# 8 Carotid and Vertebral Arteriography

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## Introduction

There has been tremendous development of advanced, noninvasive cross-sectional imaging techniques for vascular evaluation of diseases of the brain, head, and neck as well as upper cervical spine. However, there remains a very important role played by invasive catheter angiography for studying the extracranial carotid and vertebral arteries. Techniques for arteriographic evaluation not only aid in diagnosing certain conditions and hence increase the confidence of surgical treatment protocols, but they also lend themselves to exploration and minimally invasive treatment modalities by endovascular means. The following sections will provide an understanding of the fundamentals of this technique by highlighting the history and evolution of catheter angiography techniques, discuss the indications and limitations of invasive catheter angiography, describe some of the associated risks involved, and provide some case scenarios as examples.

## History

The development of cerebral angiography by pioneers such as Antonio Egas Moniz [1, 2] in the early part of the twentieth century was critical in evaluation of not only vascular disorders of the head, neck, and brain but also led to the assessment of all types of diseases that have been until then not amenable to critical diagnosis and treatment. The initial techniques for vascular access and angiographic diagnosis involved direct carotid puncture and were in common use among the neurosurgical community. The description of percutaneous arterial access by Seldinger [3] led to the widespread adoption of catheter angiography. This would eventually lead to the routine use of cerebral angiography for the diagnosis of vascular disorders of the central nervous system. Carotid and vertebral angiography was also in common use for evaluation of masses and space-occupying lesions of the central nervous system long before the development of the first-generation computed tomography scanners [4]. This would serve as a very useful tool for evaluation of tumors and other space-occupying lesions for localization prior to neurosurgical intervention.

The description of the use of a catheter for angiography of the head and neck vasculature comes from Radner [5] who inadvertently performed a vertebral arteriogram while attempting to catheterize the heart from a right radial artery approach. Catheter angiography for cervical and cerebral arteriography was mostly popular among Scandinavian abdominal radiographers, and the technique was subsequently popularized among the radiology community in North America. The development of catheter angiography eventually

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S. S. Hans (ed.), *Extracranial Carotid and Vertebral Artery Disease*,
https://doi.org/10.1007/978-3-319-91533-3_8

led to surgical treatments for a variety of conditions but also the inevitable development of endovascular treatments for a variety of vascular disorders.

Ligation treatment for tumors of the head and neck had been described by surgical methods as early as 1904 by James Dawbarn [6], and early adopters of an endovascular approach used various embolic agents for simulating this devascularization from within the vasculature through direct exposure of the feeding vessels and subsequently using appropriate delivery catheters. Eventually the use of endovascular treatment extended to the intracranial circulation for treatment of cerebral vascular lesions, pioneered by Lussenhop and Spence in the middle part of the twentieth century who used a surgical cut down to expose the internal carotid artery and used methacrylate spheres to treat an arteriovenous malformation of the brain [7].

## Evolution of Angiography

Early device development for angiography, specifically the design and production of catheters and wires for angiography, proceeded at a pace far slower than that for operative neurosurgery and vascular surgery. Early catheters for the performance of angiography were used primarily by peripheral, abdominal, and cardiac angiographers. These groups represented a larger patient population and gave the impetus for companies to improve existing designs. The earliest designs for catheters were available in a format that required shaping the tips in vitro and were especially important in supra-aortic cervical vascular access through the aortic arch, given the variations in aortic arch types, branch anatomy patterns, as well as increasing vessel tortuosity with advanced patient age. Numerous pre-shaped designs soon began to be available pioneered by experts with special interest in neurovascular diagnoses.

Advancements in engineering technology would soon see the development of smaller microcatheters and microwires which would eventually lead to the development of advanced endovascular treatment strategies for vascular diseases of the extracranial carotid and vertebral arterial system.

## Noninvasive Imaging

### Doppler Ultrasound

The use of gray-scale and color Doppler ultrasound techniques serves as a useful tool in the screening of vascular disorders of the extracranial carotid and vertebral arterial tree. These techniques are primarily used for the evaluation of vascular stenosis and obstructive disease but also play a role in evaluation of low flow and high flow head and neck vascular malformations.

### Computed Tomography (CT) Scanning

CT scans have undergone rapid development since the first scanners in the early 1970s to the latest generation multidetector scans that can complete scan acquisitions and generate images in a matter of mere seconds. Combining the impressive capability of modern scanners with the addition of contrast media administered through the intravenous route, exquisite images of the extracranial carotid and vertebral arterial anatomy can be obtained for careful evaluation. Modern post-processing capabilities available at the scanner level and by the using third-party software can be utilized to generate multiplanar reconstructions and three-dimensional models. These can be used by surgeons and interventionalists to plan surgical or endovascular treatments.

### Magnetic Resonance Imaging (MRI)

MRI is also a useful tool in the diagnostic evaluation of the extracranial carotid and vertebral arteries. MRI has the advantage of improved tissue contrast and with administration of vascular-specific, gadolinium-based contrast agents can be used to specifically image the vessels. MRI also has the advantage to obtain temporal information with sequences such as TRICKS (time-resolved imaging of contrast kinetics) or TWIST (time-resolved angiography with stochastic trajectories) sequences by obtaining a series of image acquisitions in separate phases of arterial flow obtained at rates as fast as 1–2 frames per second. Gadolinium-based contrast agents are contraindicated in patients with renal disease. There are MRI sequences such as time of flight angiography and phase-contrast imaging that do not require the use of gadolinium-based contrast and can be used in a limited manner in evaluation of the extracranial arterial vascular tree.

The advent of noninvasive vascular angiographic techniques may be considered an impediment to the educational opportunities of trainees in neuro-endovascular techniques as the volume of catheter angiography have significantly decreased. There are however enough indications for performance of catheter angiography that would enable trainees to develop this skill set to a degree that would enable the safe performance of not only diagnostic angiography but also extend that knowledge base and experience to the therapeutic aspects of cervical and cerebral vascular diseases [8].

## Indications

As mentioned previously, in the modern era of readily available noninvasive cross-sectional vascular imaging techniques, the current list of indications for invasive catheter angiography for the extracranial carotid and vertebral arteries are somewhat limited. The following table lists some of the common indications, focusing on the extracranial circulation. These will be highlighted by showing examples in the section of case scenarios.

**Indications for Catheter Angiography of Extracranial Carotid and Vertebral Arteries**

Clarifying degree of stenosis in occlusive disease with discordant results on Doppler, CTA, and MRA

Evaluation of high cervical spinal vascular malformations

Preoperative evaluation for aneurysm

Presurgical embolization of vascular head and neck tumors

Evaluation of vascular malformations of the head and neck

Balloon test occlusion prior to vessel sacrifice

## Contraindications

The list of contraindications for cervico-cerebral angiography has traditionally been divided into absolute and relative contraindications. A case-by-case assessment of the necessity to perform the procedure must be made depending on the acuity of the case and need for rapid diagnosis. With careful technique as well as newer access devices, etc., the procedure may be performed in clinical scenarios that have been hitherto been considered a contraindication. For instance, patients with coagulopathies may undergo catheter angiography by using a micropuncture kit and ultrasound guidance for femoral access and a closure device for hemostasis after completion of arteriography. Patients with borderline renal dysfunction may undergo angiography with a good hydration protocol and may be monitored carefully for rise in serum creatinine. Indeed, a recent meta-analysis of patients with acute stroke undergoing contrast administration showed that there is no significant association of contrast administration and acute kidney injury in stroke patients, even those with known chronic kidney disease [9]. Patients with anaphylactic reactions to iodinated contrast media may undergo selective arteriography with gadolinium-based contrast if absolutely required.

**Some Contraindications to Invasive Catheter Arteriography**

Anaphylactic reaction to iodinated contrast media

Uncorrected coagulopathy

Connected tissue disorders prone to vessel injury, e.g., Ehlers-Danlos syndrome (type IV)

Severe renal dysfunction

## Techniques

### Pre-procedural Evaluation

A proper review of the indication for catheter angiography as well as review of noninvasive imaging modalities is a must prior to performance of angiography. A history and physical examination and review of lab work should be performed to ensure there are no contraindications or factors that may affect the technical aspects of the case. Documentation of the peripheral arterial pulses will ensure safe access. An informed consent discussion should include the benefits and risks associated with the procedure and reasonable alternatives and a discussion of why catheter angiography has been recommended.

### Angiography Imaging Systems

Digital subtraction angiography has improved significantly with most modern angiography systems using flat panel detector technology with improved efficiency, greater dynamic range, and capability for cone-beam CT and rotational angiography. Modern systems are capable of imaging vessels with capability of fusing vessels with previously obtained cross-sectional images, removing metal artifact from vascular clips, stent tines, etc., and provide capability for road map guidance in 3D for vascular navigation of the peripheral vascular tree. This has indeed improved the safety of catheter angiography when compared to older generation systems [10].

### Vascular Access Phase

The most common site for vascular access for the performance of diagnostic angiography of the extracranial carotid and vertebral arteries is the femoral artery. Access is usually obtained by using a percutaneous approach by using a modified Seldinger technique. A short vascular sheath is usually placed for catheter introduction and helps with exchange and usage of multiple pre-shaped catheters. Other access sites may be occasionally used when femoral access is difficult, such as access via the radial or brachial approach. This is especially suited for vertebral arteriography, because of the anatomical nature of access to the vertebral arterial system from the subclavian artery. Some centers perform cervical arteriography routinely through a radial approach. Special considerations for patients on antiplatelet medication and anticoagulation include the use of ultrasound for access and use of micropuncture vascular kits. If there is anticipation of aortoiliac tortuosity, consideration may be given to the use of longer vascular sheaths.

Direct carotid puncture for access is seldom used for diagnostic catheter angiography and is reserved for certain cases of treatment of intracranial conditions such as acute ischemic stroke treatment and intracranial embolization when traditional access sites have failed [11].

### Choice of Catheters and Wires

There are many pre-shaped catheters available for supra-aortic vascular catheterization depending on aortic arch anatomy, patient age, and tortuosity as well as operator preference and experience (Table 8.1). Most centers will use a 5Fr system

**Table 8.1** Catheters used for supra-aortic neuroangiography

| Angled curve/forward curve catheters | Reverse curve catheters |
|---|---|
| Berenstein | Simmons (Sim 1, 2, 3) |
| Davis | Vitek (VTK) |
| Kumpke | Bentson (JB 2, 3) |
| Headhunter (H1, H3) | Mani (MAN) |
| Modified headhunter (H1H, HY1) | CK1 |
| TEG-T | Newton (HN 3, 4) |
| Vert | |
| Bentson (JB 1) | |
| Weinberg (WNBG) | |
| Cerebral Burke (CBL) | |

for diagnostic arteriography due to the widely available variety of catheter shapes and for the right balance of size and stiffness in a substantial proportion of the patient population that is encountered. It may be possible to perform catheter angiography in younger patients using a 4Fr system as there is a lower incidence of tortuous vascular anatomy.

Isolated angiography of the carotid and vertebral arteries is rarely performed in the pediatric population. Special consideration should be given to low profile access sheaths, smaller-sized catheters, and prudent use of fluoroscopic technique and contrast injection amounts.

Aortic arch anatomy and type is an important determinant of catheter choice. Catheters for supra-aortic neuroangiography may be broadly divided into single curve (Fig. 8.1a), double curve (Fig. 8.1b), or reverse curve (Fig. 8.1c,d) catheters. For type I and most type II arches, a variety of angled catheters may suffice to obtain access, whereas the presence of a type III arch or bovine configuration, etc. might require the use of a reverse curve catheter system.

The guidewires most commonly available for cervical arteriography are either a spring-coil guidewire with long taper such as Bentson (Cook Medical) or a hydrophilic wire with angled tip such as Glidewire (Terumo). Double flushing technique with heparinized saline to ensure no stagnant blood columns within the catheter lumen is usually sufficient. Some cases where there is anticipation of protracted catheterization times may require the use of a closed system continuous heparinized flush system. Some centers routinely use in-line air filters to reduce the risk of air embolus.

Contrast injection may be performed either by using proper hand injection of contrast, ensuring meticulous care to eliminate air bubbles or by using a power injection device at an appropriate rate and volume of contrast for the selected vessel [12].

The vascular access site may be compressed manually to achieve hemostasis with an appropriate bedrest period to follow. In patients on antiplatelet or anticoagulant medication or those patients with a coagulopathy, a closure device may be necessary to achieve hemostasis [13].

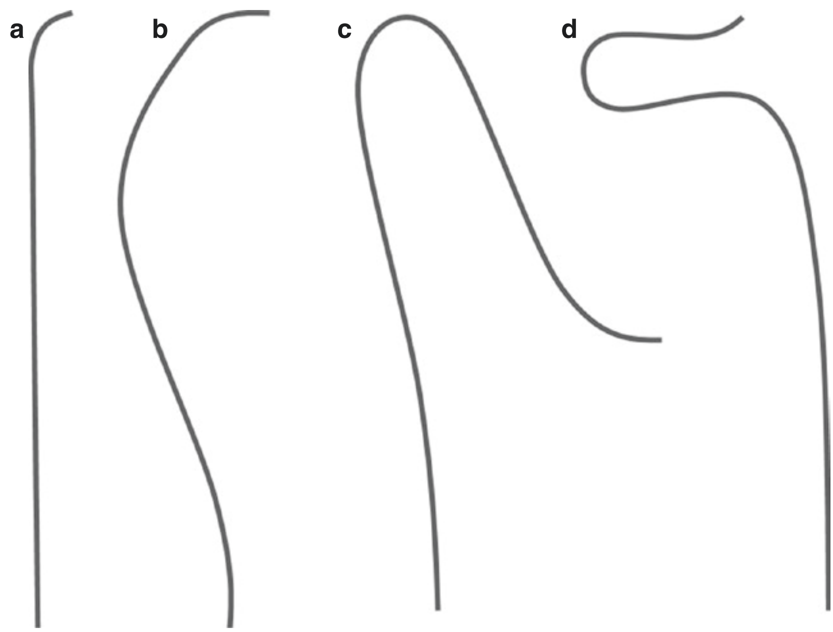


**Fig. 8.1** Examples of commonly used catheters for supra-aortic neuroangiography. (**a**) Simple curve catheter: Berenstein. (**b**) Double curve catheter: Headhunter. (**c**) Reverse curve catheter: Simmons 2. (**d**) Reverse curve catheter: Vitek

## Special Maneuvers and Dynamic Imaging

Invasive catheter angiography can provide additional diagnostic information as it pertains to collateral circulation by using cross-compression techniques with selective catheterization. For example, selective internal carotid angiography while compressing the contralateral internal carotid artery will provide information regarding patency of the anterior-communicating artery.

Dynamic angiography of the vertebral arteries while positioning the patient's head and neck in different positions that elicit posterior circulation symptoms may provide information on vascular lesions that may account for positional symptoms such as in patients with suspected Bowhunter's syndrome.

## Advanced Angiographic Techniques

Three-dimensional rotational angiography may be incorporated into the routine angiography protocol to generate vascular models of aneurysms. This not only generates images useful for surgical and interventional planning but also provides the capability for navigation using advanced 3D road map guidance [14].

Selective protocols may be used with contrast injection and cone-beam CT rotational capabilities of modern DSA units. This takes advantage of the improved efficiency and greater dynamic range of modern flat panel units, and vascular pathologies can be generated with overlay of adjacent osseous and soft tissue structures [15].

## Procedural Risks

Catheter angiography of the cervical carotid and vertebral arteries are prone to the same risks associated with angiography in general which include complications related to vascular access site bleeding and vessel injury, allergic reaction and nephrotoxicity due to iodinated contrast media, etc. There could also be complications related to dissection of vessels from either guidewire or catheter placement and power injection devices.

However, cervico-cerebral arteriography has the added risk of neurological complications related to the vascular access of head and neck arteries. In a large study by Willinsky et al. [16], a total of 2899 consecutive cerebral DSA exams were evaluated prospectively. Permanent neurological complications were encountered in 0.5% of exams performed. The authors concluded that advancing age and pre-existing cardiovascular disease as well as increased fluoroscopy times were associated with a higher incidence of neurological complications associated with cervico-cerebral angiography.

## Case Scenarios

### Case #1: Extracranial Vascular Stenosis

Steno-occlusive disease of the extracranial carotid vessels and to a lesser degree the vertebral arteries is a major cause of ischemic stroke. Evaluation of the vasculature is usually performed by noninvasive modalities such as Doppler ultrasound, CT, and MR angiography. Catheter angiography is usually performed in the setting of inconclusive results from noninvasive imaging and to clarify collateral circulation when making decisions regarding revascularization. Heavily calcified plaques may obscure the actual degree of stenosis in carotid atherosclerotic disease on CT angiography and can overestimate the degree of stenosis (Fig. 8.2).

Stenoses of the vertebral arteries are less amenable to evaluation by Doppler ultrasound, and ostial disease can be obscured in the presence of artifacts related to osseous and soft tissue structures at the thoracic inlet. Vertebral ostial disease is also less well evaluated by MR angiographic techniques due to some of the same concerns but also due to limitations of coverage on most current MRI protocols.

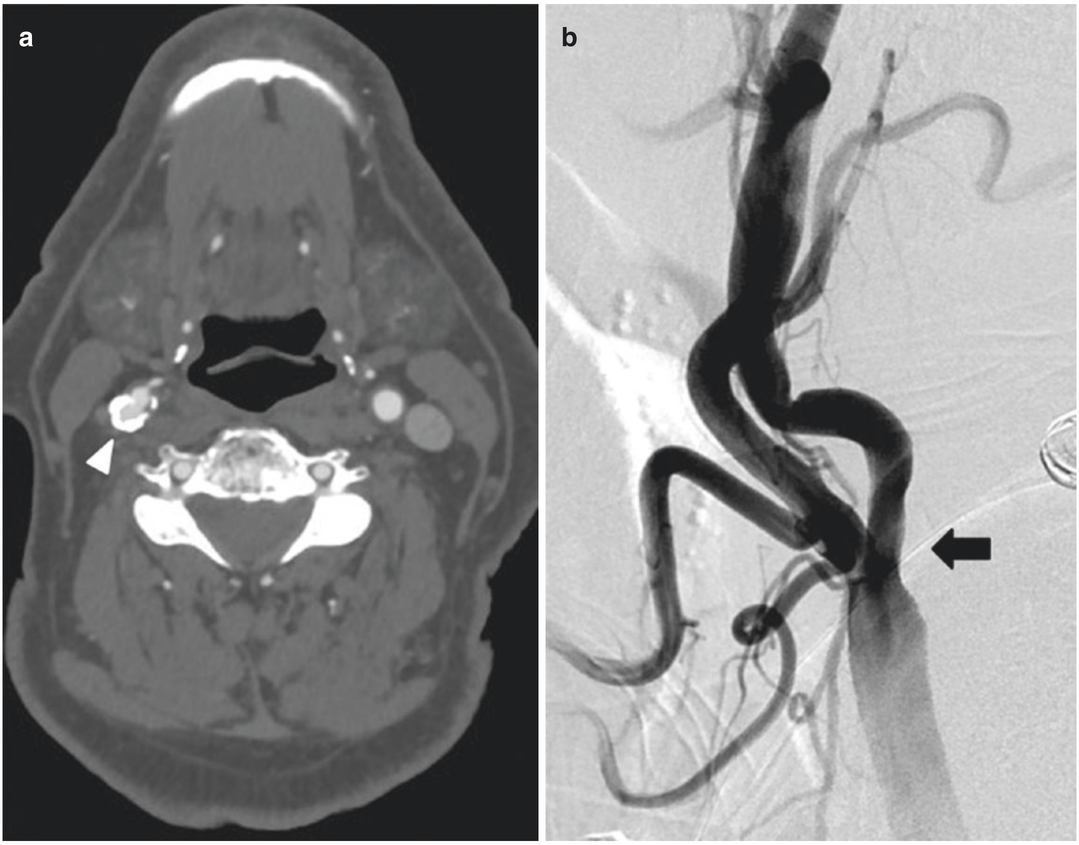


**Fig. 8.2** An elderly patient presented with right hemispheric transient ischemic attack (TIA) symptoms. (**a**) CT angiography demonstrated heavily calcified plaque in relation to the right carotid bifurcation (white arrowhead). (**b**) Catheter angiography immediately prior to planned endovascular angioplasty and stenting demonstrated non-significant stenosis, <50% (black arrow), and the patient was placed on medical management

## Case #2: Aneurysms

Aneurysmal dilatation involving the cervical vasculature is less common than intracranial aneurysms. Cervical carotid aneurysms are usually contained pseudoaneurysms seen in the setting of sequelae of prior trauma and blunt vascular injury or as a sequelae of deep neck space infections. Sometimes clarification of the anatomy requires definitive catheter angiography for treatment planning. Definitive treatment of cervical aneurysms may require endovascular treatment with either coils or use of a covered stent. The specific type of treatment may dictate the need for antiplatelet therapy, and a good preoperative angiogram will help in making this determination (Fig. 8.3).

## Case #3: Vascular Malformations

Vascular malformations of the head and neck region can be encountered either within the spinal column as part of the spectrum of spinal vascular malformations or in relation to the soft tissues of the head and neck such as high flow or low flow vascular malformations. There are various schemes for the classification of spinal vascular malformations and are beyond the scope of this chapter. The common spinal vascular malformations of the cervical regions that are seen in clinical practice include spina dural arteriovenous fistulae (Fig. 8.4), spinal cord vascular malformations, spinal metameric syndromes, and intracranial dural arteriovenous fistulae with spinal peri-medullary drainage.

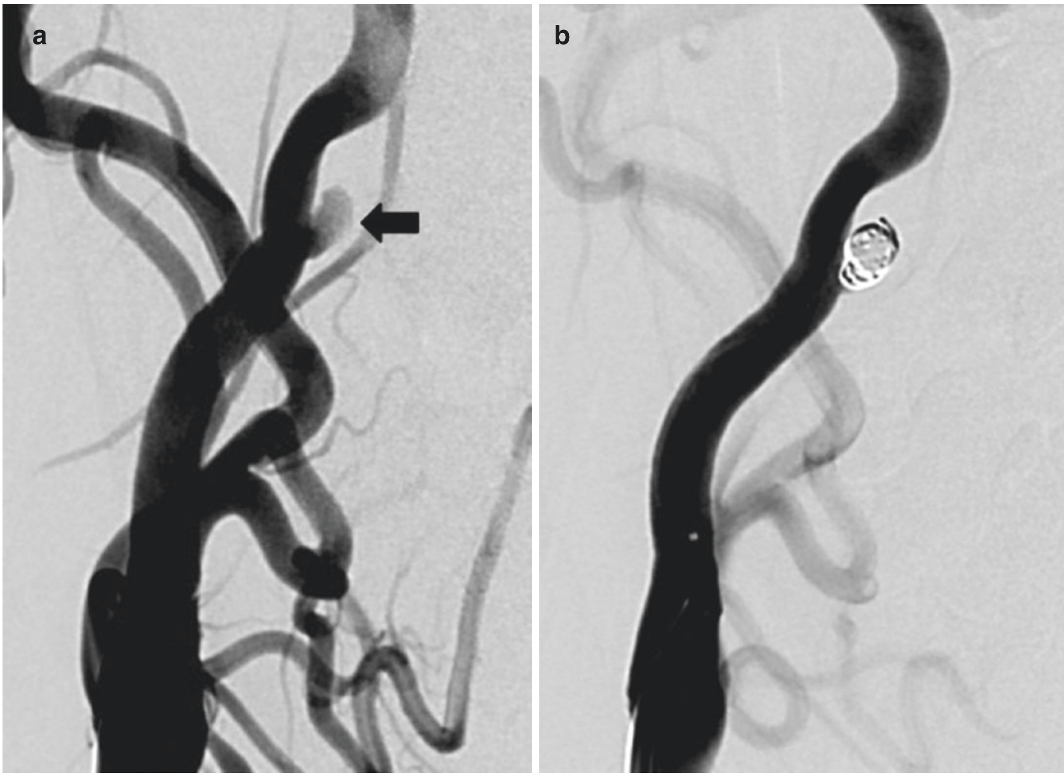


**Fig. 8.3** A young patient presented with persistent right-sided neck pain following minor neck trauma 2 months prior. (**a**) Right carotid angiography demonstrates an aneurysm arising from the right internal carotid artery above the bifurcation. The aneurysm had a relatively narrow neck on angiographic evaluation. Based on the findings of catheter angiography, a decision was made to attempt coil obliteration of the aneurysm. (**b**) Control angiography after coil embolization demonstrates satisfactory exclusion of the aneurysm from the circulation with preserved patency of the parent vessel

Soft tissue malformations of the head and neck are a not uncommon cause of symptoms related to swelling and pain and when deep also can cause symptoms related to airway compromise and swallowing difficulties. Some indeterminate lesions will require catheter angiography to ascertain the flow characteristics as this will have implications for management (Fig. 8.5). Low flow lesions are usually amenable to percutaneous interventions, whereas high flow lesions would be best managed by a multidisciplinary approach which includes a combination of embolization and surgical resection when feasible.

## Case #4: Vascular Neoplasms

Certain vascular tumors such as carotid body tumors or head and neck paragangliomas may be encountered in the head and neck region. Most of these lesions are managed by surgical resection in the appropriate context. Some surgeons may request a conventional catheter angiogram prior to surgical resection as this would determine the need and feasibility for preoperative embolization. In addition, an angiographic understanding of the regional vascular anatomy would serve as a good road map for surgical planning.

## Case #5: Balloon Test Occlusion

Collateral vascular pathways play a significant role in maintaining hemodynamic balance within the head, neck, and brain circulation. These unique anatomic variations of the supra-aortic cervico-cerebral vasculature lend an opportunity for therapeutic vessel occlusions and ligation

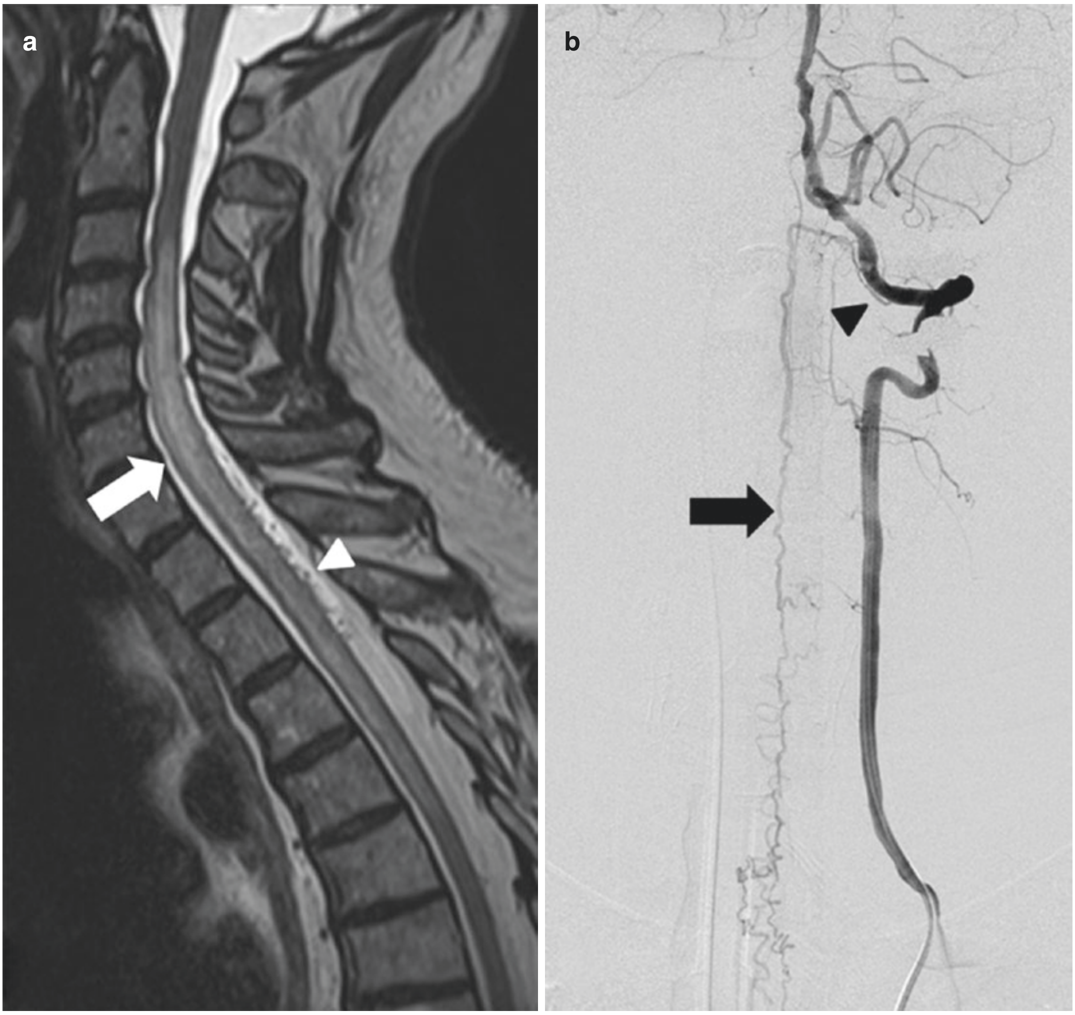


**Fig. 8.4** A middle-aged male patient presented with progressive myelopathy over the past 4 months. (**a**) Sagittal T2-weighted MRI scans demonstrated abnormal cord signal change and edema centered at the mid-cervical spinal cord with extension to the upper thoracic spinal cord (white arrow) along with multiple small flow voids along the dorsal aspect of the cord (white arrowhead) highly suggestive of enlarged peri-medullary vessels. (**b**) Left vertebral angiography demonstrates a spinal dural arteriovenous fistula centered at the level of the left C1 nerve root sleeve (black arrowhead) with enlarged peri-medullary spinal veins extending caudally toward the cervicothoracic junction (black arrow)

in the setting of traumatic vascular lesions and in preparing for surgical exploration for treatment of lesions that are in close proximity to the major arteries of the head and neck as well as the skull base. Catheter angiography offers an added advantage to evaluate the collateral pathways by temporary balloon occlusion testing and in awake patients testing for neurological changes temporarily prior to definitive occlusion (Fig. 8.6). Care should be taken to adequately anticoagulate patients for the duration of testing (typically 30 min) with careful serial neurological examination during the period of occlusion. Most practitioners also institute a hypotensive challenge for the latter third of the test occlusion duration.

## Case #6: Special Techniques

Modern neuroangiography imaging systems can perform advance application techniques such as rotational angiography and cone-beam CT acqui-

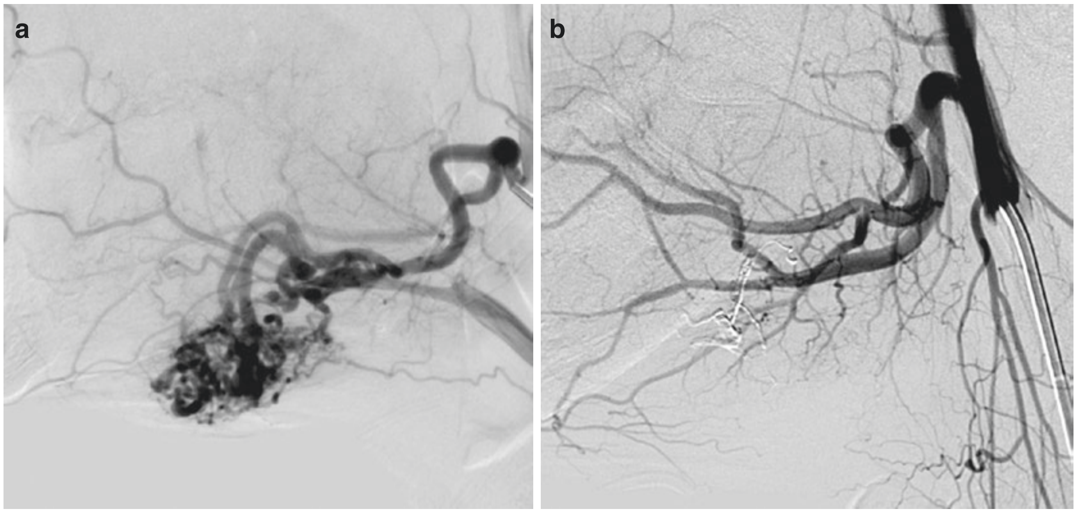


**Fig. 8.5** A young patient presented with a slowly growing submandibular mass for the past year. MR imaging of the neck (not shown) revealed a vascular lesion within the right submandibular space with flow voids. However, the flow of the lesion could not be determined. (**a**) Right external carotid angiography demonstrates the presence of a high flow vascular malformation supplied by branches of the right lingual artery with early draining veins draining via the external jugular vein. (**b**) Due to the high flow nature of the lesion a decision was made to proceed with embolization of the lesion to be followed by surgical resection. A liquid embolic agent was used to embolize the lesion through branches of the lingual artery

sitions in the angiography suite. Modern flat panel detector units are capable of acquiring and, through software based post-processing, generating images of the cervico-cerebral vasculature with exquisite details. Cone-beam CT acquisition in non-subtracted mode can demonstrate the vascular anatomy in relation to the regional osseous anatomy which is extremely useful in planning surgical and endovascular treatments (Fig. 8.7). Newer applications such as 3D road mapping can be useful for navigating the vasculature in complex cases for super-selective catheterization. The use of cone-beam CT angiography will also be useful in designing hybrid operating theaters, minimizing the time between imaging and intervention. This is especially useful in trauma patients who may require surgical and endovascular intervention at the same time.

## Limitations

The most important drawback of catheter angiography is the invasive nature of the procedure and the associated risks involved. As discussed above, the additional neurological risks related to catheterization of the head and neck vessels is another important limitation. However, in selected patients catheter angiography can be used as a problem-solving tool and direct management. Many of these conditions have significant morbidity and mortality associated with them if left untreated, and catheter angiography may be a logical next step in the treatment paradigm. With advancements in endovascular treatment techniques, catheter angiography is the first step in the logical progression to treatment.

## Future Directions

There are increasing reports in the literature of the use of direct carotid puncture for access to the intracranial vasculature for endovascular treatment of patients with acute ischemic stroke as well as treatment of other intracranial vascular disorders such as intracranial aneurysms and vascular malformations. Although its use for the sole

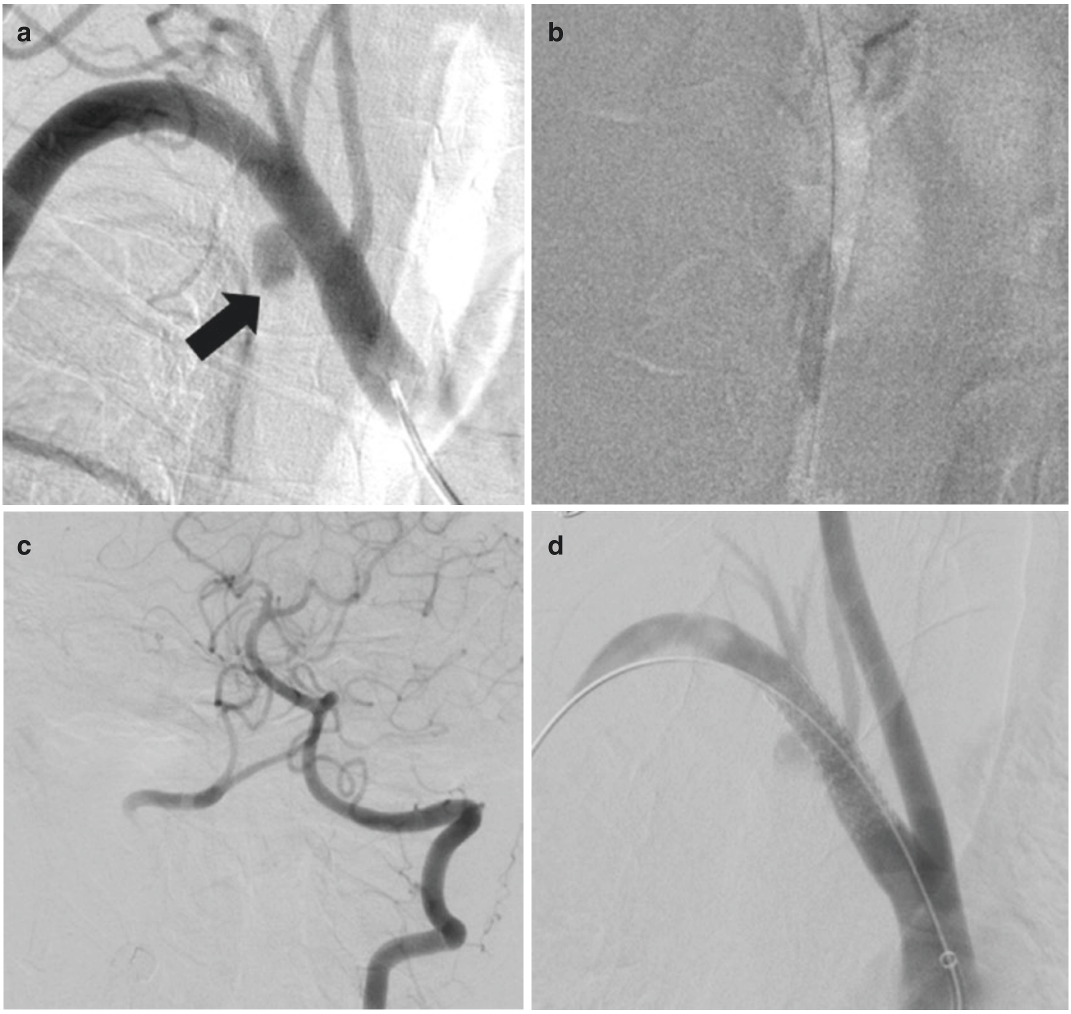


**Fig. 8.6** A middle-aged patient presented with a history of trauma and CT evaluation as part of the trauma protocol demonstrated a right-sided hemothorax related to a pseudoaneurysm of the right subclavian artery. (**a**) Catheter angiography of the right subclavian artery re-demonstrated the pseudoaneurysm (black arrow) arising distal to the origin of the right vertebral artery with a relatively wide neck. Based on the morphology of the aneurysm, endovascular treatment using a stent graft was considered. (**b**) A balloon test occlusion was performed within the right vertebral artery to plan for excluding that segment of the subclavian artery. (**c**) Contralateral vertebral arteriography with balloon inflation in situ demonstrated good collateral flow and intracranial perfusion with no associated clinical neurological deficits. (**d**) A stent graft was successfully placed across the aneurysmal segment of the subclavian artery

purpose of obtaining diagnostic angiograms will be limited, this technique might find favor in the future as experience accumulates with techniques for access and closure.

Intravascular ultrasound has been used predominantly in the coronary and peripheral vasculature for evaluation of atherosclerotic plaque morphology as well as for assessing successful revascularization with stents. There are increasing reports of the use of this technology for the assessment of steno-occlusive disease in the periprocedural period for the placement of stents during endovascular revascularization [17]. This may be potentially useful in patients with severe anaphylaxis to contrast and /or renal dysfunction.

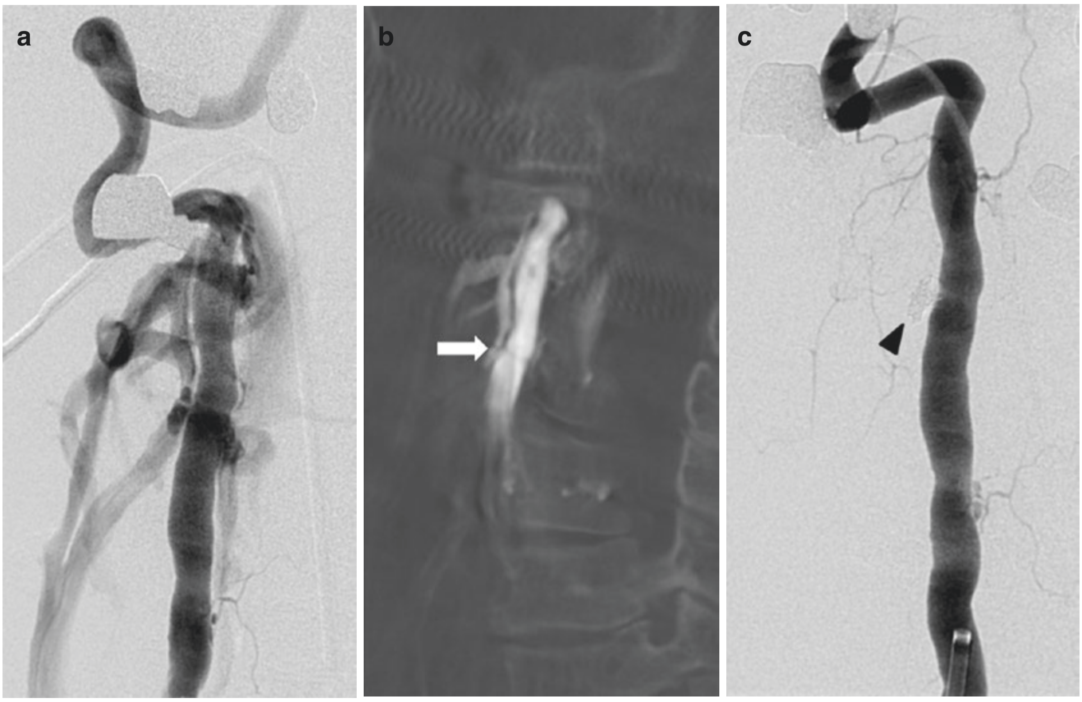


**Fig. 8.7** A young patient presented with intractable tinnitus following trauma to the neck. (**a**) Right vertebral arteriography demonstrates a high flow arteriovenous shunt from the V2 segment with rapid visualization of multiple veins within the peri-vertebral venous plexus. Due to the extremely high flow nature of the shunt, an exact determination of the site of fistulation could not be determined despite high frame-rate angiography. (**b**) A dynamic cone-beam CT acquisition with dilute arteriographic contrast injection demonstrates the site of fistulation (white arrow). (**c**) The fistula was subsequently accessed using a microcatheter and embolization performed using detachable platinum coils (black arrowhead)

## Conclusion

Invasive catheter angiography of the carotid and vertebral arteries has a role in the evaluation of certain pathological vascular conditions of the head and neck as outlined above. Advancements in noninvasive vascular imaging have led to a decreased need for catheter arteriography in general. However, in selected clinical settings, the technique may prove useful in the management of patients and should be utilized prudently when other means of diagnosis are inconclusive. Careful attention to technique can minimize the risks associated with this procedure. A detailed understanding of the anatomy of the extracranial carotid and vertebral arteries will aid in interpreting the angiographic images and help in planning a therapeutic intervention by surgical or endovascular means.

**Review Questions**

1. The technique for percutaneous vascular access for arteriography was first described by:
   A. Antonio Egas Moniz
   B. Sven Ivan Seldinger
   C. James Dawbarn
   D. Alfred Lussenhop

   *Answer: B*

2. Which of the following is a reverse curved catheter used in neuroangiography?
   A. Berenstein
   B. Headhunter
   C. Davis
   D. Simmons

   *Answer: D*

3. Which of the following is the most significant risk from carotid arteriography?
   A. Puncture site hematoma
   B. Anaphylaxis from iodinated contrast media
   C. Aortic dissection
   D. Neurological complications

   *Answer: D*

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