Diagnostic Spinal Angiography

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Abstract

Spinal angiography encompasses both transarterial catheter digital subtraction angiography and, increasingly, magnetic resonance- and computed tomography-based techniques for noninvasive imaging of spinal blood vessels.

Keywords

Spinal catheter angiography • AVF • AVM • Myelopathy

Introduction

- Spinal angiography encompasses both transarterial catheter digital subtraction angiography and, increasingly, magnetic resonance (MR)- and computed tomography (CT)-based techniques for noninvasive imaging of spinal blood vessels.
- We will discuss the clinical indications for spinal vascular imaging.
- Imaging of spinal blood vessels is technically demanding due to their small size, large number, and anatomical complexity.
- We will review the vascular anatomy of the spinal cord and vertebral column and discuss diagnostic spinal angiography (DSA) techniques with an emphasis on minimizing risk and maximizing diagnostic accuracy.
- Specific clinical scenarios require modification of angiographic technique, and these will be elaborated.

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Spinal Vascular Anatomy

Spinal Cord

Arterial

- One anterior spinal artery (ASA) and two posterior arteries (PSA).
  - ASA gives circumferential (coronal) and penetrating (sulco-commissural) branches and supplies much of the central grey matter.
  - PSAs supply posterior and posterolateral cord.
- ASA is formed cranially from branches of each vertebral artery and is also supplied by several segmental branches.
  - Arise from segmental artery and follow the ventral nerve root.
  - In the thoracolumbar spine the supply is dominated by the arteria radicularis magna (Adamkiewicz artery).
- PSAs are formed from branches of the vertebral arteries or PICA vessels and are also supplied by radicular branches of the segmental arteries.
  - More numerous segmental arterial supply, following the dorsal nerve roots
  - Extensive collateralization between sides
- ASA and PSAs anastomose around the conus and through coronal arteries on the surface of the spinal cord.

Venous

- Venous drainage by the perimedullary venous plexus.
- Plexiform but concentrated in posterior and anterior groups and along the lines of the dorsal and ventral root entry zones on each side.
- Perimedullary veins drain via radicular veins to the epidural venous plexus and superiorly to the pontomesencephalic veins around the medulla and brainstem.
- No valves.

Vertebrae and Paravertebral Soft Tissues

- Arterial supply is by segmental vessels with well-developed intersegmental and contralateral anastomosis. Each segmental vessel gives supply to:
  - Vertebral body
    - Proximal occlusion can cause hemivertebral infarction which may be evident with magnetic resonance imaging (MRI).
  - Foraminal branches
    - Supply dura and dural arteriovenous fistula (DAVF) and radicular vessels to spinal arteries.
  - Intercostal arteries
    - Potential anastomosis with internal thoracic and lateral thoracic arteries

– Posterior branches
  - To posterior elements of each vertebra and adjacent erector spinae muscles where collateral vessels crossing the midline may replicate the shape of the Adamkiewicz vessel as they loop up over the spinous process.
- Venous drainage is by a plexus of epidural veins which freely anastomose with a plexus of paravertebral veins. The radicular veins and basivertebral veins drain directly into this plexus.

Indications for Spinal Angiography

Myelopathy

Diagnose/Exclude Spinal Dural Arteriovenous Fistula (sDAVF) (Figs. 1, 2, and 3)

- Increased perimedullary venous pressure with cord venous ischemia.
- Progressive, often stepwise, myelopathic symptoms commonly pain.
- Most frequent in middle age males.
- Coexistent spinal degenerative disease often blamed (diagnostic delay).

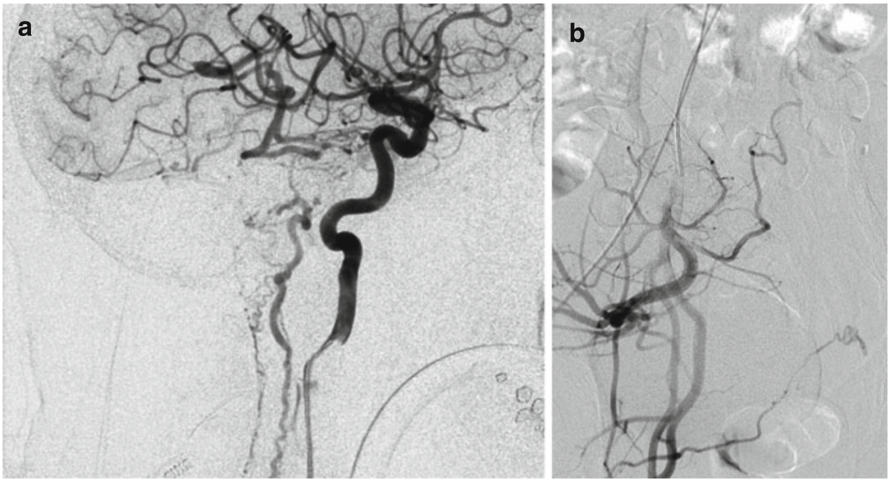

Fig. 1 Two patients presenting with spinal cord symptoms. Myelopathic changes and enlarged perimedullary veins were evident on MRI. Complete spinal angiography must include the intracranial vessels and the pelvic vessels. (**a**) A right petrous apex dural AV fistula has caused venous high flow stenosis, and venous drainage has is now via the ipsilateral basal vein and from there to give retrograde flow in the contralateral basal vein, pontomedullary venous plexus, and finally to the spinal perimedullary veins. (**b**) Patient known to have spina bifida occulta. The lateral sacral artery supplies a DAVF at the spina bifida defect. This was not evident with a pelvic flush aortogram series and was only visualized with a selective internal iliac injection

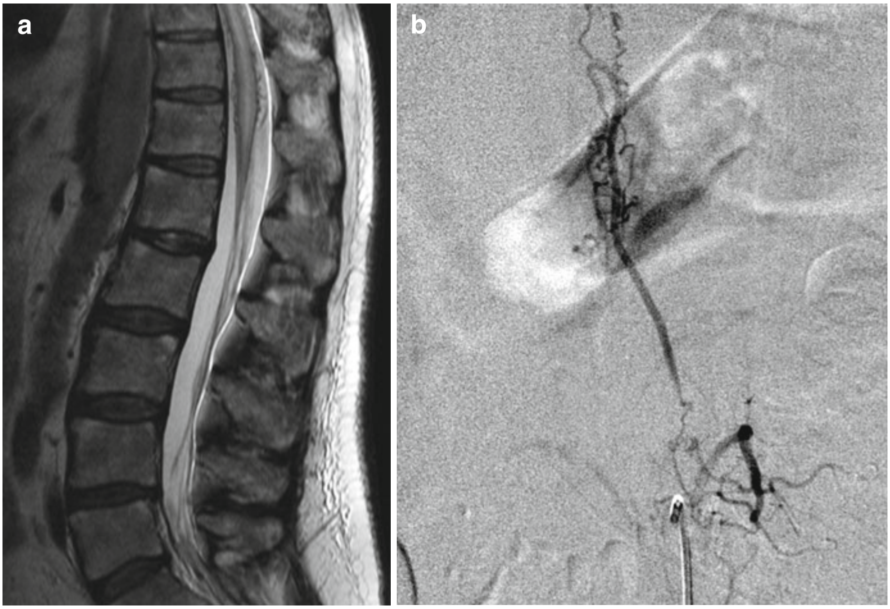

Fig. 2 Typical magnetic resonance imaging (MRI): (**a**) and DSA (**b**) appearances of a spinal DAVF. The combination of cord edema, mild cord swelling, and abnormally enlarged perimedullary veins is strongly indicative of a spinal vascular abnormality. The DSA reveals the arterial supply from a small radicular branch (*), the fistula (+), and the draining vein (x) which follows the nerve root to reach the perimedullary venous plexus

- MRI – usually swollen/edematous (occasionally hemorrhagic) lower cord and conus (irrespective of the fistula site) and prominent vessels in spinal subarachnoid space.
- MRI appearances overlap with other causes of cord swelling, including spinal cord infarction, tumor, and demyelination.

Spontaneous Intraspinal Hemorrhage

- Spontaneous intraspinal hemorrhage is rare in the absence of a coagulation disorder or a history of spinal instrumentation.
- Spinal arteriovenous abnormalities are a recognized cause of spontaneous epidural, subdural, and subarachnoid hemorrhage.
- Spinal angiography should be considered in patients with intracranial subarachnoid hemorrhage where cerebral angiography has been normal, particularly if there is a heavy posterior fossa/foramen magnum blood load.
- Structural (and possibly angiographic) MR imaging is desirable prior to undertaking DSA.

Planning for Surgery/Embolization

- Vascular spinal tumors are surgically challenging to treat, and preoperative embolization reduces operative time and blood transfusion requirement.

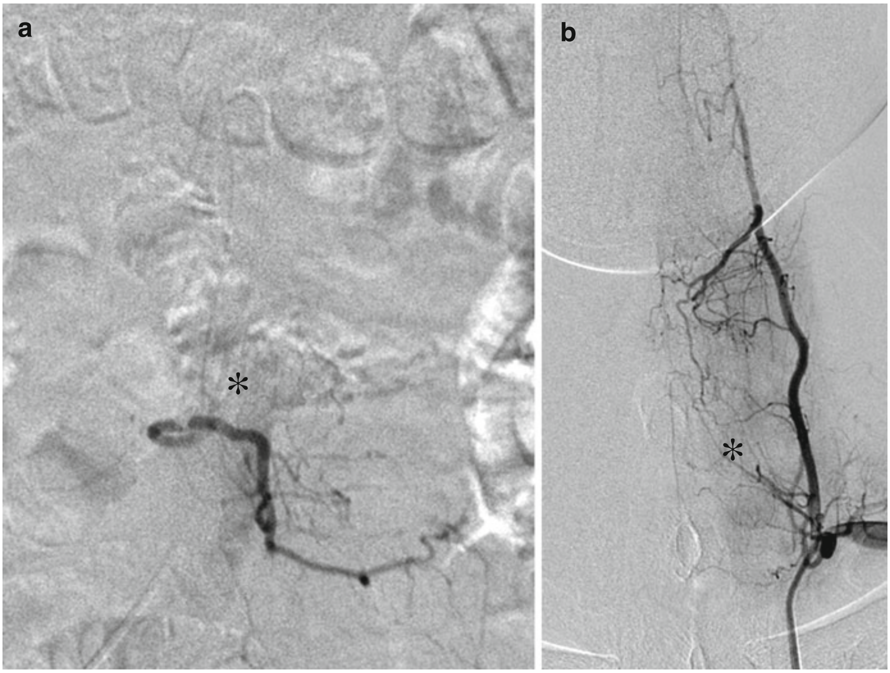

Fig. 3 Care is needed with every injection. (**a**) Patient presented with rapidly progressive paraparesis. MRI suggested cord ischemia but possible abnormal perimedullary vessels also noted. The DSA at T12 on the left revealed a tight stenosis of the radicular vessel and the Adamkiewicz artery (*) taking origin distal to the stenosis. Atheromatous disease is more frequently encountered at the vessel origins, and even careful catheterization may cause vessel occlusion. Avoid excessive catheter and wire manipulation. (**b**) Proximal injection in the left thyrocervical trunk reveals a large radiculomedullary artery (+) taking origin from the origin of the ascending cervical artery. Inadvertent trauma with a guidewire could have disastrous consequences

- Diagnostic angiography is indicated to map the vascular supply to the tumor deposit prior to surgery, and plan preoperative embolization.
- Surgery to the lower thoracic/upper lumbar spine or to the adjacent aorta risks occlusion of the Adamkiewicz vessel. Angiography is indicated to localize the segmental vessel which gives rise to Adamkiewicz.

Diagnostic Spinal Angiography

Cross-Sectional Angiographic Imaging

Spinal vascular lesions fall into the differential diagnosis in a relatively large number of patients where there is evidence of myelopathy and possibly abnormal spinal vascularity on cross-sectional CT/MRI. It may be desirable to establish the exact position of the artery of Adamkiewicz prior to embarking on major spinal or thoracic vascular surgery. Comprehensive spinal DSA is not always appropriate in these circumstances due to the inherent risk of spinal cord ischemia. Safer, but less sensitive, spinal angiography can be obtained with noninvasive cross-sectional techniques.

CT Angiography

- Multi-slice scanners have improved acquisition times, contrast, and spatial resolution.
- Low sensitivity for spinal vascular lesions due to proximity of bony structures.
  - Bone subtraction techniques are improving and may further improve sensitivity.
- Low risk and well tolerated.
- Large radiation dose to cover whole spine.

MR Angiography

- Contrast-enhanced elliptically centered acquisition.
- Low spatial resolution but very good contrast resolution now possible.
  - Moderate sensitivity for spinal vascular lesions.
- Some difficulty studying patients with myelopathy due to involuntary movements.
- Low risk.
- Time resolved studies can now be performed with promising results – may aid localization of level of shunt allowing more targeted catheter angiography.

Cone Beam CT

- Modern angiographic equipment can be used to obtain cross-sectional imaging during aortic contrast injection.
- Very good spatial and contrast resolution (very high arterial contrast concentrations can be achieved with aortic injection).
- Invasive but risk lower than selective angiography and better tolerated.
- Sensitivity in detection of spinal vascular lesions not well established but likely to be significantly better than with CT or MRI.
- Can be used in combination with selective injections to clarify complex vascular anatomy.

Spinal Digital Subtraction Angiography (SDSA)

Techniques

Consent

Fully informed consent

- Statement of the reason for performing the test.
- Statement of expected benefit.
  - Increased diagnostic accuracy
  - Planning for treatment
  - Exclusion of potentially curable diagnosis
- Explanation of the possibility of spinal cord infarction leading to paraplegia and incontinence.
  - Risk is difficult to quantify but is in the order of 1 % – higher in patients with known atheromatous disease or underlying systemic vascular abnormality.
- List the risks related to arterial access, use of contrast agents, and thromboembolic complications, and discuss the need for cerebral angiography with its inherent risk of stroke.
- Provide written information.
- Best practice is to allow time to "cool off" between consent and procedure.
- Consent to be obtained by the operator in person.
- Record details in the patient's files.

Preparation

- Check renal function (eGFR) – potential for large contrast doses.
- Urinary catheter should be considered in all cases as long cases and often preexisting urinary dysfunction.
- Prophylactic intravenous antibiotic therapy recommended prior to catheterization if there is a history of urinary symptoms.
- Consider fasting for 12 h prior for general anesthetic and will reduce bowel gas shadowing.
- Bowel preparation with oral or rectal agents has been advocated to reduce artifact.
- Intravenous cannula should be placed.
- Cardiac and oxygen saturation monitoring is essential.

- General anesthesia (GA) improves image quality.
  - Eliminates involuntary movements in patients with cord pathology.
  - Avoids respiration artifact.
  - Keep anesthetic and monitoring equipment out of the field of view.
  - Explain that repeated respiration holds will be required.
- Local anesthesia can be used.
  - Cooperative patients.
  - Avoid the use of intravenous sedation – patient cooperation is essential.
  - Coach patient about breath holding before you get started.
  - It may be necessary to stage the examination in an awake patient, particularly if vessel selection is difficult.
- Intravenous (IV) hyoscine or IV glucagon may be used to paralyze the bowel and reduce artifact.

Radiography

- This is a high radiation dose study. Take all possible steps to minimize your patient's, your staff's, and your own dose:
  - Single AP plane almost always adequate.
  - Keep collimation relatively tight – also improves image quality.
  - Use pulsed fluoroscopy at a low frame rate.
  - Slow image acquisition (1 frame/s) is acceptable for most vessels.
    - Thoracic and lumbar radicles are small and have slow flow when catheterized.
    - Ensure that it is possible to extend a run to at least 30 s (preferably at 0.5 or 0.33 frames/s) for attempting to image the venous phase when the Adamkiewicz vessel is identified.
  - Appropriate radiation protection.
- Accurate recording of levels is essential.
  - Skin markers/opaque ruler can be used, but be aware that they "move" in respect to the vertebrae due to parallax (worse if placed at the patient's back) and due to respiration phase and patient movement (worse if placed at the front).
  - Markers can overlap vessels if placed too near the midline.
  - Establish vertebral body anatomy and anomalies in numbers of segments from spinal MRI.
  - Find an angiographic "baseline."
    - Identify the superior mesenteric artery or a renal artery and establish its level by correlation with cross-sectional imaging.
    - Use this as a fixed reference point for numbering vertebrae
    - Confirm this by counting up from lumbosacral junction and down from T1.
  - Select a field of view which covers five vertebrae starting at a known level.
  - Avoid any table movement until all vessels in that section of the spine have been studied.

- The catheter tip can then be used as a fixed reference point to move to the next section up or down.
- The vessels are numbered by the segmental level supplied, not by the vertebral body opposite which they arise – *Tip*: the hemivertebral blush tells you which vertebra.
- Ensure that all segmental arteries are studied.

Catheter Selection

This is very subjective, but some general observations hold true:

- Radicles are cranially directed in the thoracic spine but progressively more caudally directed towards the lower lumbar spine. A forward-facing catheter (e.g., cobra shape) works well in the thoracic spine, but a retroflexed (Simmons 2 or 3) catheter shape may be better in the lumbar region. Look at the angulation of the vessel origins as you study each level.
- Good shape retention and torquability are essential: consider 5 F or even 6 F catheters.
- The radicles are small: larger catheters increase the vessel dissection risk. Try to find a catheter with a supportive body but soft, tapered tip. It may be necessary to use a 4 Fr catheter if the radicles are very small. These have poor shape retention and poor tolerance to repeated torque maneuvers so consider a fresh catheter after each few runs.
- It is useful to have pigtail and straight tip catheters available for aortic runs.
- Use a retroflexed catheter to study the internal iliacs and have your preferred cerebral catheters available for studying the intracranial circulation and cervical vessels.

Techniques for Vessel Selection

- Position the catheter in the aorta at the level to be studied.
- Ensure that the tip is not impacted in the vessel wall.
- Rotate clockwise to determine the tip position (tip moves right to left implies that it is pointing forwards and vice versa).
- The right-sided segmental vessels arise from the posteromedial aortic wall on the right. The left-sided vessels generally arise from the posterior wall close to the midline.
- Start "searching" with the catheter tip just below the level of the pedicles.
- When you have selected a vessel, a small increase in forward pressure (or tension if using a retroflexed catheter shape) is helpful to engage in the vessel origin although.
- Care is needed to prevent ostial dissection and reactive vessel spasm
- Inject contrast using an angiographic run: avoid unnecessary contrast administration under fluoroscopy to minimize the dose and to prevent a standing column of contrast in the vessel (the catheter tip often occludes arterial inflow).

Tips

- Each segmental vessel tends to lie in line with its cranial and caudal neighbors, approximately one vertebral body height above or below.
- The contralateral vessel generally arises at the same craniocaudal level as its counterpart.
  - It is common for there to be a small infundibulum from which both segmental vessels arise, and it may be possible to move from right to left without completely disengaging the catheter and merely torquing and re-engaging in the other vessel.
  - Always disengage the catheter tip atraumatically before moving on – pull out a forward-facing catheter and push out a retroflexed one.
  - Start cranially (caudally if a retroflexed catheter is required) and select each vessel on one side in series before moving to the other side.
- If there is a "missing" vessel:
  - Use a straight tip catheter to perform an aortic run.
    - The contrast layers at the back of the aorta fill several segmental vessels in one injection.
    - Compare with cross-sectional angiography if available – aberrant or conjoined vessels are not unusual.
  - Do not rely on aortic injections to exclude DAVF.
    - Always try for a selective injection.

Vessels to Study

For a complete spinal angiogram:

- Subclavian arteries
- Vertebral arteries (catheter tip must be proximally placed)
- Thyrocervical and costocervical trunks
- Each segmental vessel
- Median sacral artery
- Internal iliac vessels
  - Lateral sacral arteries

A comprehensive cerebral angiogram should be included if there is any suggestion of abnormality involving the cervical or posterior fossa structures.

Artery of Adamkiewicz

- T8 to L2 and more often on the left.
- Characteristic hairpin loop configuration.
- Analyze ASA carefully to exclude enlargement or abnormally high flow.
  - May indicate cord arteriovenous malformation (AVM) out with field of view

- Extended run to look for venous phase.
  - Wide craniocaudal field of view.
  - Delayed or absent indicates AVM/AVF draining to perimedullary veins.
  - Early indicates cord AVM with shunting and early venous drainage.
  - Normal phase with no distension of the perimedullary veins indicates that there is venous hypertension, and AVM/AVF is less likely.
- Do not leave the catheter in place after injection.
  - Restricts flow due to proximal vessel occlusion
  - Can cause cord ischemia
  - Alters the normal hemodynamics and will prevent the normal flow of contrast to the perimedullary veins

Found a Vascular Lesion?

- Targeted run AP, LAO, RAO, and lateral if possible.
- Three-dimensional DSA if possible.
- Double check that good quality runs are available for each segmental vessel for two levels above and below.
- Ensure that Adamkiewicz/ASA has been positively identified.
- For cervical lesions it may be possible to study the ASA by using a nondetachable balloon to temporarily occlude the vertebral just distal to the ASA origin and injecting the vertebral proximal to this.
- Analyze the venous drainage to exclude intracranial involvement/venous stenotic disease and venous ectasia – all predispose to subarachnoid hemorrhage.

Complications

- Spinal Cord Infarction
  - Occlusion or embolism in spinal radicular vessel
  - Can cause primary infarct in the arterial territory or “watershed” infarct at the edge of the territory
  - Cord swelling and T2 hyperintensity: can take a day or more to become apparent on MR
  - Diffusion restriction
  - Occasional microhemorrhage
- Other Vessel Injury
  - Segmental vessels
  - Aorta
  - Puncture site
  - Cerebral vessels

- Bleeding Complications at Puncture Site
  - Groin hematoma
  - Pseudoaneurysm
  - Retroperitoneal hemorrhage
- Bacteraemia/Septic Shock
  - Traumatic urinary catheterization in patient with urinary retention/infection
- Contrast or Drug reactions
- Incomplete Study/Poor Technique
  - Missed diagnosis

Key Points

› Spinal angiography is challenging and requires a thorough knowledge of spinal arterial and venous anatomy.
› Spinal vascular pathologies are complex and may be difficult to find and delineate.
› A careful, considered, and systematic approach is key to a successful study.
› An exhaustive examination of all potential vessels supplying the neuroaxis and its linings may be necessary.

Suggested Reading

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