Purpose: This study was carried out to investigate whether 3.0T dynamic enhanced 3 dimensional magnetic resonance angiography (3D DCE-MRA) could identify spinal cord vascular malformations efficiently.

Material and Methods: 32 suspected cases of spinal vascular disease with MR imaging and clinical symptoms were detected using DCE-MRA. 28 patients were valued through DSA for 3-5 days, and surgical treatment was performed on 24 patients.

Results: DCE-MRA was used to examine all the cases which recognized abnormal vascular lesions clearly, and 28 cases were consistent with DSA or surgical diagnosis. The arterial blood supply was evaluated accurately in 28 cases. The findings were correct in 26 cases.

Conclusion: 3.0T DCE-MRA features high sensitivity and accuracy in detecting and characterizing SVMs, especially SDAVF.

1. Introduction

Spinal vascular malformations (SVMs) occur rarely in clinic, but myeloradiculopathy as their clinical manifestation is usually progressive which results in devastating outcomes when untreated. It can be the best way to observe them using magnetic resonance imaging[1, 2],but routine MRI can't detected the location of feeding arteries and fistulas. In the past, confirmed diagnosis was dependent on digital subtraction angiography (DSA) of spinal cord [3]. However, DSA is invasive, time-consuming and complicated with many complications. Spinal dynamic contrast enhanced MRA (DCE-MRA) is safe and can avoid many complications caused by DSA [4, 5]. Spinal DCE-MRA at 3.0T provides higher spatial and temporal resolutions, which greatly helps to diagnostic SVMs [6–8]. As lesions of SVMs often occur in the long axis of spine, DCE-MRA at 3.0T offers a greater field of view (FOV) than 1.5T MR for detecting and characterizing SVMs. In order to evaluate diagnostic efficacy of 3.0T DCE-MRA in SVMs, we have examined more patients using DCE-MRA with DSA or surgery comparing with previous research[7].

2. Materials And Methods

2.1 Patients

235 patients were examined with spinal DCE-MRA from June 2010 to January 2019, 32 of whom (20 men and 12 women, range from 22 to 81 years old, mean age 48.3 years old) were SVMs with the main clinical symptoms of progressive numbness, weakness and pain of lower limbs. Patients who were suspected of spinal vascular lesions according to clinical symptoms and MRI were examined using MR spinal angiography. 28 cases were diagnosed through DSA technique within 3–5 days and 24 cases were confirmed by surgery within 2 weeks. Informed consent was provided to all patients before examination. This study was approved by the Medical Research Ethics Committee of China Medical University.

2.2 Methods

2.2.1 3D CE-MRA: MRA was equipped with clinical 3.0t MR system m (GE, Signa Advantage HDxt3.0, USA) and 8-channel phased array coils. Gadodiamide (0.5mmol/ml) was injected through the cubital vein with a high-pressure syringe of 20ml at a speed of 3ml/s. Cycle time was recorded through test-bolus technique before detection, and then the 3D rf-fast gradient-echo volume was used at TE/TR,1.3ms/3.6ms. Turning Angle of 20°, matrix size = 448×384, FOV = 35cm, thickness = 0.6mm, bandwidth (BW) = 25Hz were taken as parameters to achieve the acquisition. The initial images were collected on the sagittal plane, while the contrast agent was injected during the scanning period. The scanning time is about 3 minutes.

The images were uploaded to ADW 4.6 workstation. Volume rendering (VR), curved reconstruction (CPR) and thin maximum strength projection (MIP) reconstruction techniques were applied.

2.2.2 DSA was performed according to the conventional method. MRA imaging demonstrated major feeding arteries.

2.2.3 The images were analyzed together by two neuroradiologists with 30 and 10 years of experience in neuroimaging. The results were compared with DSA or surgical results including the type of disease, the extent of the lesion, the blood supply, and the fistula of vascular malformations.

3. Results

Conventional contrast-enhanced MRI was performed on all cases. Perimedullary curved vessels or vascular ball signals were observed by MRI on t2-weighted images. Flexural or bulbar enhancement is demonstrated after enhancement. The results showed that the studies of the three neuroradiologists were consistent (Table 1).

Table 1
Patient clinical information

Patient (no.)	Age(y)/ sex	MRA			DSA				Surgery		
		Disease type	Scope of lesions	Feeding arteries	Fistulas	Disease type	Feeding arteries	Fistulas	Disease type	Feeding arteries	Fistulas
1	49/M	SDAVF	C1-L1	Lt VA	C2	SDAVF	Lt VA	C2			
2	61/M	SDAVF	T4-12	Lt T8	T8	Negative	Negative	Negative			
3	59/M	SDAVF	T5-L1	Lt T11	T11	SDAVF	Lt T11	T11	SDAVF	Lt T11	T11
4	52/M	SDAVF	T2-T9	Lt T4	Lt T4	SDAVF	Lt T4	T4	SDAVF	Lt T4	T4
5	33/F	SDAVF	T7-L2	Lt T11	T12	SDAVF	Lt T11	T12	SDAVF	Lt T11	T12
6	60/M	SDAVF	T11-L2	Lt T11	T11	SDAVF	Rt T11	T11	SDAVF	Rt T11	T11
7	66/F	SDAVF	T2-L1	Lt T6	T6	SDAVF	Lt T6	T6	SDAVF	Lt T6	T6
8	44/M	SDAVF	T6-L3	Rt T8	T8						
9	39/M	SDAVF	C7- T11	Rt T7	T7	SDAVF	Rt T7	T7	SDAVF	Rt T7	T7
10	70/M	SDAVF	T5- T12	Rt T11/T12	T11/T12	SDAVF	Rt T11/T12	T11/12			
11	40/F	SDAVF	T8-L5	Lt T11	T12	SDAVF	Lt T12/L1	T12/L1			
12	22/F	SDAVF	T6-L2	Rt T10	T10				SDAVF	Rt T10	T10
13	52/M	SDAVF	T1-T6	Lt T4	T4	SDAVF	Lt T4	T4	SDAVF	Lt T4	T4
14	43/M	SDAVF	T8-L3	Rt L1	L1	SDAVF	Rt L1	L1	SDAVF	Rt L1	L1
15	68/F	SDAVF	T1- T12	Lt T6	T6	SDAVF	Lt T6	T6	SDAVF	Lt T6	T6
16	73/M	SDAVF	T5-L5	Rt L1	L1	SDAVF	Rt L1	L1			
17	63/M	Negative	T5-L2	Negative	Negative	SDAVF	Rt T11	T11			
18	63/M	SDAVF	T4-L2	Lt T7	T7	SDAVF	Lt T7	T7	SDAVF	Lt T7	T7
19	32/F	PMAVF	T8- T11	Rt T9 /Lt T10	T10	PMAVF	Rt T9	T10	PMAVF	Rt T9	T10
20	81/M	PMAVF	T8-L1	Rt T10	T11				PMAVF	Rt T10	T11
21	47/M	PMAVF	T7-L3	Lt T10	T12	PMAVF	Lt T10	T12			
22	35/M	PMAVF	T3- T10	Lt T6/Lt T7/Lt T8	Negative	PMAVF	Lt T6	T6	PMAVF	Lt T6	T6
23	31/M	PMAVF	T1-6	Right costocervical trunk	T3	PMAVF	Right costocervical trunk	T3			
24	66/F	PMAVF	T8-L4	Lt T12	T12	PMAVF	Lt T12	L1	PMAVF	Lt T12	L1
25	55/M	PMAVF	T2-L1	Rt T5	T3	PMAVF	Rt T5	T3			
26	39/M	PMAVF	T9- T11	Rt T10	Negative						
27	63/M	PMAVF	T6-L3	Negative	T11	Negative	Negative	Negative			
28	52/M	PMAVF	C5-T8	Rt T3	T4	PMAVF	Rt T3	T5			
29	33/M	PMAVF	T10-L4	Lt L1/Lt L2	Negative	PMAVF	Lt L1	L1			
30	25/M	SCAVM	C2-T1	∅ VA	—	SCAVM	∅ VA	—			
32	34/F	SCAVM	C1-C6	∅ VA	—	SCAVM	∅ VA	—			

Note: Lt: Left; Rt: Right; VA: vertebral artery; Blank space means this examination was not performed.

3.1 Disease Type:

18 cases of SDAVF were diagnosed according to DCE-MRA, among which, except 2 cases (DSA negative) and 3 cases (DCA-MRA negative), 16 cases were consistent with DSA or surgical diagnosis. 11 cases were PMAVF, among which 9 cases were consistent with DSA diagnosis, and 1 case was in accord with the operation. The three cases were AVM, and the DSA diagnosis results were the same. In 12 of the 235 patients, arteriovenous abnormalities were found in DCA-MRA, but no supply arteries or fistulas were found.

3.2 Feeding Artery:

SDAVF corresponded with DCA-MRA and DSA in 16 of the 18 cases. The diagnosis of PMAVF was the same in 9 of the 11 cases. Three cases were diagnosed as bilateral vertebral artery by arteriography, DSA and DCA-MRA.

3.3 Fistula Location

Results showed DCA-MRA accurately predicted fistula condition in 16 of 18 cases of SDAVF. Fistula was found in DCA-MRA 11 cases of PMAVF, but 4 cases were inconsistent with DSA.

4. Discussion

The diagnosis of SVMs was made on the basis of an enlarged and tortuous perimedullary vein together with abnormal arteriovenous communication in the spinal canal[7, 9, 10]. For the former, we can use conventional T2 MR imaging for detection, while for the latter, we need angiography (MRA, CTA or DSA) to diagnose. In order to facilitate clinical diagnosis and treatment for SVMs, lesion type was based on the locations of the fistulas such as spinal dural arteriovenous fistulas (SDAVF) (Fig. 1), spinal cord perimedullary arteriovenous fistula (PMAVF) (Fig. 2) and spinal cord arteriovenous malformations (SCAVM). AVF of spinal cord is the most common spinal vascular malformation[11]. In this study, it accounted for 94.1%. SDAVF commonly involve the thoracolumbar spine, and shunt lesions located along a nerve root sleeve within a neural foramen and venous congestion of the spinal cord[12] [13]. The shunt of PMAVF is located in the epidural space and drains into epidural veins[14]. Microsurgery and transarterial embolization are the mainstays of treatment for SVMs, but the associated success rates depend upon the disease type and blood flow status[15]. Stereotactic radiosurgery and fractionated radiotherapy may have the relative safety and effectiveness which can bring significant promise for rare and complex lesions, but the optimal treatment parameters are required[16]. So it is very important to find feeding arteries and fistulas accurately.

DSA is the diagnostic gold standard for SVMs. It can accurately dynamic observe fistula, feeding arteries and draining vein, but it is invasive, high radiation doses, large volumes of iodinated contrast material, complex high technical requirement, and may occur paraplegia and other serious complications. The morbidity of 0.03% and mortality of 0.06% have been reported for patients undergoing diagnostic cerebral angiography[17, 18]. DCA-MRA is sensitive, no radiation exposure, shorter scanning time, convenient operation, can be repeated to operate and be able to observe the change about spinal cord etc advantages. So it can be widely applied to clinical diagnosis. The main advantages of DCA-MRA are good image quality, high temporal resolution, and can get three-phase images(arterial, venous and delay phase)(Fig. 3) to observe small blood vessels and the difference between spinal cord artery and vein.

Noninvasive imaging modalities such as DCA-MRA reliably detect SVMs and may predict the level of their location[6, 8]. In 1995, Bowen described that spinal CE-MRA can provide valuable information for SDAVF, but they were not use the dynamic phase to classification of the vascular malformations[19]. With technical improvements in 3.0TMR, Spinal MRI using 3D sequences (CE-3D fast spoiled gradient echo, Dynamic CE-3D MRA) can provide more information than conventional 2D sequences in the evaluation of spinal[20]. Such as the use of parallel imaging, compressed sensing or other parallel imaging techniques at 3T, DCA-MRA have allowed to get a bigger FOV of scan and greatly accelerate a high temporal and spatial resolution, which can help to better locate feeding arteries and fistula as well as visualization of arterial and venous separation, thus allowing improved classification of vascular malformations. For avoid the side effects of renal fibrosis, the dose of contrast is only need 20ml on 3.0T which less the reported in the literature of 25-45ml on 1.5T MR [4, 21].

DSA examination demands high technology. In case 2 and 15, DCA-MRA showed feeding artery and fistula clearly, while DSA was negative. The reason may be that the pressure of the blood supply artery and the drainage vein resist each other, so that the iodine contrast agent cannot reach the drainage vein of the fistula[22]. Although DSA is the gold standard, but sometime the results were not entirely reliable. Due to iodine contrast agent allergy(Case 12),some patients only underwent DCA-MRA to find the feeding arteries and fistulas before surgery. The diagnosis of DCA-MRA was proved to be correct after operation and follow-up. Case 16 DCA-MRA mistake to predict the localize of fistula. The possible reason maybe the dilated feeding artery has bigger turning angle on the level of T12, leading to the discontinuous DCA-MRA appearance.

It is often difficult to locate the fistula of PMAVF, in our research 4 cases did not inconsistent with DSA. Based on the characteristics of angioarchitecture, PMAVF is the direct communication between root pulp artery and perimedullary vein, the diameter is relatively smaller. For example, the feeding artery of case 1 can be clearly determined, but the fistula needs to be carefully searched. According to the analysis of multiple cases and the comparison of surgical results, gadolinium contrast agent concentration is generally considered to be the location of the fistula(Fig. 2). The reason may be the pressure difference between the supplying artery and the draining vein on both sides of the fistula. In case 6 Fig. 1, DCA-MRA results was consistent with DSA and surgery, the patient's clinical symptoms was not completely alleviated after surgery. DCA-MRA found abnormal vascular still exist after 3 months of surgery, but the blood supply artery was not found. The feeding artery from T10 may be the Adamkiewicz

(AKA) in case 11. We seem to find the level of the fistula about case 20 (Fig. 3) and 21, but did not find the feeding artery by DCA-MRA and DSA also was negative. This case may be classified as PMAVF.

In recent years, there are some new MR sequences for the diagnosis of spinal vascular malformations, such as volumetric T2 MRI[23] and first-pass contrast-enhanced MRA[24], which can improve the sensitivity of finding SVMs or help the accuracy of DCA-MRA scanning. But in our experience, with the guidance of conventional T2 and the support of test bolus technology, the imaging success rate of DCA-MRA is very high, which can resolve the evaluation of SVMs, identifying the location of the feeding artery to guide DSA and assist in treatment planning. The MRA technique used in the study is three-phase MRA technique and 43 seconds for one phase, but it can provide more temporal information for better image post-processing.

5. Conclusion

DCA-MRA at 3.0T is highly sensitive and accurate for the detection and characterization of SVMs, especially for SDAVF. They are reliable, rapid and operability, and may take place of DSA in iodine contrast agent allergy cases.

Declarations

Ethics approval:

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent to participate:

Informed consent was obtained from all individual participants included in the study.

Consent for publication:

Authors are responsible for correctness of the statements provided in the manuscript.

Availability of data and material:

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

All authors declare that all data and materials as well as software application support our published claims and comply with field standards.

Funding:

The authors did not receive support from any organization for the submitted work.

Code availability:

All authors are requested to make sure that all data and materials as well as software application or custom code support their published claims and comply with field standards.

Authors' contributions:

JC collected data, drafted initial analyses, wrote the manuscript. SG supervised the data analysis and reviewed the manuscript. WS was responsible for examination and data collecting. LC conceptualized the study design, wrote, and reviewed the manuscript. All authors read and approved the final manuscript.

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Not applicable

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Table

Table 1 Patient clinical information

Patient (no.)	Age(y)/sex	Disease type	Scope of lesions	MRA Feeding arteries	Fistulas	Disease type	DSA Feeding arteries	Fistulas	Disease type	Surgery Feeding arteries	Fistulas
1	49/M	SDAVF	C1-L1	Lt VA	C2	SDAVF	Lt VA	C2			
2	61/M	SDAVF	T4-L2	Lt T8	T8	Negative	Negative	Negative			
3	59/M	SDAVF	T5-L1	Lt T11	T11	SDAVF	Lt T11	T11	SDAVF	Lt T11	T11
4	52/M	SDAVF	T2-T9	Lt T4	Lt T4	SDAVF	Lt T4	T4	SDAVF	Lt T4	T4
5	33/F	SDAVF	T7-L2	Lt T11	T12	SDAVF	Lt T11	T12	SDAVF	Lt T11	T12
6	60/M	SDAVF	T11-L2	Lt T11	T11	SDAVF	Rt T11	T11	SDAVF	Rt T11	T11
7	66/F	SDAVF	T2-L1	Lt T6	T6	SDAVF	Lt T6	T6	SDAVF	Lt T6	T6
8	44/M	SDAVF	T6-L3	Rt T8	T8						
9	39/M	SDAVF	C7-T11	Rt T7	T7	SDAVF	Rt T7	T7	SDAVF	Rt T7	T7
10	70/M	SDAVF	T5-T12	Rt T11/T12	T11/T12	SDAVF	Rt T11/T12	T11/12			
11	40/F	SDAVF	T8-L5	Lt T11	T12	SDAVF	Lt T12/L1	T12/L1			
12	22/F	SDAVF	T6-L2	Rt T10	T10				SDAVF	Rt T10	T10
13	52/M	SDAVF	T1-T6	Lt T4	T4	SDAVF	Lt T4	T4	SDAVF	Lt T4	T4
14	43/M	SDAVF	T8-L3	Rt L1	L1	SDAVF	Rt L1	L1	SDAVF	Rt L1	L1
15	68/F	SDAVF	T1-T12	Lt T6	T6	SDAVF	Lt T6	T6	SDAVF	Lt T6	T6
16	73/M	SDAVF	T5-L5	Rt L1	L1	SDAVF	Rt L1	L1			
17	63/M	Negative	T5-L2	Negative	Negative	SDAVF	Rt T11	T11			
18	63/M	SDAVF	T4-L2	Lt T7	T7	SDAVF	Lt T7	T7	SDAVF	Lt T7	T7
19	32/F	PMAVF	T8-T11	Rt T9 /Lt T10	T10	PMAVF	Rt T9	T10	PMAVF	Rt T9	T10
20	81/M	PMAVF	T8-L1	Rt T10	T11				PMAVF	Rt T10	T11
21	47/M	PMAVF	T7-L3	Lt T10	T12	PMAVF	Lt T10	T12			
22	35/M	PMAVF	T3-T10	Lt T6/Lt T7/Lt T8	Negative	PMAVF	Lt T6	T6	PMAVF	Lt T6	T6
23	31/M	PMAVF	T1-6	Right costocervical trunk	T3	PMAVF	Right costocervical trunk	T3			
24	66/F	PMAVF	T8-L4	Lt T12	T12	PMAVF	Lt T12	L1	PMAVF	Lt T12	L1
25	55/M	PMAVF	T2-L1	Rt T5	T3	PMAVF	Rt T5	T3			
26	39/M	PMAVF	T9-T11	Rt T10	Negative						
27	63/M	PMAVF	T6-L3	Negative	T11	Negative	Negative	Negative			
28	52/M	PMAVF	C5-T8	Rt T3	T4	PMAVF	Rt T3	T5			
29	33/M	PMAVF	T10-L4	Lt L1/Lt L2	Negative	PMAVF	Lt L1	L1			
30	25/M	SCAVM	C2-T1	□ VA	—	SCAVM	□ VA	—			
32	34/F	SCAVM	C1-C6	□ VA	—	SCAVM	□ VA	—			

Note: Lt: Left; Rt: Right; VA: vertebral artery; Blank space means this examination was not performed.

Figures

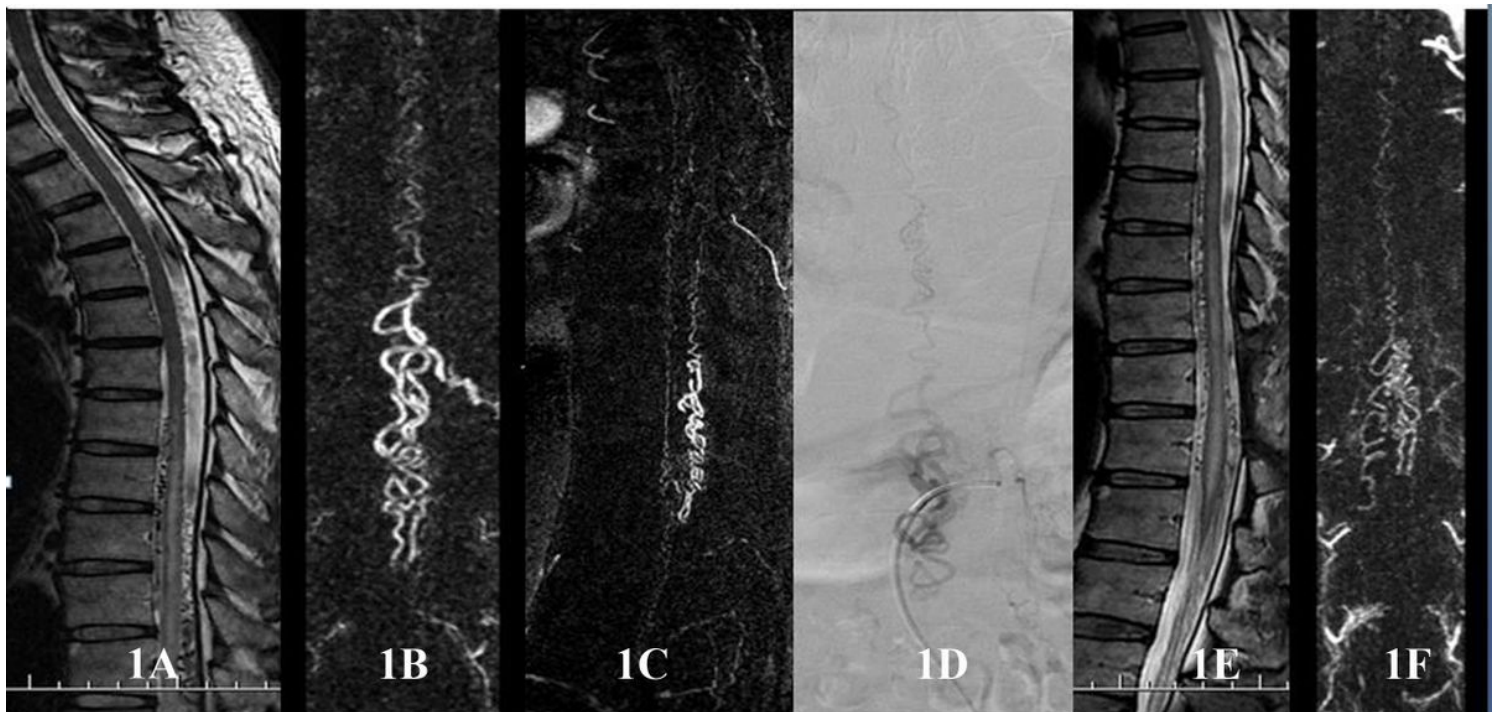


Figure 1

Case 6, a 59-year-old male complained of numbness and weakness of both lower extremities for 5 months and progressively aggravated for 2 months. (1A) MR sagittal T2WI image, (1B) MRA coronal thin MIP reconstruction image clearly showed the range of lesion and the feeding artery, (1C) MRA coronal thin MIP inverse gray image, (1D) DSA image, (1E) MR sagittal T2WI image after surgery, (1F) MRA coronal thin MIP inverse gray image after surgery.

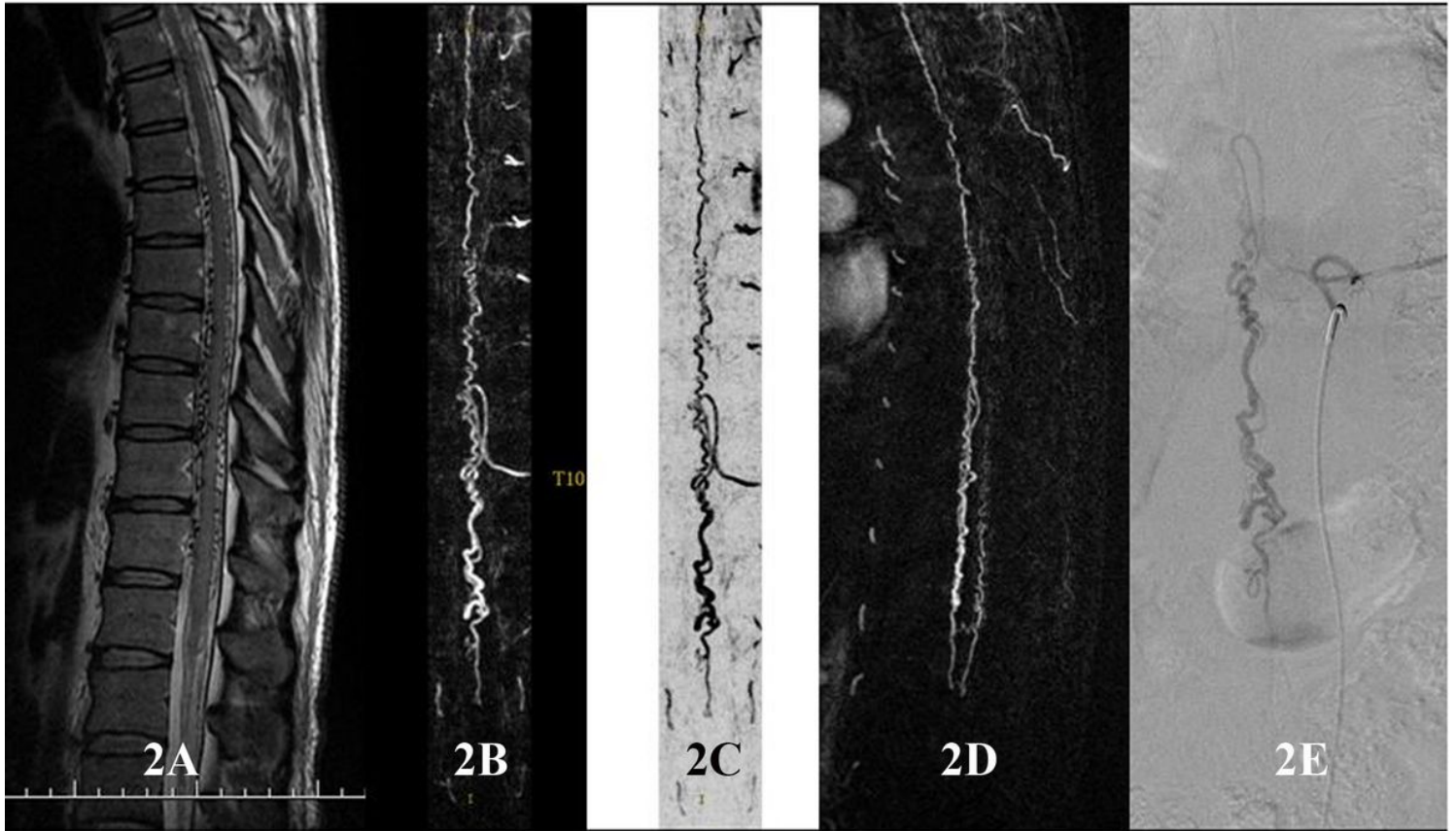


Figure 2

Case 18, a 47-year-old male patient presented with waist pain for 18 months, numbness and weakness of both lower extremities for 12 months and progressively aggravated for 4 months. (2A) MR sagittal T2WI image, (2B) MRA coronal thin MIP reconstruction image clearly showed the range of lesion and the feeding artery, (2C) MRA coronal thin MIP inverse gray image, (2D) MRA sagittal thin MIP, (2E) DSA image.

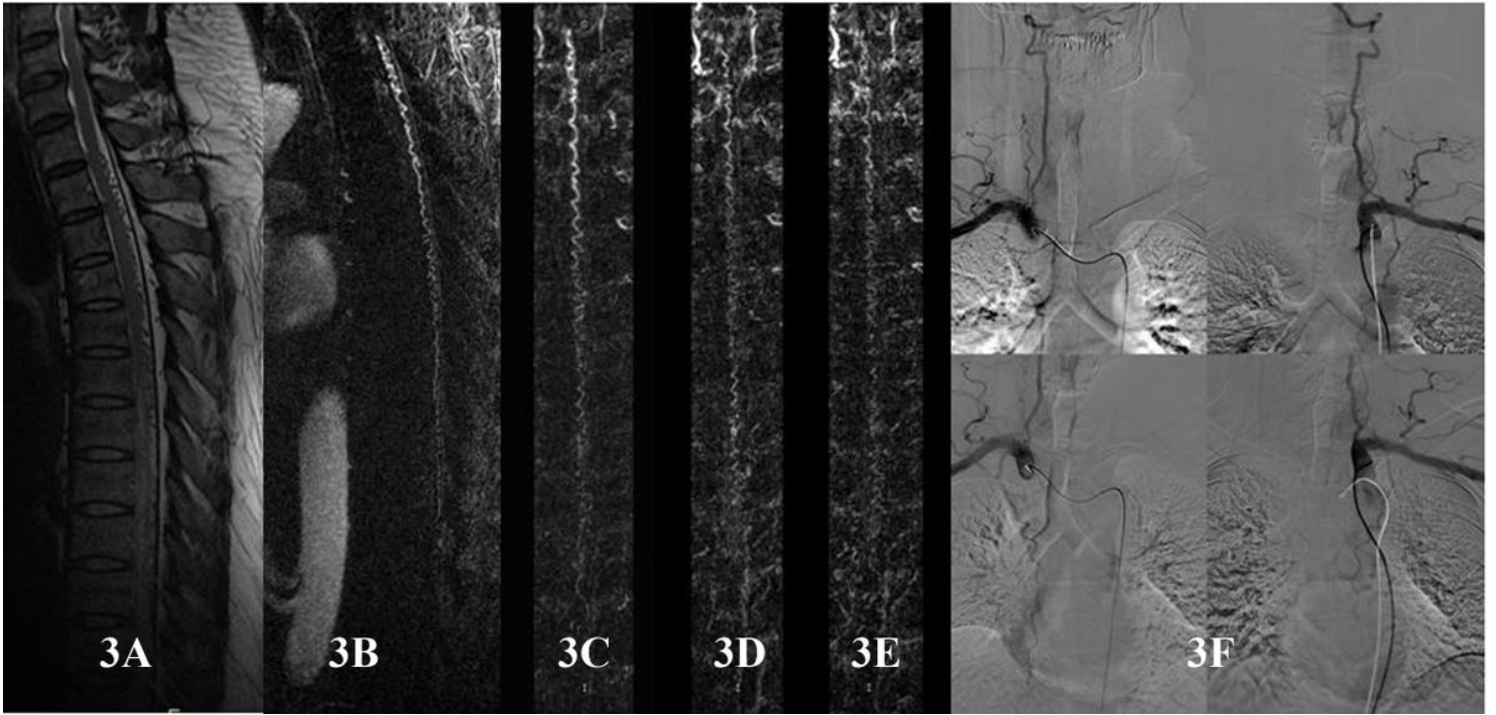


Figure 3

Case 20, a 63-year-old male complained of numbness and weakness of both lower extremities for 7 months. (4A) MR sagittal T2WI image, (4B) MR sagittal contrast T1WI image, (4C)MRA coronal thin MIP reconstruction image only found fistulas , (4D)MRA coronal thin MIP inverse gray image, (4F) MRA sagittal thin MIP in venous phase.