Spinal Angiography and Intervention

8

Spinal Angiography

Indications and Case Selection

- Evaluation prior to biopsy or surgical intervention, e.g., evaluation of tumors suggestive of hypervascularity on MRI.
- Localization of origin of spinal cord arteries prior to transthoracic operative approaches or other extensive spinal instrumentation.
- Diagnosis of suspected vascular malformations or tumors.

Contraindications

- Uncorrected bleeding disorders.
- Thoracic aortic aneurysm (relative).

Preoperative Management

- Verify laboratory values including platelet count, BUN, CR, APTT, PT/INR, and ß-HCG for females of reproductive age group.
- In case of renal insufficiency, diabetes, CHF, etc., ensure usage of diluted non-ionic contrast agent and carefully pre-plan to maintain contrast load to minimum.
- Liquids only on morning of procedure.
- NPO (for ≈6 h) when procedure performed under general anesthesia (GA).
- Obtain informed consent for angiography.
- Ensure two IV lines inserted.
- Insert Foley. Patient will be more comfortable and cooperative with an empty bladder in case the procedure becomes prolonged.

S.H. Khan and A.J. Ringer, *Handbook of Neuroendovascular Techniques*,
DOI 10.1007/978-3-319-52936-3_8

- Position patient on neuroangiography table.
- Attach patient to pulse oximetry and ECG leads for monitoring O_2 saturation, HR, cardiac rhythm respiratory rate, and BP.

Technique

Planning

- A complete spinal angiography would include external carotids, vertebral arteries (VA), thyrocervical trunks, costocervical, and intercostal arteries. Due to previous investigations, e.g., MRI indicating the location of lesion, usually a complete spinal angiography is unnecessary. It may occasionally be needed, e.g., in some cases of dural arteriovenous fistulae (DAVF).
- In case of tumors, plan investigation of 2 spinal levels above and below the expected pathology.
- In case of spinal arteriovenous malformation (AVM) or arteriovenous fistula (AVF), plan investigation of 4 levels above and below expected fistula site.
- Plan your procedure beforehand to minimize the amount of contrast used.
- The arteries that will need to be catheterized is based on the region of the spine being studied, as shown in Table 8.1.
- Remember the artery is being labeled with respect to the vertebral body (VB) at that level. Therefore, an artery labeled T5 may not necessarily be a true T5 since the intercostal arteries are not concordant with the VBs in the thoracic region.

Table 8.1 Arteries to be catheterized

Spinal region	Arteries to be catheterized
Upper cervical region C1–C4	Vertebral arteries Occipital arteries Ascending pharyngeal arteries Thyrocervical (anterior) trunks Costocervical (dorsal) trunks
Midcervical region C5–C7	Vertebral arteries Thyrocervical trunks Costocervical trunks Supreme intercostal arteries Ascending pharyngeal arteries
Upper thoracic region T1–T4	Supreme intercostal arteries Thyrocervical trunks
Thoracic and upper lumbar regions T5–L3	Intercostal/segmental artery of the involved level Intercostal/segmental arteries of two levels above and below the tumor site
Lower lumbar arteries L3–L4	Segmental arteries of two levels above and below the tumor site
Sacrum	Internal iliac arteries lateral sacral arteries (from internal iliac arteries) Median sacral artery (from aortic bifurcation)

- As the spine is a midline structure, the arteries on both right and left sides will need to be catheterized and studied.
- Infrequently, intracranial vessels also have to be studied when suspecting spinal dural arteriovenous malformation (DAVM). As an example, a DAVM of middle meningeal artery draining into a restricted venous compartment may cause distention of anterior and posterior spinal veins. This may cause venous hypertension of the spinal cord and myelopathy.

Procedure

- Fluoroscopy is performed, and the parallax is removed by placing the desired markers and catheter tip in the center of the fluoroscopic field.
- Ensure the VB spinal processes are aligned halfway between the spinal pedicles (on A-plane).
- Radiopaque markers attached to a plastic ruler are taped to the back of the patient after positioning the patient supine on operating table to help demarcate the vertebral bodies.
- It should be positioned to the right of the spine so as not to overlap the spine or the aorta.
- The lettering on the ruler is correlated with the VB, e.g., the letter 'Q' may be at T12 level. The angiography run performed will depict the radiopaque letter, and the artery at this level will therefore be identified as T12 (i.e., by the level) and documented. The reason for doing this is to eliminate any difficulties in identification during interpretation later.
- We use a preprinted table, as shown in Table 8.2, for documentation of reference letter and angiography scene number at each level.
- Prep and drape both femoral regions.
- Gain access to the femoral artery using modified Seldinger technique (see Chap. 2 for details on access).
- Immobilize a segment of the artery between the index and middle fingers.
- Infiltrate the skin overlying the immobilized segment and underlying tissue with local anesthesia using 1% lidocaine with epinephrine.
- Make a small stab incision in the anesthetized skin.
- Immobilize the artery, and with the bevel of single-wall needle leading, puncture the artery at 45° through the previously created stab.
- When blood emanates from the needle hub, stop and advance the provided wire into the needle hub and into the arterial lumen.
- Retract the needle over the wire. Make sure to maintain control of the wire at all times.
- Introduce the pre-assembled 4 Fr sheath with dilator over the wire into the artery.
- Withdraw the wire and dilator leaving the sheath in the artery.
- Cover the hub of the sheath with your thumb to prevent unnecessary blood loss.

Table 8.2 Reference letter and angiography scene number at each level

Letter	Level	Right	Left
	T1	[a]	[a]
	T2		
	T3		
	T4		
	T5		
	T6		
	T7		
	T8		
	T9		
	T10		
	T12		
	L1		
	L2		
	L3		
	L4		
	L5		
	L5 S1		

[a]Document the number assigned to the angiography run here

- Introduce a J wire (60–70 cm) into the sheath until it is in the artery well beyond the sheath.
- Maintaining control of wire at all times, retract and completely withdraw the small sheath over the wire.
- Compress the artery with the same hand which is holding onto the wire to prevent bleeding from the enlarged entrance wound.
- Introduce the 5 Fr or larger sheath over the wire into the arterial lumen.
- Retract and remove the wire when the sheath has been positioned in the artery.
- Connect the hub of the sheath to a RHV which is attached to tubing with three-way stopcock and neonatal transducer to ensure the continuously running heparinized saline solution is at a rate of 30 ml/h. Make a wet connection so that no air bubbles enter the vascular system.
- Secure the sheath by suturing it to the skin using 2–0 silk.
- Prepare a Cobra catheter (AngioDynamics, Queensbury, NY). Other options when having difficulties are indicated shown in Table 8.3.
- We do not connect the diagnostic catheter to a flush system, and perform hand injections for angiography due to the frequency of injections performed. A one-way stopcock may be interposed between the catheter and syringe to prevent excessive blood loss. Meticulous catheter hygiene is maintained to prevent blood clot formation in the catheter, or embolism.
- Introduce the catheter into the sheath and advance over a glidewire.
- Once the diagnostic catheter is in the desired location, e.g., in the descending aorta for studying the thoracolumbar region, remove the guidewire.

Table 8.3 Scenario options

Scenario	Catheter
Standard	Cobra catheter, Mikaelsson
Difficulty catheterizing intercostal arteries in thoracic region	H-1-H
Difficulty catheterizing segmental arteries in lumbar region	HS-1
Difficulty catheterizing because of an ample or capacious aorta	HS-2 Mikaelsson

- Usually, the catheter tip needs to be pointed slightly posteriorly and laterally to enter the ostium of the spinal artery. Advance and retract it rostrally and caudally to find the ostium.
- When the ostium is engaged, inject a small amount of contrast to confirm. Additionally, you will note that the catheter tip ceases its bobbing movement with arterial pulsations, when it is in a vessel origin.
- Perform angiography. We hand-inject the contrast. Do so at a gentle gradually increasing rate.
- The scale with radiopaque markers placed at the side of the patient is used to label each artery.
- Remember, for practical convenience, the intercostal artery is labeled by the vertebral body at the same level.
- For efficiency, once an ostium is found, catheterized, and angiography completed, it is pulled down maintaining the tip's position. It will jump into the ostium of the next (caudal) vessel. The catheter tip may need to be rotated slightly posteriorly for more inferior branches and laterally for more cranial branches. Systematically complete one side in this fashion then address the opposite side. However, if the ostium on the opposite side is unintentionally catheterized, do not relinquish it before performing angiography. The idea is to perform the procedure efficiently in terms of time and contrast used.
- When an intercostal artery at the level of lesion is injected, it will demonstrate the osseous, epidural, and paraspinal extensions of the lesion.

Postoperative Management and Follow-up

- If the procedure was diagnostic only, the patient is monitored for approx 2 h and then discharged if he/she remains asymptomatic.
- Any inexplicable change in neurological examination should lead to thorough investigation including CT head and if indicated repeat angiography.
- Also monitor the access site for pseudo-aneurysm, vessel occlusion, etc.
- The patient should be ambulatory, able to void, and back to pre-procedure status at time of discharge.
- Site of vascular access should be documented, so that in a future study, the contralateral side is used.

- Any unusual aspect encountered during navigation including difficult vasculature and how it was addressed should be documented for future reference.

Spinal Interventional Procedures

Indications and Case Selection

- Embolization of spinal vascular malformations for cure or for preoperative embolization.
- As an adjunct to surgery, e.g., pre-surgical embolization for devascularization of vascular tumors. Such intervention may prove beneficial in benign or malignant (e.g., metastatic renal or thyroid tumors) spinal tumors.
- Benign lesions which may require intervention include hemangiomas, aneurysmal bone cysts, and very rarely osteoblastomas.
- Embolization following an unsuccessful attempted resection because of excessive bleeding.
- Palliation, for example, of inoperable tumors including or relief of symptoms such as pain.
- Incidental asymptomatic lesions should not be treated.

Contraindications

- If anticoagulant and/or antiplatelet therapy is contraindicated (relative).
- Severe vascular tortuosity or anatomy that would preclude the safe introduction or maintenance of a guide catheter, sheath, or interventional devices. This would include the anterior spinal artery (ASA), posterior spinal arteries, or spinal medullary arteries being visualized on pedicle injection, along with vascular supply to the lesion.
- Uncorrected bleeding disorders.

Preoperative Management

- Complete workup including metastatic workup in case of tumor. This includes CT and/or MRI to diagnose primary tumor, as well as, assess the extent of metastases.
- Verify laboratory values including platelet count, BUN, CR, APTT, PT/INR, and ß-HCG for females of reproductive age group.
- In case of renal insufficiency, diabetes, CHF, etc., ensure usage of diluted non-ionic contrast agent and carefully pre-plan to maintain contrast load to minimum.
- Liquids only on morning of procedure.
- NPO (for $\approx$6 h) when procedure performed under GA.

- Obtain informed consent for angiography, and the indicated interventional procedure.
- Ensure two IV lines inserted.
- Insert Foley. Patient will be more comfortable and cooperative with an empty bladder in case the procedure becomes prolonged.
- Position patient on neuroangiography table with lettered markers taped to back.
- Attach patient to pulse oximetry and ECG leads for monitoring O_2 saturation, HR, cardiac rhythm respiratory rate, and BP.

Technique

- We usually perform spinal angiography and intervention under local anesthesia with mild to moderate conscious sedation. The advantage of this is the availability of a neurological examination.
- If GA is elected, then SSEPs should be performed through the procedure.
- Unlike diagnostic spinal angiography, for interventional procedures the catheters are connected to a continuous flush of heparinized saline.
- Perform angiography to ensure the pedicle to be embolized does not concurrently supply the radiculomedullary, or radiculopial arteries. Perform highly selective angiography to determine this, since the tumor blush may obscure the spinal supply on less selective injections. If the pedicle concurrently supplies the cord, then it is not suitable for embolization.
- After selecting the segmental branch supplying the target for embolization, superselective catheterization is achieved with a microcatheter distal to the ostium to avoid reflux into the aorta. The microcatheter selected must be compatible with the embolic agent chosen (see below).

Postoperative Management and Follow-up

- Admit to NSICU for overnight observation.
- 0.9% NS + 20 meq KCl @ 150 cc/h X 2 h.
- Keep right/left leg (whichever side was used for procedure) straight X 2 h, with HOB elevated 15°.
- Check groins, DPs, vitals and neuro checks q 15 min X 4, q 30 min X 4, then q h.
- Advance diet as tolerated.
- Review/resume pre-procedure medications (except oral hypoglycemics, which are resumed 48 h after the procedure and when oral intake has been established).
- D/C next morning after mobilizing (if no complications/other ongoing medical concerns requiring hospitalization).
- F/u on outpatient basis in 4 weeks.
- F/u angiography at 3 months, e.g., if AVF was treated.

Spinal Fistulae

Indications and Case Selection

- Simple DAVF with single draining vein is usually treated surgically. This is because of the low rates of permanent cures and eventual recurrence with proximal feeding artery occlusion with agents such as PVA. With the advent of Onyx, the permanent cure rate may be >60%.
- Another consideration is inadvertent embolization of normal spinal vasculature through connections. During diagnostic procedure, if it is felt that the single fistula can be treated especially with onyx, without imperiling the normal spinal cord supply, then it may be a worthwhile attempt (Fig. 8.1).

Contraindications

- When embolization would also result in interruption of normal spinal arteries.

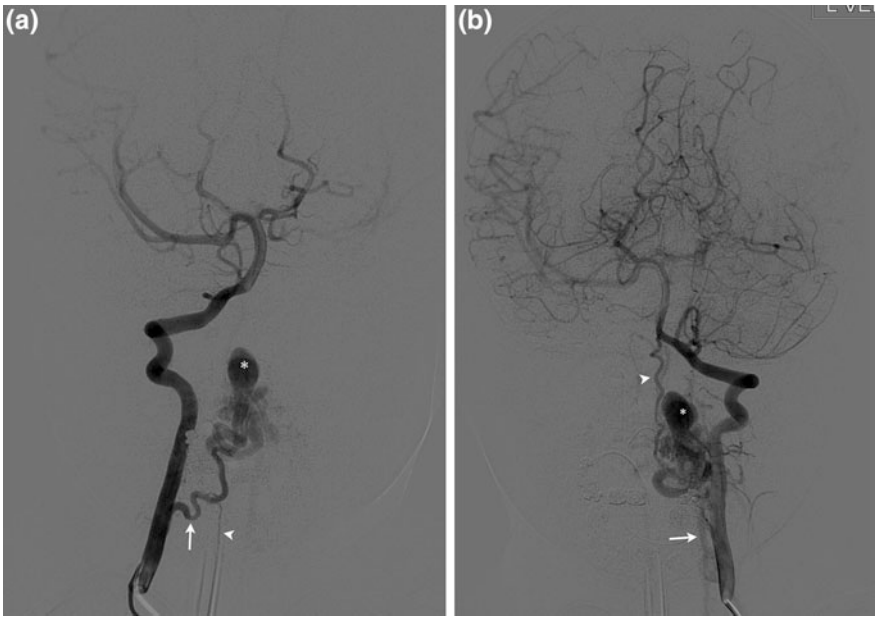

Fig. 8.1 **a** Right vertebral angiography demonstrates a high cervical cord DAVF. One of the main supplying branches (*arrow*) is demonstrated. The anterior spinal artery (*arrowhead*) is also seen with a pedicle supplying it arising from the VA. If the VA is followed rostrally to the basilar artery, it is noted that the posterior circulation is significantly supplying the anterior circulation. Left VA angiography **b** demonstrates additional arterial supply to the AVF from ASA (*arrowhead*). The asterisk (*asterisk*) demarcates a venous pouch or an aneurysmal dilatation. The *arrow* points to venous drainage further caudally

Preoperative Management

- As described above.
- Document patient's preoperative myelopathy and any other neurological deficit.

Technique

- Gain arterial access as indicated above (also see Chap. 2 for details on access).
- Advance Guide catheter over glidewire into the spinal artery pedicle.
- An Envoy catheter, Cobra catheter or any of the catheters indicated above may be used as the guide catheter provided it is of sufficient caliber (ideally, at least 5 Fr).
- Unlike the diagnostic spinal angiogram, in this case the guide catheter is connected to a continuously running flush of heparinized saline.
- Once the guide catheter is securely positioned in the pedicle, prepare a microcatheter (e.g., Marathon®, Micro Therapeutics, Inc., Irvine, CA) and connect it to a continuously running flush of heparinized saline.
- Ensure the system is free of air bubbles or foreign bodies.
- Advance the microcatheter over a microguidewire through the RHV of guide catheter. The microguidewire options include Mirage™ (0.008; ev3, Irvine, CA), Agility® steerable wires (0.010 Codman & Shurtleff, Inc., Raynham, MA), Transend, (0.010, Stryker Neurovascular, Fremont, CA) and Synchro2 (0.010 or 0.014, Stryker Neurovascular, Fremont, CA).
- If the guide catheter is of sufficient caliber (at least 5 Fr, preferably 6 Fr), perform a roadmap before the microcatheter is advanced beyond the distal tip of the guide catheter.
- If the guide catheter is of small caliber or there is considerable difficulty in injecting, then the roadmap should be performed prior to introducing the microcatheter.
- Using roadmap guidance, advance the microcatheter over the microwire to intended location.
- Remove the microwire.
- Perform angiography through the microcatheter to ascertain the normal spinal vasculature is not involved.
- If satisfied with the position of the catheter, embolization can commence.

Embolic Agents

PVA

- Not recommended for treatment of spinal fistula since the occlusion is only temporary and the fistula in all likelihood will recur.

Onyx

- Onyx embolization for endovascular cure of spinal fistula has been reported as far back as 2003.
- It may be more advantageous for this purpose than NBCA because of its higher viscosity. The greater viscosity enables better control in delivering the agent.
- A DMSO compatible microcatheter is required. Use one of the following:

  – Marathon™ (ev3 Neurovascular, Irvine CA)
  – Echelon™ (ev3 Neurovascular, Irvine CA)
  – Rebar™ (ev3 Neurovascular, Irvine CA)
  – Ultraflow™ (ev3 Neurovascular, Irvine CA)

- The following will also be required:

  – Onyx® 18, or Onyx® 34 (consider the latter for cases with brisk blood flow across fistula)
  – Onyx mixer

- Place the selected onyx bottles on the mixer, and set it at 8. The mixing has to be performed for at least 20 min, so it is efficient to initiate it beforehand.
- Once the microcatheter has been positioned as indicated above, then commence as follows.

Procedure

- When ready to perform embolization, perform a blank roadmap, i.e., step upon the pedal as if performing a roadmap, but not actually injecting contrast.
- Ensure the entire microcatheter system is free of blood.
- Draw up the DMSO into the provided yellow colored syringe.
- Disconnect the RHV from the microcatheter and attach a syringe with DMSO to the microcatheter. Make a meniscus-to-meniscus connection. Again, ensure there are no air bubbles or blood in the microcatheter. If needed, fill the hub of microcatheter with saline, to ensure a proper connection.
- Forewarn the patient that he/she may sense a ‘garlic-like taste’ in the back of the throat with DMSO injection. Additionally, during injection and for a day or two thereafter, the patient’s breath and skin may carry the peculiar odor of DMSO.
- Very slowly, inject 0.3–0.8 ml of DMSO (depending on the dead space of the microcatheter), such that the entire catheter is primed with it. Rapid injection of DMSO may also cause pain and discomfort.
- While undertaking the placement of the microcatheter and its priming, Onyx 18 or 34 is prepared concurrently, bearing in mind the following:

  - The numbers 18 or 34 following 'Onyx' are indicative of its viscosity at 40 °C.
  - Onyx solidifies in 5 min after exposure to blood or saline. To prevent this solidification within the microcatheter itself, ensure that the catheter is free of contrast, saline, and blood during Onyx injection.
  - The temperature of Onyx should be between 19–24 °C, when used. If it is frozen because it was stored at a cooler temperature, allow it to thaw at room temperature.

- Place the bottle of onyx on the Onyx mixer and set the mixer at 8. Keep the Onyx bottle on the mixer for at least 20 min. The mixing should continue until you are just ready to inject Onyx. This will cause a thorough mixing of Onyx and tantalum powder, which assists in satisfactory visualization of the deposited onyx.
- Immediately prior to injection, draw up Onyx into the provided white 1-ml syringes. To do so, hold the bottle upright (in contrast to when drawing up other fluids into a syringe, e.g., 1% Lidocaine), using an 18G or 20G needle. If any air is noted in the syringe, invert the bottle such that the bottle is superior and the syringe is below it. Inject the air from the syringe into the bottle. Turn the bottle upright again, so that the syringe is again on top and continue to draw up onyx. Draw a total of 1 ml of air-free onyx into the syringe.
- Detach the yellow DMSO syringe from the hub of the microcatheter.
- Hold the catheter hub vertically and overfill the hub with DMSO.
- Holding the Onyx syringe upright, make a meniscus-to-meniscus connection, ensuring that no air is introduced into the system.
- Maintain the syringe containing onyx in a vertical position. Maintain this position until the onyx passes beyond the hub of the microcatheter. After that, the syringe can be held in a more comfortable position.
- Inject Onyx slowly at a rate of 0.16 ml/min and not to exceed 0.3 ml/min. The injection should be slow and deliberate, using thumb pressure.
- When injecting, track the onyx under live fluoroscopy.
- The goal for embolization in case of spinal fistula is to deposit onyx in the proximal radicular vein.
- If there is reflux of onyx, wait for a couple of minutes to allow the Onyx to solidify. The solid Onyx plug may prevent further reflux. However, the reflux over the microcatheter should be no greater than 1 cm. Otherwise, it may become difficult to extract the catheter and lead to complications.
- When the fistulous connection is occluded, perform angiography to confirm the same.

NBCA

- Indicated for the embolization of brain and spinal cord vascular malformations, this is now used less commonly due to the tendency for rapid solidification resulting in proximal occlusion, but may prove useful in single-pedicle dural AV

fistulae. In our opinion, due to better control on delivery, onyx is the agent of choice if the fistula is to be treated endovascularly.
- The indications for NBCA use in spinal fistulae are the same as for Onyx.

Additional Equipment/Devices

- Trufill kit comprising of NBCA/ethiodol/tantalum (Trufill, Cordis Endovascular).
- For NBCA administration, we recommend a small (1.5–1.8 Fr) flow-directed, non-reinforced catheter, e.g.,

  – Regatta (Cordis, Miami, FL).
  – Spinnaker Elite (Boston Scientific, Fremont, CA).
  – Ultraflow (ev3).
  – (See Chaps. 1 and 2 for additional equipment/devices for vascular access and navigation).

Procedure

- Advance and position the microcatheter, attached to a continuously running flush of heparinized saline, as instructed above.
- Prepare the NBCA mixture on a separate table using clean gloves. This is to prevent any contamination with ionic catalysts.
- Add the vial of tantalum powder to above mixture to enhance its radiopacity.
- For spinal fistula, we recommend a relatively concentrated NBCA preparation, i.e., a 1:1 or 1:2 Ethiodol: NBCA concentration.
- To do so mix 1 cc of NBCA with 1 cc of ethiodol or 2 cc of NBCA with 1 cc of ethiodol in a shot glass.
- Increasing the ratio of ethiodol to NBCA slows the rate of solidification permitting deeper penetration.
- Perform test injections using subtracted fluoroscopic observation (blank roadmap) to assess catheter position and optimal rate of injection.
- Choose the desired ratio of ethiodol/NBCA (typically between 50:50 and 80:20) based on the test injections, drawing the desired volume of each into a 3-ml syringe, mixing continuously until ready for injection.
- Ensure microcatheter lumen is devoid of ionic catalysts by irrigating with 5% dextrose.
- Obtain a blank roadmap; then, commence injecting NBCA slowly, under continuous visualization, over few seconds.
- Adjust the injection rate in order to obtain a solid caste without reflux.
- Stop injecting once the proximal aspect of draining vein of fistula is occluded

  – Injection may need to stop if reflux occurs, coating the microcatheter, which may make removal impossible.

- At higher concentrations (NBCA $\geq 50\%$), up to 0.5 g of tantalum should be added to the mixture and the injection rate is faster and injection time is shorter (1–3 s).
- If there is a large direct fistula, or rapid flow, induce hypotension and use a very high concentration of NBCA. Alternatively, coils may be used first to slow down the rate of blood flow, followed by NBCA.
- After completion of procedure, aspirate the microcatheter briskly and remove it quickly.
- Aspirate the guide catheter and examine it fluoroscopically.

Postoperative Management and Follow-up

- As indicated in section above.
- In addition, the patient is monitored for any persistence, return or worsening of symptoms, which would be an indication of recurrence of DAVF. In such a situation, the spinal angiogram is repeated.

Spinal Tumors

Indications and Case Selection

- Preoperative embolization of tumors for devascularization.
- Palliation of symptoms in untreatable tumors/metastases.
- Retarding tumor growth.

Contraindications

- Significant risk of neurological deficit as pedicle supplying tumor also supplying normal cord and superselective catheterization not possible.

Preoperative Management

- As indicated above.

Technique

- In case of spinal tumors, the vascular supply 2 levels above and 2 levels below should be studied. If the lesion is extensive, the number of pedicles catheterized and studied rostrally and caudally should be increased.

- For more effective embolization, first close the collaterals and less direct feeders, such that the tumor is left supplied by a single dominant pedicle. Do not occlude this pedicle proximally, to enable retreatment later, if needed.
- The guide catheter and microcatheter are positioned as indicated above.
- Microcatheter selection should depend upon the size of the PVA particles to be used, in order to prevent catheter occlusion by the particles. Preferably use a larger caliber catheter (e.g., 2.3 Fr). If possible, avoid using tapered tip Microcatheter, as it is more likely to occlude. We commonly use Marathon (ev3) while treating fistulae in the ECA branches.
- Other microcatheter considerations include Prowler Plus (Codman & Shurtleff, Inc., Raynham, MA) and Rapidtransit (Codman).

Embolic Agents

PVA

- Suitable for preoperative embolization.
- Do not embolize particles with the tip of the catheter in a wedged position, as this may result in intra-tumoral hemorrhage.
- Polyvinyl alcohol (PVA) is available in sizes ranging from 50 to 1000 μm.

Procedure

- Advance the microcatheter to its planned location.
- Inspect angiograms carefully for potentially dangerous collaterals, i.e., those that supply the spinal cord.
- Measure the feeding vessels and lesion to select the appropriate size particles.
- Bear in mind, the smaller the particles, the greater the likelihood of deep penetration into smaller vessels, e.g., pre-capillaries, resulting in cranial nerve deficits, etc.
- Proceed to prepare the PVA mixture on a separate table/space, taking care that other equipment used during procedure does not get contaminated with the particles. Once the mixture is prepared, change gloves. Take extreme precautions that the PVA particles do not inadvertently contaminate drapes, catheters, etc., leading to possibility of embolic complications.
- Inspect the PVA particles for uniformity of size.
- Inject 15 ml of non-ionic contrast and 5 ml saline into the bottle containing PVA. Conversely, it may be safer to remove the top of the bottle and empty the contents into a shot glass and then add the non-ionic contrast to it.
- Shake to suspend the particles in the contrast.
- Attach a 3-way stopcock to a 20-ml syringe.
- Draw up the suspension into the syringe.

- Attach a 3-ml syringe to the 3-way stopcock. The 3-ml syringe should be attached to the port in line with that which will be attached to the catheter. The larger 20-ml syringe is attached to the port perpendicular to these two.
- Ensure the syringes and stopcock system are free of air bubbles.
- Use the plungers of the small and large syringes to push the suspension back and forth between the syringes, while the stopcock is turned to close off the third (free) port, intended for the microcatheter. The movement will assist in keeping the PVA particles in suspension.
- Draw suspension into the 3-ml syringe from the larger syringe and turn the stopcock, so that the port with the 20-ml syringe is blocked.
- Change gloves and discard any towels, etc., contaminated by PVA particles.
- Detach the RHV from the microcatheter and make a meniscus-to-meniscus connection between the microcatheter and the free portal of the 3-way stopcock. Ensure the system is free of air bubbles.
- Place a towel on the drape under the microcatheter to ensure it catches any errant PVA particles and the operating field is not inadvertently contaminated by potential emboli.
- Confirm that the microcatheter tip has maintained its position. Perform angiography, if necessary.
- Make a blank roadmap.
- Gradually commence injecting the PVA from the 3-ml syringe under direct visualization.
- Monitor carefully to ensure there is no reflux. Also monitor closely to ensure the PVA particles are not flowing into the draining vein/sinus. If this is detected, stop immediately.
- As the feeding vessel is occluded, resistance may be felt during injection.
- Do not attempt to overcome this resistance by using greater force. Such attempts may lead to reflux, or untoward embolization of an unintended vessel.
- As needed, refill the 3-ml syringe from the 20-ml syringe by turning the stopcock to the microcatheter and closing the system to the catheter. Then, aspirate the PVA suspension into the 3-ml syringe from the large syringe. To ensure uniform distribution of the PVA particles, agitate the suspension by initially drawing it back and forth between the two syringes. Once a smooth suspension is achieved, fill the 3-ml syringe for administration of PVA via the microcatheter. During the agitation process, ensure that the stopcock is closed to the microcatheter, to avoid inadvertent and potentially catastrophic embolization.
- After the 3-ml syringe is filled, turn the stopcock to open the microcatheter to the 3-ml syringe and close it to the 20-ml syringe.
- Resume injecting PVA under direct vision.
- Once the vessel/nidus is occluded, perform angiography to confirm.
- If the catheter appears obstructed, do not attempt to open it in vivo by a forceful injection or passing microwire through it. Remove the microcatheter completely from the guide catheter, and inspect it. If occluded and unable to re-establish flow by irrigating it, replace it with a new microcatheter.

- When the embolization procedure has been completed, withdraw and remove the microcatheter while maintaining gentle suction upon it, so that the PVA particles still contained within it do not inadvertently embolize.
- Discard the microcatheter along with the protective towel placed under it.
- Complete post-procedure angiography.

Onyx

- Please refer to usage technique as described above for spinal fistulas.

Alcohol

- Alcohol is used infrequently for the vessel sclerosis in tumors or in treatment of AVM.
- It acts by immediate cytotoxic effect upon the vessel endothelium near the microcatheter tip and the resultant vessel thrombosis is manifest within 5–10 min.
- The risks associated with ETOH include significant toxicity of brain parenchyma (when injected in high concentrations) and pulmonary edema.
- A possible advantage is the dilution of alcohol downstream from the site of treatment, thereby avoiding injury to normal venous drainage.

Procedure

- All current microcatheters are compatible with alcohol.
- Alcohol is supplied in 5-ml vials.
- The volume of ETOH injected during one session should not exceed 1 ml/kg body weight.
- Use injection of contrast through the microcatheter to gauge the force needed for the alcohol injection in order to impact the entire vessel wall. Remember, unlike other agents, alcohol is not visible fluoroscopically during the injection so reflux must be estimated before injection.

Postoperative Management and Follow-up

- As indicated above.

Location Specific Considerations Including Difficult Access

Cervical

- When performing angiography for arteries such as thyrocervical trunk, a usual diagnostic catheter, e.g., 5 Fr front angled catheter (Terumo), will suffice. Cobra

catheter is more suitable for studying intercostal arteries in the thoracic/lumbar regions.
- Study the spinal arterial supply on both sides.
- The competence of the circle of Willis as well as the dominant VA will need to be determined, in case one of the VAs needs to be sacrificed.
- Angiography will also allow the operator to determine the potential technical difficulties that may be encountered during embolization.
- When embolizing a cervical tumor, consider temporary balloon occlusion distally during embolization, for cerebral protection.

Thoracic

- The posterior portion of the vertebral body is usually best visualized by injecting the left intercostal artery.
- The anterior portion of the vertebral body is usually best visualized by injecting the right intercostal artery.
- The intercostal arteries arise from the aorta with a sharp superior angulation especially in T2 to T4 region. The pattern gradually changes with the caudal arteries such that the lumbar segmental arteries are directed horizontally or caudally.
- Table 8.4 lists some possible problems and solutions.

Table 8.4 Difficult access problems/solutions thoracic location

Problem	Solution
Difficulty catheterizing the intercostal artery	• Switch from Cobra catheter to an H-1-H catheter
Catheter jumps out of pedicle during angiography	• Inject gently with gradual rise of pressure • Switch from Cobra catheter to an H-1-H • Position catheter a little further in the pedicle. To do so, may need to rotate the tip further in the direction of the pedicle, concurrently with a gentle push – In case using a Mikaelsson catheter, maintain a downward tension • Ensure the external segment of the catheter outside the sheath is stable and has not built countertorque that will undo the position of the tip • If still having difficulties – Perform roadmap and introduce a soft wire into the pedicle and advance the catheter into the pedicle over it. If this fails then using roadmap, advance a coaxial system • Advance a microwire into the pedicle, and then, advance a microcatheter over the wire • Perform angiography through the microcatheter

Table 8.5 Difficult access problems/solutions lumbar location

Problem	Solution
Difficulty catheterizing the segmental artery	• Switch from Cobra catheter to an HS-1 catheter
Catheter jumps out of pedicle during angiography	• Inject gently with gradual rise of pressure • Switch from Cobra catheter to an HS-1 • Position it a little further in the pedicle. To do so, may need to rotate the tip further in the direction of the pedicle, concurrently with a gentle push – In case using a Mikaelsson catheter, maintain a downward tension • Ensure the external segment of the catheter outside the sheath is stable and has not built countertorque that will undo the position of the proximal tip • If still having difficulties – Perform roadmap and introduce a soft wire into the pedicle and advance the catheter into the pedicle over it. If this fails, then, using roadmap, advance a coaxial system • Advance a microwire into the pedicle and then advance a microcatheter over the wire • Perform angiography through the microcatheter

Lumbar

- Lumbar segmental arteries are more likely than thoracic intercostal arteries to have a conjoined pedicle. Therefore, on injection both the right- and left-side branches will be visualized.
- The origin of lumbar segmental arteries is directed horizontally or caudally. This pattern gradually changes to a superiorly directed origin of the intercostal arteries in the thoracic region.
- Table 8.5 lists some possible problems and solutions.

Suggested Readings

1. Berenstein A, Lasjaunias P, Ter Brugge KG. Surgical neuroangiography, vol. 2.2. Heidelberg: Springer-Verlag; 2004. p. 874–911.
2. Morris PP. Practical neuroangiography. Philadelphia: Lippincott Williams & Wilkins. 2007. pp. 36–85; 396–403; 456–65.
3. Song JK, Gobin YP, Duckwiler GR, Murayama Y, Frazee JG, Martin NA, Viñuela F. N-butyl 2-cyanoacrylate embolization of spinal dural arteriovenous fistulae. AJNR Am J Neuroradiol. 2001;22:40–7.
4. Warakaulle DR, Aviv RI, Niemann A, Byrne JV, Teddy P. Embolisation of spinal dural arteriovenous fistulae with Onyx. Neuroradiology. 2003;45:110–2.