

2. Diagnostic Cerebral Angiography

2.1. Introduction

Catheter angiography is still considered the gold standard for imaging cerebral vasculature. Diagnostic angiography is also typically done as the first step during neurointerventional procedures. Mastery of diagnostic angiography is a prerequisite for neurointerventional training. Training standards formulated by the American Society of Interventional and Therapeutic Neuroradiology (ASITN), the Joint Section of Cerebrovascular Neurosurgery, and the American Society of Neuroradiology (ASNR) recommend the performance of at least 100 diagnostic angiograms before entering neuroendovascular training.¹ The authors' preference, however, is for a neurointerventionalist-in-training to perform at least 250 diagnostic cerebral angiograms prior to becoming the lead operator in neurointerventional cases.

2.2. Indications

1. Diagnosis of primary neurovascular disease (e.g., intracranial aneurysms, arteriovenous malformations, dural arteriovenous fistulas, atherosclerotic stenosis, vasculopathy, cerebral vasospasm, acute ischemic stroke)
2. Planning for neurointerventional procedures
3. Intra-operative assistance with aneurysm surgery
4. Follow-up imaging after treatment (e.g., after aneurysm coiling or clipping, treatment of arteriovenous fistulas)

2.3. A brief history of cerebral angiography

The first report of X-ray angiography of blood vessels was in 1896. In Vienna, E. Haschek and O.T. Lindenthal obtained x-rays of blood vessels by injecting a mixture of petroleum, quicklime, and mercuric sulfide into the hand of a cadaver.² Antônio de Egas Moniz, a Portuguese neurologist, is credited with the introduction of cerebral angiography. Moniz was interested in developing "arterial encephalography" as a means to localize brain tumors. He obtained cerebral angiograms in cadavers using a solution of strontium bromide and sodium iodide. These early studies demonstrated universal branching patterns among the intracranial arteries, which were contrary to popular theories based on cadaver dissection. After studies in dogs and monkeys, Moniz and his colleague Almeida Lima, a neurosurgeon, performed the first angiogram on a living human patient in 1927, in a 53-year-old man with a history of seizures and hemiparesis.³ The cervical internal carotid artery was surgically exposed and temporarily occluded with a ligature while a total of 5 mL of a solution of 25% sodium iodide was injected into the vessel. Flow was restored in the artery while simultaneously obtaining an X-ray. Although no complications were noted during the procedure and the X-rays showed good filling of the intracranial circulation, the patient died two days later in status epilepticus.⁴ Moniz went on to obtain successful angiograms in other patients with epilepsy, brain tumors, and postencephalitic Parkinsonism.^{5, 6} The first cerebral venogram was accomplished in 1931 when an inadvertent delay in photographing an angiographic plate led to an image of the venous angiographic phase, which Moniz termed a "cerebral phlebogram."

The technique became fully developed in the 1930s. By then, cerebral angiography involved direct percutaneous puncture of the carotid artery and injection of iodinated

organic contrast media.⁷ Despite a flurry of publications about cerebral angiography over the ensuing decade, many by Moniz himself, ventriculography and encephalography remained more popular as methods to image intracranial pathology.⁸ Moniz was awarded the Nobel Prize in Physiology and Medicine in 1949 for his work on frontal leucomy for psychiatric disorders, which, unlike cerebral angiography, gained early and widespread acceptance by the medical community.⁹ The popularity of cerebral angiography did rise significantly by the 1950s, becoming the premier method to image the intracranial space. The neurosurgeon Gazi Yasargil performed some 10,000 angiograms between 1953 and 1964.⁸

Direct percutaneous puncture of the cervical carotid artery remained the primary technique for cerebral angiography in the 1950s and 1960s. Direct puncture of the vertebral artery was reported in 1956;¹⁰ the posterior circulation was also imaged by puncture of the right brachial artery and retrograde injection of the contrast into the vertebral artery.^{11, 12} The movie *The Exorcist* (1973) featured a graphic (and realistic) depiction of a direct carotid stick. The transition from direct puncture of the cervical vessels to transfemoral artery arteriography began in the late 1960s¹³ and became widespread in the 1970s.

The introduction of computed tomography (CT) in the early 1970s sharply reduced the demand for diagnostic angiography, although the field continued to develop because of the advent of interventional cardiology and other interventional fields. Metrizamide, introduced in the 1970s, was the first nonionic isosmolar iodinated contrast medium. Nonionic contrast media improved the safety and comfort of angiographic procedures considerably.

Digital subtraction angiography (DSA) was introduced in the 1980s as a method for intravenous injection of contrast for imaging the arterial system, as the contrast in the arterial system following intravenous injection was too dilute to be imaged with standard X-rays. Over the ensuing decade, the spatial resolution of DSA imaging improved to the extent that it began to rival the resolution of unsubtracted X-ray images. Further technical refinements in recent years include rotational angiography, 3D angiography, and flat panel detectors for imaging.

2.4. Complications of diagnostic cerebral angiography

Informed consent prior to an angiogram should include an estimate of the risk of complications.

2.4.1. Neurological complications

Neurological complications in cerebral angiography are most commonly cerebral ischemic events that occur as a result of thromboembolism or air emboli from catheters and wires. Other causes include disruption of atherosclerotic plaques and vessel dissection. Less common neurological complications include transient cortical blindness^{14 15} and amnesia.¹⁶

In a prospective analysis of 2,899 diagnostic cerebral angiograms, the largest recent series published to date, Willinsky and colleagues reported an overall rate of neurological complications of 1.3%.¹⁷ Of these, 0.9% were transient or reversible, and 0.5% were permanent. The Asymptomatic Carotid Atherosclerosis Study (ACAS) reported an often quoted neurological complication rate of 1.2% with angiography.¹⁸

The risk of complications appears to be related to the underlying disease process. Patients with atherosclerotic carotid disease have been reported to be at elevated risk of neurological complications with cerebral angiography.¹⁹ Other risk factors for neurological complications include a recent cerebral ischemic event,^{20, 21} advanced age,^{17, 19} a long angiography procedure time,^{19, 22, 23} and a diagnosis of hypertension,²³ diabetes²³ or renal insufficiency.²⁴

The risk of neurological complications in patients with subarachnoid hemorrhage, intracranial aneurysms, and arteriovenous malformations was found to be relatively low in a meta-analysis of prospective studies of angiography.²¹ For these patients, the overall rate of neurological complications was 0.8%, and the rate of permanent neurological complications was 0.07%. The Joint Standards of Practice Task Force of the Society of Interventional Radiology, the American Society of Interventional and

Table 2.1 Quality improvement guidelines for adult diagnostic neuroangiography

		Suggested complication – specific threshold (%)
Neurological complications	Reversible neurologic deficit	2.5
	Permanent neurologic deficit	1
Non-neurologic Complications	Renal failure	0.2
	Arterial occlusion requiring surgical thrombectomy or thrombolysis	0.2
	Arteriovenous fistula/pseudoaneurysm	0.2
	Hematoma requiring transfusion or surgical evacuation	0.5
All major complications		2

Quality improvement guidelines for adult diagnostic neuroangiography: Cooperative study between ASITN, ASNR, and SIR²⁵

Therapeutic Neuroradiology, and the American Society of Neuroradiology reviewed the complications reported in clinical series and produced guidelines for expected complication rates in neuroangiography (Table 2.1).²⁵ The figures in these guidelines can be quoted to patients during informed consent.

2.4.2. Nonneurological complications

Nonneurological complications of cerebral angiography via the femoral artery include groin and retroperitoneal hematoma, allergic reactions, femoral artery pseudoaneurysm, thromboembolism of the lower extremity, nephropathy, and pulmonary embolism.²⁶ In a review of 2,899 cerebral angiograms, hematomas occurred in 0.4% of procedures, allergic cutaneous reactions occurred in 0.1%, and a pseudoaneurysm occurred after one (0.03%) procedure.¹⁷

2.5. Selective cerebral angiography: basic concepts

2.5.1. Preprocedure evaluation

1. A brief neurological exam must be conducted to establish a baseline, should a neurologic change occur during or after the procedure.
2. The patient should be asked if he or she has had a history of iodinated contrast reactions.
3. The femoral pulse, as well as the dorsalis pedis and posterior tibialis pulses, should be examined.
4. Blood work, including a serum creatinine level and coagulation parameters, should be reviewed.

2.5.2. Pre-angiogram orders

1. NPO except medications for 6 h prior to the procedure.
2. Place 1 peripheral IV (2 if an intervention is anticipated)
3. Place foley catheter (only if an intervention is anticipated)

2.5.3. Contrast agents

Nonionic contrast agents are safer and less allergenic than ionic preparations.^{27–30} Iohexol (Omnipaque®, GE Healthcare, Princeton, NJ), a low osmolality, nonionic contrast agent, is relatively inexpensive and probably the most commonly used agent in cerebral angiography.

1. Diagnostic angiogram: Omnipaque®, 300 mg I mL⁻¹
2. Neurointerventional procedure: Omnipaque®, 240 mg I mL⁻¹

Patients with normal renal function can tolerate as much as 400–800 mL of Omnipaque®, 300 mg I mL⁻¹ without adverse effects.³¹

2.5.4. Femoral artery sheath (vs. no sheath)

Trans-femoral angiography can be done with or without a sheath.

Sheath:

1. Allows for the rapid exchange of catheters and less potential for trauma to the arteriotomy site.
2. Shown in a randomized trial to lessen the frequency of intraprocedural bleeding at the puncture site, and to ease catheter manipulation.³²
3. Short sheath (10–13-cm arterial sheath) is used most commonly
4. Longer sheath (25 cm) is useful when iliofemoral artery tortuosity or atherosclerosis might impair catheter navigation.
5. Technique: A 5-F sheath (Check-Flo® Performer® Introducer set; Cook, Bloomington, IN) is slowly and continuously perfused with heparinized saline (2,000 U heparin per liter of saline) under arterial pressure.
6. Sheaths come in sizes 4 F up to 10 F or larger. The size refers to the inner diameter. The outer diameter is 1.5–2.0 F larger than the stated size.

No sheath:

1. Slightly smaller arteriotomy and permitting earlier ambulation.
2. Use a 4-F, 5-F, or 3-F catheter.³³
3. Technique: After the Potts needle enters the femoral artery, a 145 cm 0.035 in. J-tipped wire (for most 4-F catheters) or a 145 cm 0.038 in. J-tipped wire (for most 5-F catheters) is introduced instead of a short J-wire. The Potts needle is then exchanged for an appropriately sized dilator, which is then exchanged for the diagnostic catheter.
4. Note: If a 4-F catheter is going to be used without a sheath, use a 19 gauge arterial access needle or a micropuncture set, because a standard 18 gauge Potts needle creates an arteriotomy larger than the catheter, resulting in bleeding around the catheter.

2.5.5. Sedation/analgesia

1. Midazolam (Versed®) 1–2 mg IV for sedation; lasts approximately 2 h
2. Fentanyl (Sublimaze®) 25–50 mcg IV for analgesia; lasts 20–30 min

The use of sedation should be minimized, as over-sedation makes it hard to detect subtle neurological changes during the procedure. Paradoxical agitation has been reported in up to 10.2% of patients,³⁴ particularly elderly patients and patients with a history of alcohol abuse or psychological problems.³⁵ Flumazenil (Romazicon®) 0.2–0.3 mg IV can reverse this effect.³⁶

2.5.6. Suggested wires and catheters for diagnostic cerebral angiography

2.5.6.1. Hydrophilic wires

- The 0.035 in. angled Glidewire® (Terumo Medical, Somerset, NJ) is soft, flexible, and steerable.
- The 0.038 in. angled Glidewire® (Terumo Medical, Somerset, NJ) is slightly stiffer than the 0.035 in., making it helpful when added wire support is needed.
- Extra-stiff versions of these wires are available for even more support, but they should be used with extreme caution because of the tendency of the tip to dissect vessels.

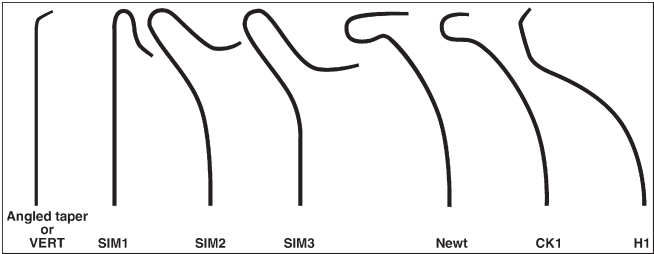


Fig. 2.1 Recommended diagnostic catheters.

Catheter	Use
5-F Angled Taper	Good all-purpose diagnostic catheter
4- or 5-F Vertebral	Good all-purpose diagnostic catheter, slightly stiffer than the Angled Taper but similar in shape
4 or 5F Simmons 1	Spinal angiography
4 or 5F Simmons 2 or 3	Left common carotid artery; bovine configuration; tortuous aortic arch; patient's age >50
5F CK-1 (aka HN-5)	Left common carotid or right vertebral artery
5F H1 (aka Headhunter)	Right subclavian artery; right vertebral artery
4 or 5F Newton	Tortuous anatomy, patients >65

Measurement systems

- *Needles*: Gauge, which is a measurement system too obscure for the human mind to grasp. The larger the gauge, the smaller the needle
- *Catheters*: French (F), defined as the outer diameter of a catheter measured as a multiple of thirds of a millimeter ($\text{French number}/3 = \text{outer diameter in mm}$)
- *Wires*: Measured in thousandths of an inch. (a 0.035 wire is 0.035 in. thick)

2.6. Catheter navigation

Diagnostic catheters should usually be advanced over a hydrophilic wire. The wire keeps the catheter tip from rubbing against the wall of the vessel and causing a dissection. When advancing the wire and catheter toward the aortic arch from

the femoral artery, the tip of the wire should be followed by direct fluoroscopic visualization. The catheter/wire assembly should never be advanced with <8–10 cm of wire extending from the tip, as a short length of leading wire can act as a spear and cause injury to the intima. A catheter/wire assembly with only a few cm of wire sticking out can resemble a Roman short sword (Fig. 2.2).

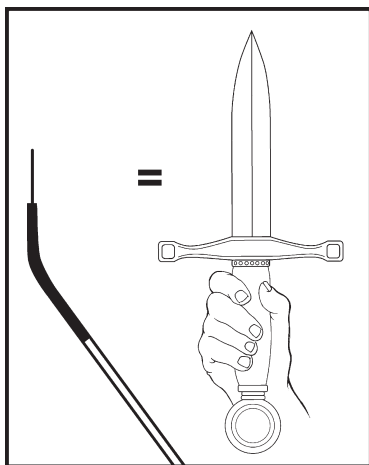


Fig. 2.2 Roman short sword.

2.7. Roadmapping

Roadmapping should be used when engaging the vertebral arteries, and the internal and external carotid arteries. Roadmapping is essential during intracranial navigation. In some angiography suites, a “false roadmap” can be created using a regular digital subtraction angiogram; a frame from an angiographic run is selected, then inverted (i.e., vessels are turned white against a black background). This technique conserves contrast and reduces radiation exposure.

2.8. Double flushing

Double flushing consists of aspiration of the contents of the catheter with one 10-mL syringe of heparinized saline, followed by partial aspiration and irrigation with a second syringe of saline. This maneuver clears clots and air bubbles from the catheter, and should be done every time a wire is removed from the catheter, prior to the injection of contrast. Meticulous attention to detail is required to prevent blood from sitting in the catheter lumen, where it can coagulate into potential emboli. Any air bubbles in the system can also occlude small vessels if injected intravascularly.

2.9. Continuous saline infusion

A three-way stopcock or manifold can be used to provide a heparinized saline drip through the catheter. This continuous drip is particularly useful if there is any delay between injections of contrast, because it keeps the catheter lumen free of blood products. Careful double flushing is still required if a wire is inserted and removed or if any blood is present in the lumen. Use of stopcocks and continuous infusion is mandatory for any therapeutic intervention.

2.10. Hand injection

A 10-mL syringe containing contrast should be attached to the catheter, and the syringe should be snapped with the middle finger several times to release bubbles stuck to the inside surface. The syringe should be held in a vertical position, with the plunger directed upward, to allow bubbles to rise away from the catheter (Fig. 2.3). For larger vessels, like the common carotid artery, the plunger on the syringe can be depressed with the palm of the hand in order to generate enough force; for smaller vessels, like the vertebral arteries, thumb-depression of the plunger is sufficient. An adequate angiographic run can be done with a single swift injection of 4–6 mL of contrast (70%) mixed with saline (30%). The patient should be instructed to stop breathing (“Don’t move, don’t breath, don’t swallow”) for several seconds during the angiogram, then told to start breathing again.

A Poetic Interlude

Bubbles

I love ‘em in my lager.

I love ‘em in my stout.

But when they get inside my head

I want to get them out!

I hate them in carotids.

I hate them in the “verts.”

They end up doing something bad.

Oh yes, it really hurts!

The small ones make me stupid.

The big ones make me dead.

‘Cause when they get inside me

They dance around my head!

The little doctors search and search

And shake out all they find.

The ones they missed

(It makes me pissed!)

Will make me lose my mind!

They find them in my saline.

They find them everywhere!

And superficial temporal ones

Will make me lose my hair!

Prevention of cerebral air emboli

- Use meticulous technique for flushing and contrast injections (see above).
- Whenever possible, flush the catheter in the descending aorta to keep bubbles away from the cerebral circulation.
- After filling a syringe, allowing it to sit for a few minutes before injection will allow bubbles to come out of suspension and become visible.³⁷
- A slower flush is less likely to cause bubbles than a rapid flush.³⁷
- 1.2- μ m Intrapur[®] filter (B. Braun Medical, Bethlehem, PA) in the tubing for contrast or saline injections can reduce the risk of air emboli.³⁸

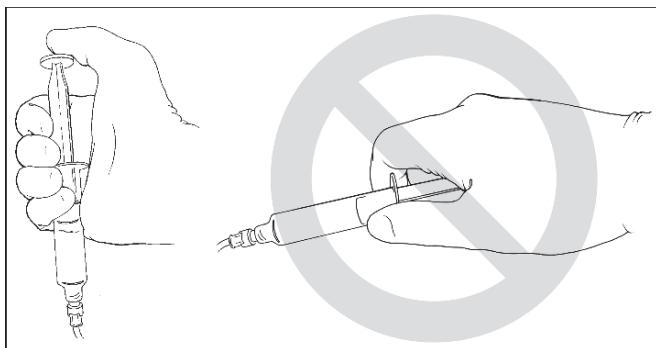


Fig. 2.3 Syringe holding method for hand injections. Correct method (*left*): The syringe is grasped in the palm of the hand when it is attached to the catheter; this position places the plunger in an upright position to allow bubbles to rise away from the attachment to the catheter. Incorrect method (*right*): The syringe is held in a horizontal position, like a weapon. Bubbles can go any which way.

Management of cerebral air emboli

Prevention is best, but if air emboli are suspected, urgent treatment is required to prevent stroke caused by occlusion of flow in vessels due to the surface tension produced by the interface between air and blood.

- If the gas embolus is large enough to be detected fluoroscopically, and the vessel is easily accessible, a microcatheter may be used to aspirate the gas embolus and flush the vessel with heparinized saline to break up the remaining bubbles.
- Quick and readily available (though unproven) methods include the use of transcranial Doppler (to agitate and break up bubbles), heparinization (to prevent clot from forming in vessels stagnating from the air), and administration of oxygen and induction of hypertension (as in vasospasm therapy).
- If available, hyperbaric oxygen chambers have been shown (anecdotally and in small series) to result in good outcomes.^{39–42} One series suggests that even after considerable delay in initiating therapy, hyperbaric oxygen helps.⁴³ However, a larger series showed 67% good outcome when hyperbaric treatment was started within 6 h after the onset of symptoms, vs. only 35% good outcomes when treatment began later.⁴⁴
- Induction of retrograde cerebral flow by infusing arterial blood under pressure in the jugular vein has been shown to limit ischemic damage to the brain.⁴⁵
- When in doubt, a variety of methods can be used simultaneously, including hyperbaric oxygen *plus* retrograde cerebral flow *plus* induction of barbiturate coma to attempt to protect the brain.⁴⁶
- The most important thing is to recognize that air emboli have occurred and then use whatever treatment modalities that are available.

2.11. Mechanical injection

A power contrast injector is necessary for aortic arch angiograms, and some operators prefer to use an injector routinely for other vessels as well. Mechanical injection can lower radiation exposure to the operator's hands and body.⁴⁷ The pressure (pounds per square inch, psi) and flow rate during the injection should not exceed the rated pressure or flow rate of the catheter. Likewise, if a stopcock is used, the psi during injection should not exceed the rated pressure and flow rate. Common power injector settings for selective catheter digital subtraction diagnostic angiograms using a

5-F catheter are listed in Table 2.2. The term “rate rise” refers to a setting on the mechanical injector that causes it to gradually increase the rate of contrast flow during the injection, to prevent the catheter tip from being kicked out of the vessel it is in. Rate rise is defined as the time required during the injection to reach the maximum flow rate. If the vessel is smaller than average, occluded, or if the catheter is in an unstable position within the vessel, a rate rise of 0.3–0.5 s should be used. Power injector settings are different (longer) when a 3D angiogram is done; typical settings for 3D images are 3 mL s⁻¹, total of 6 mL or 4 mL s⁻¹, total of 12 mL.

Table 2.2 Standard power injector settings

Vessel	Power injector settings
Aortic arch	20 mL s ⁻¹ ; total of 25 mL
Common carotid artery	8 mL s ⁻¹ ; total of 12 mL
Subclavian artery	6 mL s ⁻¹ ; total of 15 mL
Internal carotid artery	6 mL s ⁻¹ ; total of 8 mL
External carotid artery	3 mL s ⁻¹ ; total of 6 mL
Vertebral artery	6 mL s ⁻¹ ; total of 8 mL

For digital subtraction angiography using a 5-F catheter

2.12. Vessel selection

A cerebral angiogram should begin with the vessel of interest first, so that the most important vessels can be imaged in case problems with the equipment or the patient prevents completion of the entire angiogram. Following catheterization of the vessel of interest, it is usually easiest to navigate from right to left (i.e., the right vertebral artery, followed by the right common carotid artery, etc.).

2.12.1. Angiographic Images and standard views

Biplane angiography is the standard of care for cerebral angiography. It allows for orthogonal images to be simultaneously obtained with a single contrast injection, limiting the time and amount of contrast needed to adequately visualize the cerebral vasculature. Monoplanar cerebral angiography is acceptable only when biplane equipment is not available; the use of monoplane imaging is limited by its inability to perform automatic optical calibration and to image from orthogonal views simultaneously.

1. When viewing the angiographic images, the contrast and brightness of the image should be adjusted so that vessels are semitransparent; this can allow visualization of aneurysms, branches, or filling defects (e.g., intraluminal thrombus) which may otherwise not be visible.
2. Other imaging features worthy of attention during the performance of a cerebral angiogram:
 - (a) Vessel contour and size (“angioarchitecture”)
 - (b) Contrast flow patterns
 - (c) Presence or absence of a vascular blush
 - (d) Venous phase (i.e., do not forget to examine the venous phase)
 - (e) Bony anatomy

Standard postero-anterior (PA) projections are illustrated in Fig. 2.4. The standard PA view places the petrous ridges in the lower 1/3 of the orbits. The Caldwell projection aligns the petrous ridges with the bottoms of the orbits to provide an optimal view of orbital and supratentorial structures unobstructed by the petrous ridges. The Towne’s view aligns the petrous ridges with the superior rim of the orbits and is the standard PA view for imaging the posterior fossa. The Water’s view is inclined 45° relative to the skull base and positions the petrous ridges some distance below the orbits; this is a good view for imaging the maxillary sinuses.

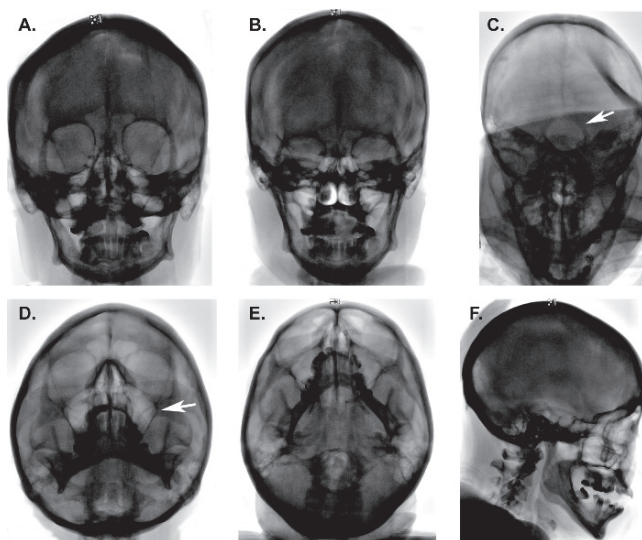


Fig. 2.4 Standard PA and lateral projections

- PA (postero-anterior). The petrous bones are at the lower edge of the orbits.
- Caldwell. The petrous bones are about one third of the way up the orbits.
- Towne. The foramen magnum (arrow) can be seen through the calvarium.
- Water. The view is from below; the maxillary sinuses (arrow) can be seen clearly.
- Submentovertex. The view is from way below; the vertex of the skull is framed by the mandible.
- Lateral. On a straight lateral view, the floors of the left and right frontal fossas directly overlapping.

The Houghton projection is a lateral view and is helpful for imaging the carotid siphon and the middle cerebral bifurcation. The patient's head is inclined away from the side of the injected carotid artery;⁴⁸ this view opens up the carotid siphon.

Pearl

Mnemonic for remembering the relative positions of the standard PA projections: The *Water(s)* runs beneath the *Town(e)*. *Caldwell* is in between.

2.12.2. Frame rates for digital subtraction angiography

Most cerebral angiography can be done with 3–5 frames per second (fps). Higher rates (e.g., 8–20 fps) are useful for imaging arteriovenous malformations and other high-flow lesions. Usually, a variable frame rate may be used to limit radiation dose, since a higher frame rate (3 per second) is needed in the arterial phase, whereas a lower rate (0.5–1 per second) can be used in the venous phase. For standard cerebral

Table 2.3 Standard views

Target	Optimal views	Additional views/ comments
Carotid bifurcation	PA	Ipsilateral oblique
	Lateral	
Anterior intracranial circulation	Caldwell	Transorbital oblique
	Lateral	
ICA cavernous segment	Caldwell	Haughton
	Lateral	
ICA ophthalmic segment	Caldwell	Transorbital oblique
	Lateral	
Posterior communicating artery aneurysms	Haughton	Lateral
	Transorbital oblique	
ICA bifurcation	Transorbital oblique	
Anterior communicating artery aneurysms	Transorbital oblique	
Middle cerebral artery aneurysms	Transorbital oblique	.
	Submentovertex	
Middle cerebral artery candelabra	Lateral with Haughton	
	Waters with oblique	
Vertebral artery origin	Towne	The vertebral artery arises from the posterior aspect of the subclavian artery
Posterior circulation	Water	Ipsilateral oblique
	Lateral	
Basilar artery	Water	Ipsilateral oblique
	Lateral	Water will "elongate" the basilar artery trunk
PCA, SCA, AICA, PICA	Towne	Ipsilateral oblique
	Lateral	
Basilar apex aneurysms	Water	Ipsilateral oblique
	Lateral	

Angiographic positions for common anatomical targets. *ICA* internal carotid artery, *PCA* posterior cerebral artery, *SCA* superior cerebellar artery, *AICA* anterior inferior cerebellar artery, *PICA* posterior inferior cerebellar artery

arteriography, a 10–12s imaging sequence allows for visualization of arterial, capillary, and venous phases.

2.12.3. Calibration and measurement

Biplanar angiography units are capable of auto-calibration by analysis of simultaneous orthogonal images. Monoplanar angiography requires placement of a marker on or in the patient. A United States dime is 18mm in diameter and can be taped to the patient's face or head; however a marker on the surface of the patient's body can

be inaccurate in the measurement of internal structures because of magnification. Magnification error can lead to errors in linear measurement of up to 13%.⁴⁹ Markers on intravascular catheters and wires, placed close to the angiographic target, are more accurate. The ATW[™] Marker Wire (Cordis, Miami Lakes, FL) has radio-opaque markers that are 1-mm wide and spaced 10 mm apart. “Two-tipped” microcatheters for detachable coil deployment have markers that are spaced 3 cm apart. To maximize accuracy, the calibration marker and the structure being measured should be as close to the center of the image as possible to minimize the effect if X-ray beam divergence.

2.13. Procedures

2.13.1. Femoral artery puncture

1. The groin area is prepped and draped.
2. The femoral pulse is palpated at the inguinal crease, and local anesthesia (2% lidocaine) is infiltrated, both by raising a wheal and injecting deeply toward the artery.
3. Five-millimeter incision is made parallel to the inguinal crease with an 11-blade scalpel.
4. A Potts needle is advanced with the bevel facing upward. The needle is advanced at a 45° angle to the skin, pointing toward the patient’s opposite shoulder.
5. A single wall puncture is useful if heparin or antiplatelet agents are used. It can be done by looking for blood return from the hollow stylet of the Potts needle. The needle should be advanced one to two millimeters after the first blood return since the stylet protrudes that far beyond the tip of the needle.
6. A two wall puncture is obtained by advancing the needle through and through both vessel walls, then removing the stylet, and slowly withdrawing the needle until pulsatile blood return is obtained.
7. When bright red, pulsatile arterial blood is encountered, a J-wire is gently advanced through the needle for 8–10 cm.
8. The needle is then exchanged for a 5-F sheath, which is secured with a silk stitch.

Pearls

If the artery is difficult to locate, try the following tricks:

- When the Potts needle is inserted, let go of the needle. If the needle pulsates, the artery is usually located to the side that the needle is pulsating toward.
- Fluoroscopic bony landmarks. On PA fluoroscopy, the femoral artery is located 1 cm medial to the center of the femoral head (Fig. 2.5).
- Use a micropuncture set (see instructions below). An atherosclerotic femoral artery can be heavily calcified and deflect larger needles; a smaller needle can be helpful.
- Use a needle with a doppler ultrasound stylet (Smart-needle®, Peripheral Systems Group, Mountain View, CA) (20 gauge or smaller) to allow puncture of a non-palpable vessel.
- Try the opposite groin or the upper extremity approach.
- Puncturing vascular grafts can be difficult due to extensive scar tissue. This may require use of a stiff Amplatz guidewire, use of dilators one size larger than the inserted catheter or sheath, and certain soft catheters should not be used because they may fracture. In general, it is best to use a sheath in Gortex grafts.



Fig. 2.5 Fluoroscopic landmarks for femoral artery puncture. The femoral artery is located approximately 1 cm medial to the center of the femoral head. The "X" indicates the center of the femoral head.

Micropuncture technique

1. Obtain micropuncture set
2. Insert the 21 gauge needle in same fashion as a Potts needle.
3. Insert 0.018 in. microwire.
4. Exchange 21 gauge needle for the dilator.
5. Exchange dilator for the sheath.

2.13.2. Aortic arch imaging

1. A 4-F or 5-F pigtail catheter is guided over a hydrophilic wire into the ascending part of the aortic arch.
2. The image intensifier (II) is placed on low magnification and rotated 30° to the left.
3. The patient's head is rotated to the left, so that his or her face is facing the II (this position will permit visualization of the cervical vessels).
4. A power injector is used to administer contrast.
5. Standard left anterior oblique (LAO) view can be supplemented with a lateral view by rotating the II 30° to the right.

2.13.3. Carotid artery catheterization

1. An angled diagnostic catheter is advanced over a hydrophilic wire over the aortic arch to a position proximal to the innominate artery.
2. The wire is then brought back into the catheter, and the catheter is gently pulled back, with the tip of the catheter facing superiorly, until the innominate artery is engaged. The wire is then advanced superiorly in the right common carotid artery, followed by the catheter.
3. To engage the left common carotid artery, the catheter is gently and slowly pulled out of the innominate artery, with the wire inside the catheter and the tip facing to the patient's left, until the catheter "clicks" into the left common carotid. The wire is then advanced superiorly, followed by the catheter.
4. For older patients (>50 years), and those with a bovine arch configuration, the Simmons II catheter is helpful for accessing the left common carotid.

5. If selective internal carotid artery catheterization is planned, angiography of the cervical carotid system should be done to check for internal carotid artery stenosis for any patient at risk of atherosclerosis. Catheterization of the internal carotid artery should be done under road-map guidance.
6. Turning the patient's head away from the carotid being catheterized may allow the wire and/or catheter to enter the vessel more easily.
7. Once the common carotid is catheterized, turning the head away from the side being catheterized facilitates internal carotid catheterization, and turning toward the ipsilateral side facilitates external carotid catheterization.
8. When the wire or catheter does not advance easily into the vessel of interest, asking the patient to cough may sometimes bounce the catheter into position.

2.13.4. Vertebral artery catheterization

1. An angled diagnostic catheter is advanced over a hydrophilic wire and placed in the subclavian artery. Intermittent "puffing" of contrast will allow identification of the vertebral artery origin.
2. A road map is made and the wire is passed into the vertebral artery until the tip of the wire is in the upper third of the cervical portion of the vessel. Placing the wire relatively high in the vertebral artery provides adequate purchase for advancement of the catheter, will help straighten out any kinks in the artery that may be present near the origin, and will also facilitate smooth passage of the catheter past the entrance of the of artery into the foramen transversarium at C6. The C6 foramen transversarium is where the vertebral artery makes a transition from free-floating to fixed, and is a region at risk for iatrogenic dissection if the catheter is allowed to scrape against the wall of the vessel.
3. Remember that the vertebral artery makes a right angle turn laterally at C2, so be careful not to injure the vessel at that point with the wire.
4. After removal of the wire, and double flushing, an angiogram should be done with the tip of the catheter in view, to check for dissection of the vessel during catheterization.
5. For patients at risk of atherosclerosis, an angiogram of the vertebral artery origin should be done prior to accessing the vessel to check for stenosis.
6. Uncommonly, the left vertebral artery arises directly from the aorta, which should be kept in mind when the origin of the vessel cannot be found on the left subclavian artery.
7. When kinks or loops in the vessel prevent catheterization, tilting the head away from the vertebral artery being catheterized can help.

Several options exist for patients in whom vessel tortuosity (usually of the innominate artery) makes catheterization of the vertebral artery difficult.

1. The roadmap should be done with an ipsilateral oblique Towne view; this will show the vertebral artery origin, and separate the vertebral artery from the common carotid artery.
2. A Headhunter catheter is well suited for navigation through a tortuous innominate artery.
3. Other catheters that can be helpful in negotiating a difficult right vertebral artery are the Vertebral catheter and the DAV catheter.
4. When catheterization of the vertebral artery is not possible because of tortuosity of the great vessels or atherosclerotic stenosis, an adequate angiogram can be done by inflating a blood pressure cuff on the ipsilateral upper extremity and injecting 100% contrast into the subclavian artery with a power injector. Be careful not to place the catheter with its tip in the thyrocervical or costocervical trunks. A large volume contrast injection in these small vessels can be painful, and can cause spinal cord injury in cases where large spinal cord feeders arise from these branches, or even directly from the subclavian artery. If the catheter tip cannot be placed in a stable position in the subclavian artery proximal to the origin of the vertebral artery, place the tip distal to the origin of the vertebral artery.
 - The power injector should be set to allow a good injection without kicking the catheter out.
 - 6 mL s⁻¹; total of 25 mL
 - Linear rate rise: 0.5 s

2.13.5. Reconstituting a Simmons 2 catheter

The Simmons 2 catheter is useful in the catheterization of the left common carotid artery, particularly when there is a bovine configuration, when the aortic arch is tortuous, and in patients aged >50. The catheter can be reconstituted in the left subclavian artery, the aortic arch, or the aortic bifurcation (Figs. 2.6 and 2.7). Reconstitution in the left subclavian or aortic bifurcation is preferred to the aortic arch, to minimize risk of dislodging atherosclerotic plaque material and subsequent embolization into the intracranial circulation.

Remember that the tip of the Simmons catheter advances into the vessel when you pull back on the catheter at the groin and pulls out of the vessel when the catheter is pushed forward at the groin. This effect is the reverse of the behavior of more simple-curved or angled catheters. The Simmons catheter can also be advanced antegrade over a wire, allowing for selective catheterization of the internal or external carotid arteries.

2.13.6. Femoral artery puncture site management

The “gold standard” for management of the arteriotomy after an angiogram is manual compression.

1. The sheath is removed while pressure is applied to the groin 1–2 cm superior to the skin incision.
2. Pressure is applied for 15 min, usually 5 min of occlusive pressure, followed by 10 min of lesser pressure.
 - (a) For patients on aspirin and/or clopidogrel, a longer time is required, usually 40 min. At the end of the time period, pressure on the groin is slowly released and a pressure dressing is applied.
3. At the end of the time period, pressure on the groin is slowly released and a pressure dressing is applied.
4. The Chito-seal[™] pad (Abbott Laboratories, Abbott Park, IL) and the Syvek[®] NT Patch (Marine Polymer Technologies, Inc., Danvers, MA) are topical hemostatic agents that can be applied to the incision after sheath removal to accelerate hemostasis.
 - (a) In an animal model, the Syvek[®] Patch was found to control bleeding better than Chito-seal[™].⁵⁰
 - (b) These topical agents cannot be expected to produce the same security of hemostasis as the closure devices described below, especially if the sheath size is greater than 5 French.

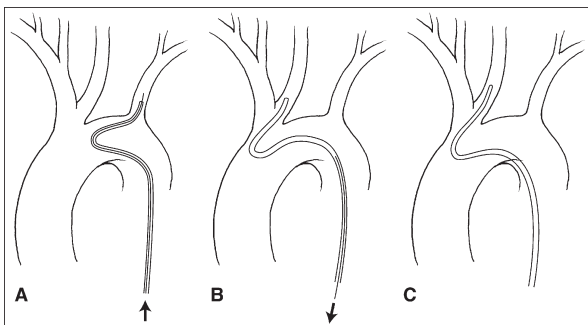


Fig. 2.6 Reconstituting a Simmons 2 Catheter in the left subclavian artery. The catheter is advanced over a hydrophilic wire into the left subclavian artery so that the tip is in the subclavian artery (A), and the primary bend in the catheter (the “elbow”) is in the aortic arch. The wire is then withdrawn until the tip is proximal to the elbow (B), and the catheter is then pushed forward, until the elbow moves into the proximal part of the aortic arch (C), and the tip of the catheter is out of the subclavian artery, directed backward toward the shaft of the catheter.

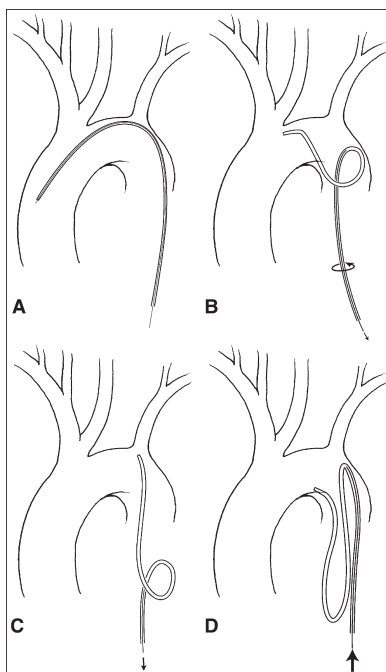


Fig. 2.7 Alternative method for reconstituting a Simmons 2 Catheter. The catheter is advanced over a hydrophilic wire so the tip of the catheter is in the ascending aorta (A). The wire is then withdrawn until the wire tip is proximal to the elbow, and the catheter is rotated clockwise as it is simultaneously withdrawn so that the loop is in the descending aorta (B–C). The wire is then advanced swiftly (D), to reconstitute the catheter.

5. The femoral artery clamp (Compressor[®], Instromedex, Hillsboro, OR) can be used instead of manual compression; the patient must be cautioned to remain still while the clamp is in place.
6. A balloon compression dressing (FemoStop[®]plus Femoral Compression System, Radi Medical Systems, Wilmington, MA) compresses the site with a balloon, but the balloon must be deflated after 1 h to prevent pressure injury to the skin. The dressing is then left in place and the balloon can be reinflated if oozing from the site occurs.
7. After compression, the patient should remain supine for 5 h, then be allowed to ambulate but remain under nursing observation for one more h prior to discharge.
8. Using topical hemostatics, the patient should remain flat in bed for 2 h, and can ambulate in 3 h.

2.13.7. Closure devices

Percutaneous femoral artery closure devices can allow the patient to ambulate sooner than with compression techniques, and can be helpful when the patient is on antiplatelet or anticoagulant medications. When a closure device is used, the patient should remain supine for 1 h. These devices are particularly useful in patients receiving anticoagulation or antiplatelet therapy. However, there is a greater risk of

complications with the use of closure devices. In a meta-analysis to assess the safety of closure devices in patients undergoing percutaneous coronary procedures, an overall analysis favored mechanical compression over closure devices.⁵¹

2.13.8. Selected femoral artery closure devices

1. Perclose® Pro-glide™ (Perclose, Inc., Menlo Park, CA).
 - (a) Closure method: A proline stitch is placed in the arteriotomy.
 - (b) Requires a femoral artery angiogram; the puncture site must be at least 1 cm away from major branches of the vessel, such as the femoral artery bifurcation (Fig. 2.8).
 - (c) Advantage: The same artery can be re-punctured immediately if necessary.
2. Angio-Seal™ (St. Jude Medical, St. Paul, MN).
 - (a) Closure method: The device creates a mechanical seal by sandwiching the arteriotomy between a bioabsorbable anchor and a collagen sponge, which dissolves within 60–90 days.
 - (b) May be used at femoral artery branch points.
 - (c) Manufacturer recommends that the vessel not be re-punctured for at least 3 months.

2.13.9. Post-angiogram orders

1. Bed rest with the accessed leg extended, head of bed $\leq 30^\circ$, for 5 h, then out of bed for 1 h. (If a closure device is used, bed rest, with head of bed $\leq 30^\circ$, for 1 h, then out of bed for 1 h).
2. Vital signs: Check on arrival in recovery room, then Q 1 h until discharge. Call physician for SBP < 90 mmHg or decrease 25 mmHg; pulse > 120 .

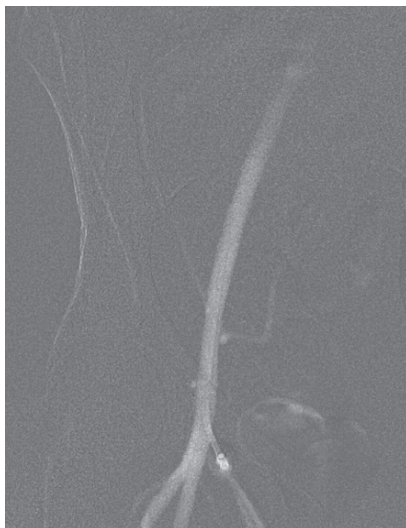


Fig. 2.8 Femoral artery angiogram done prior to the use of a closure device. Injection of contrast through the sheath shows that the sheath enters the femoral artery proximal to the bifurcation. Optimal visualization of the femoral bifurcation is usually obtained with an ipsilateral or contralateral oblique angiogram.

3. Check the puncture site and distal pulses upon arrival in recovery room, then Q 15 min $\times$ 4, Q 30 min $\times$ 2, then Q 1 h until discharge. Call physician if
 - (a) Bleeding or hematoma develops at puncture site.
 - (b) Distal pulse is not palpable beyond the puncture site.
4. Extremity is blue or cold.
5. Check puncture site after ambulation.
6. IVF: 0.9 N.S. at a maintenance rate until patient is ambulatory.
7. Resume pre-angiogram diet.
8. Resume routine medications.
9. PO fluids 400 mL.
10. D/C IV prior to discharge.

2.14. Special techniques and situations

2.14.1. Radial or brachial artery puncture

The arteries of the upper extremity are a useful alternative to the femoral artery for both diagnostic cerebral angiography and some neurointerventional procedures. Access via the radial⁵² or brachial artery⁵³ eliminates the risk of retroperitoneal hemorrhage and the need for several hours of bed rest that are associated with femoral artery puncture. In addition, an upper extremity approach can be advantageous when vessel tortuosity makes access to the vertebral artery difficult from a femoral approach. The authors prefer the radial approach to the brachial artery approach, as the radial approach seems to be easier⁵⁴ and less prone to complications than the brachial approach.

Prior to the radial artery puncture, an Allen test is necessary to ensure adequate collateral circulation to the hand from the ulnar artery. A pulse oximeter is placed on the patient's thumb, and the patient is instructed to repeatedly clench the fist. The examiner begins by compressing both the radial artery and the ulnar artery until the pulse oximetry tracing flattens, then pressure is taken off the ulnar artery. Normal capillary refill time is 5 s or less; a refill time of greater than 10 s is abnormal and an evidence of poor collateral circulation to the hand from the ulnar artery via the palmar arch. In a series of patients undergoing coronary catheterization, an Allen test finding indicating poor collateral circulation was found in 27% of patients.⁵⁵

Once adequate circulation is confirmed by the Allen test, the forearm is prepped and draped. Injection of lidocaine is used for local anesthesia, and a micropuncture set is used to place a 4-F or 5-F sheath in the radial artery. Once the sheath is inserted, the stopcock on the sheath is opened briefly and pulsatile arterial backflow is observed to confirm adequate positioning of the sheath within the artery. A 10 mL "radial artery cocktail" is then infused into the sheath as a measure to minimize the risk of vasospasm and thrombosis of the radial artery. Unlike sheaths in the femoral artery, a continuous heparinized saline drip is not used in the radial sheath, due to the pressure and pain it can produce. An alternative to using a sheath is to use a 3-French Angioptic[™] catheter (AngioDynamics, Queensbury, NY) directly in the radial artery. After completion of the angiogram, the sheath and/or catheter is removed and a pressure dressing is applied to the wrist. The patient can sit up immediately.

Radial Artery Cocktail

Ten mL of saline containing heparin (5,000 IU), verapamil (2.5 mg), cardiac lidocaine (2%, 1.0 mL), and nitroglycerin (0.1 mg)

2.14.2. Selected patient-specific considerations

1. Patients receiving heparin: The heparin infusion should be stopped 6 h prior to the angiogram.
 - (a) If the need is urgent, an angiogram can be done in patients on heparin or who are coagulopathic with minimal risk. The initial puncture should be made with a micropuncture set to minimize potential bleeding.

2. Patients receiving warfarin: Warfarin should be held (and the patient should be placed on a heparin infusion if necessary) until the INR ≤ 1.4 .
3. Patients receiving metformin. See below.
4. Thrombocytopenia: Minimum platelet count for angiography is $75,000 \mu\text{L}^{-1}$.
5. Diabetic patients:
 - (a) Patients taking insulin: The insulin dose should be reduced to half of the usual dose on the morning of the procedure, when the patient is NPO. The procedure should be done as early in the day as possible, and the patient's usual diet and insulin should be resumed.
 - (b) Patients taking metformin-containing oral anti-hyperglycemic medications: See below
 - (c) Protamine should not be used to reverse heparin if the patient has received neutral protamine Hagedorn [NPH] insulin.^{56, 57}
6. Pregnant patients: Every effort should be made to study pregnant patients non-invasively. Occasionally, a catheter angiogram is necessary (e.g., head and neck trauma with possible vascular injury, spontaneous epistaxis, intracranial AVM). Cerebral angiography can be performed safely during pregnancy.
 - (a) Informed consent of the patient or guardian should include a theoretical risk of injury to the fetus.
 - (b) Current recommendations for radiation exposure of the fetus include a maximum dose of 0.5 rem (roentgen-equivalent-man).⁵⁸
 - By shielding the uterus with a lead apron, the maximum dose to the fetus is less than 0.1 rem during cerebral angiography.⁵⁹
 - In general, fetal malformations only occur above a threshold dose of 100–200 mGy ($\sim 10\text{--}20$ rem).⁶⁰
 - (c) Iodinated contrast agents are physiologically inert and pose little risk to the fetus.⁶¹
 - (d) Adequate hydration should be provided to avoid fetal dehydration.⁶²
 - (e) Fluoroscopy: Minimize time and pulse/sec rate during the procedure.
 - (f) Decrease fps during diagnostic runs to a minimum.
7. Pediatric patients. See below.

2.14.3. Contrast-induced nephropathy

Iodinated contrast-induced nephropathy usually appears as an acute worsening in renal function within 3–4 days of the procedure.⁶³ Contrast-induced nephropathy is usually defined as an increase in serum creatinine of 25–50% over baseline, or an absolute rise in serum creatinine of $0.5\text{--}1 \text{ mg dL}^{-1}$.^{64, 65} Patients with renal insufficiency are up to ten times more likely to develop contrast-induced renal failure with administration of iodinated contrast than patients in the general population.⁶⁶ Patients with renal insufficiency (creatinine $\geq 1.5 \text{ mg dL}^{-1}$)⁶⁷ require measures to minimize the risk of contrast-induced injury nephropathy during angiography. Nonionic, low-osmolality contrast agents, such as iohexanol (Visipaque[®], GE Healthcare, Princeton, NJ) and iopromide (Ultravist[®], Schering, Berlin) have been shown to be less renal-toxic when compared to iothexol (Omnipaque[®]).⁶⁸ The smallest possible amount of contrast should be used during the procedure. One of the authors was able to do a carotid angioplasty and stent procedure using a total of 27 mL of Visipaque[™] by diluting the contrast with saline and using it sparingly. Forty-eight hours should be allowed to elapse between procedures utilizing iodinated contrast when possible.⁶⁹ The antioxidant, N-acetylcysteine (Mucomyst[®], Bristol-Myers Squibb, New York) is thought to function as a free-radical scavenger and to stimulate intrarenal vasodilation. Acetylcysteine was shown in a randomized trial to reduce serum creatinine elevation in patients undergoing radiological procedures using non-ionic, low osmolality contrast material.⁷⁰ Prophylactic administration of acetylcysteine (600 mg PO BID) and 0.45% saline IV, before and after administration of the contrast agent, leads to a significant decrease in serum creatinine compared to patients receiving saline only. Subsequently, isotonic IV fluid was found to be superior to half-isotonic IV fluid in reducing the incidence of contrast-induced nephropathy in patients undergoing coronary angioplasty.⁷¹ Gadolinium contrast has also been used as a non-iodinated contrast agent in cerebral angiography,^{72, 73} but extensive testing has not been done to ensure the safety of gadolinium compounds in the cerebral arteries. Hemofiltration has been shown to reduce creatinine elevations after angiography.⁷⁴ For patients with dialysis-dependent renal failure, arrangements should be made with the patient's nephrologist to schedule dialysis after the angiogram.

2.15. Risk factors for contrast-induced nephropathy

- Serum creatinine level $\geq 1.5 \text{ mg dL}^{-1}$
- Diabetes mellitus
- Dehydration
- Cardiovascular disease and the use of diuretics
- Age ≥ 60 years
- Paraproteinemia (e.g., multiple myeloma)
- Hypertension
- Hyperuricemia

The patients at greatest risk for contrast nephrotoxicity are those with both diabetes and renal insufficiency.^{75, 76}

2.16. Methods to reduce risk of contrast-induced nephropathy

- Minimize the use of contrast
- Use Visipaque™ instead of Omnipaque™⁶⁸
- PO hydration (water, 500mL prior to the procedure and 2,000mL after the procedure)
- IV hydration with 0.9 sodium chloride⁷¹
- Acetylcysteine 600mg (3mL) PO BID on the day before and the day of the procedure⁷⁰

2.17. Metformin

Metformin is an oral anti-hyperglycemic and is used in several preparations (listed below). Metformin-associated lactic acidosis is rare but has been reported to have a mortality rate as high as 50%.⁷⁷ Metformin use should be held for 48h after the procedure, and restarted only after serum creatinine has been checked and found to be unchanged. The procedure may be done even if the patient has taken metformin earlier on the same day of the procedure.⁷⁸ Although metformin use seems to be associated with lactic acidosis, a recent systematic review article has questioned whether there is a causal relationship.⁷⁹

2.18. Metformin-containing medications

- Metformin (generic)
- Glucophage®
- Avandamet®
- Glucovance®
- Metaglip®

2.18.1. Contrast reactions: prevention and management

Life-threatening contrast reactions are rare with the use of low-osmolality contrast agents, occurring with a frequency of 0.04%.⁸⁰ Non-life threatening reactions, including cutaneous reactions, which usually occur in a delayed fashion, have an incidence of approximately 1–2%.⁸⁰

2.19. Risk factors for contrast reactions

- History of a reaction to iodinated contrast agents (except flushing, a sensation of heat, or a single episode of nausea).
- History of serious allergic reactions to other materials
- Asthma
- Renal insufficiency
- Significant cardiac disease (e.g., patients with angina, congestive heart failure, severe aortic stenosis, primary pulmonary hypertension, severe cardiomyopathy).
- Anxiety

Previous reaction to contrast medium is the most important risk factor in the prediction of an adverse event.⁸¹ Patients who have had a previous reaction to ionic contrast may not have a reaction to nonionic agents.⁸² A history of seafood allergies, without a specific history of an iodine reaction, usually indicates a hypersensitivity to allergens in seafood, and does not indicate that the patient is unable to tolerate contrast media.⁸³

Premedication with steroids can reduce the risk of a serious contrast reaction.⁸⁴

2.20. Premedication regimen

1. Prednisone 50 mg PO (or hydrocortisone 200 mg IV) 13 h, 7 h, and 1 h prior to contrast injection
2. Diphenhydramine (Benadryl®) 50 mg IV, IM or PO 1 h prior to contrast injection

Steroids should be given at least 6 h prior to the procedure; administration less than 3 h prior to the procedure does not reduce the risk of an adverse reaction.⁷⁸

2.21. Acute contrast reactions: signs and symptoms

- Cutaneous signs (flushing, urticaria, pruritis)
- Mucosal edema
- Generalized edema
- Sudden loss of consciousness
- Hypotension + tachycardia (anaphylactic reaction)
- Hypotension + bradycardia (vasovagal reaction)
- Respiratory distress

2.22. Acute contrast reactions: treatment

Effective treatment depends on prompt recognition of the problem and rapid management (Table 2.4).⁸⁵

2.23. Intraoperative angiography

Intraoperative angiography is employed by some neurosurgeons during surgery for intracranial aneurysms and arteriovenous malformations. In aneurysm surgery, intraoperative angiography findings, such as residual aneurysm or parent vessel compromise, have led to reexploration and clip adjustment in up to 12.4% of cases.^{86, 87} Factors associated with a need for revision include large aneurysm size,⁸⁶ the

Table 2.4 Management of acute contrast reactions in adults**Urticaria**

1. Discontinue procedure if not completed
2. No treatment needed in most cases
3. Give H₁-receptor blocker: Diphenhydramine (Benadryl®) PO/IM/IV 25–50 mg. If severe or widely disseminated: Alpha agonist (arteriolar and venous constriction) Epinephrine SC (1:1,000) 0.1–0.3 mL (=0.1–0.3 mg) (if no cardiac contraindications)

Facial or Laryngeal Edema

1. Give alpha agonist (arteriolar and venous constriction): Epinephrine sc or IM (1:1,000) 0.1–0.3 mL (=0.1–0.3 mg) or, if hypotension evident, Epinephrine (1:10,000) slowly IV 1 mL (=0.1 mg). Repeat as needed up to a maximum of 1 mg
2. Give O₂ 6–10 L min⁻¹ (via mask)
3. If not responsive to therapy or if there is obvious acute laryngeal edema, seek appropriate assistance (e.g., cardiopulmonary arrest response team)

Bronchospasm

1. Give O₂ 6–10 L min⁻¹ (via mask)
2. Monitor: electrocardiogram, O₂ saturation (pulse oximeter), and blood pressure
3. Give beta-agonist inhalers [bronchiolar dilators, such as metaproterenol (Alupent®), terbutaline (Brethaire®), or albuterol (Proventil®)(Ventolin®) 2–3 puffs; repeat PRN. If unresponsive to inhalers, use SC, IM, or IV epinephrine
4. Give epinephrine SC or IM (1:1,000) 0.1–0.3 mL (=0.1–0.3 mg) or, if hypotension evident, Epinephrine (1:10,000) slowly IV 1 mL (=0.1 mg)
5. Repeat as needed up to a maximum of 1 mg

Alternatively: Give aminophylline: 6 mg kg⁻¹ IV in D₅W over 10–20 min (loading dose), then 0.4–1 mg kg⁻¹ h⁻¹, as needed (caution: hypotension)

Call for assistance (e.g., cardiopulmonary arrest response team) for severe bronchospasm or if O₂ saturation <88% persists

Hypotension with Tachycardia

1. Legs elevated 60° or more (preferred) or Trendelenburg position
2. Monitor: electrocardiogram, pulse oximeter, blood pressure
3. Give O₂ 6–10 L min⁻¹ (via mask)
4. Rapid intravenous administration of large volumes of isotonic Ringer's lactate or normal saline

If poorly responsive: Epinephrine (1:10,000) slowly IV 1 mL⁻¹ (=0.1 mg) (if no cardiac contraindications). Repeat as needed up to a maximum of 1 mg

If still poorly responsive seek appropriate assistance (e.g., cardiopulmonary arrest response team)

Hypotension with Bradycardia (Vagal Reaction)

1. Monitor vital signs
2. Legs elevated 60° or more (preferred) or Trendelenburg position
3. Secure airway: give O₂ 6–10 L min⁻¹ (via mask)
4. Secure IV access: Rapid fluid replacement with Ringer's lactate or normal saline
5. Give atropine 0.6–1 mg IV slowly if patient does not respond quickly to steps 2–4
6. Repeat atropine up to a total dose of 0.04 mg kg⁻¹ (2–3 mg) in adult
7. Ensure complete resolution of hypotension and bradycardia prior to discharge

Hypertension, Severe

1. Give O₂ 6–10 L min⁻¹ (via mask)
2. Monitor electrocardiogram, pulse oximeter, blood pressure
3. Give nitroglycerine 0.4 mg tablet, sublingual (may repeat × 3); or, topical 2% ointment, apply 1 in. strip
4. Transfer to intensive care unit or emergency department
5. For pheochromocytoma – phentolamine 5 mg IV

Seizures or Convulsions

(continued)

Table 2.4 (continued)

1. Give O₂ 6–10 L mm⁻¹ (via mask)
 2. Consider diazepam (Valium®) 5 mg (or more, as appropriate) or midazolam (Versed®) 0.5–1 mg IV
 3. If longer effect needed, obtain consultation; consider phenytoin (Dilantin®) infusion 15–18 mg kg⁻¹ at 50 mg min⁻¹
 4. Careful monitoring of vital signs required, particularly of pO₂ because of risk of respiratory depression with benzodiazepine administration
 5. Consider using cardiopulmonary arrest response team for intubation if needed
- Pulmonary Edema**
1. Elevate torso; rotating tourniquets (venous compression)
 2. Give O₂ 6–10 L min⁻¹ (via mask)
 3. Give diuretics – furosemide (Lasix®) 20–40 mg IV, slow push
 4. Consider giving morphine (1–3 mg IV)
 5. Transfer to intensive care unit or emergency department
 6. Corticosteroids optional

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superior hypophyseal artery and clinoidal segment locations,⁸⁶ and the occurrence of an intraoperative rupture.⁸⁸ A portable C-arm digital subtraction angiography unit is necessary for intraoperative angiography, and a radiolucent head holder (Ohio Medical Instruments, Cincinnati, OH) and radiolucent operating table (Skytron, Grand Rapids, MI) are helpful, although adequate intraoperative imaging can be done even without radiolucent hardware. A femoral artery sheath should be placed prior to the operation. Use of a braided sheath will prevent kinking if the patient is moved after sheath placement. Continuous infusion of heparinized saline (5,000 U in 500 mL saline on a pressure bag at 3 mL h⁻¹) will maintain the patency of the sheath without a perceptible effect on systemic coagulation. A technique for intraoperative angiography for anterior circulation aneurysms by injection of contrast into the superficial temporal artery has also been described.⁸⁹

2.24. Pediatric cerebral angiography

Use noninvasive imaging modalities whenever possible. Although neurological complications are rare, children have higher rates of femoral artery access complications than adults do. In a series of 176 pediatric cerebral angiograms, no neurological complications occurred but puncture site complications (groin hematoma, bleeding, or reduced pedal pulse) occurred in 4.5%.⁹⁰

2.24.1. Access

1. Draping: use small aperture drape for the groin, and a regular femoral angiography drape for the rest of the angio table.
2. Newborns: the umbilical artery and vein can be used to access both arterial and venous circulations which allow for fairly easy catheterization.
3. The femoral artery is surprisingly superficial.
4. The femoral artery in children is prone to catheter-induced vasospasm, so minimize the amount of manipulation and the size of devices (e.g., use a micro-puncture kit and small catheters).
5. Work without a sheath if possible.
6. Caveat: Initial catheterization of the femoral artery is sometimes surprisingly difficult because of the integrity of the connective tissue around the femoral artery; be sure that the wire that is used to introduce the diagnostic catheter is size-matched to the catheter to facilitate entry.

7. A twisting action can be helpful as the catheter is passed into the femoral artery.
8. An 18 or 20 gauge butterfly needle is useful for the initial femoral artery puncture (hint: cut clear the plastic tubing off the butterfly needle hub).
9. Sometimes an ultrasound-guided needle (e.g., Smart-needle®, Peripheral Systems Group, Mountain View, CA) (20 gauge or smaller) is helpful.⁹¹
10. Femoral artery puncture site management:
 - (a) When compressing the artery after removal of the catheter, pay close attention to the distal lower extremity to ensure adequate perfusion. Overly aggressive manual compression or trauma to the femoral artery can result in long-standing femoral artery stenosis or occlusion, leading to limb atrophy.
 - (b) After compression, the hip and lower extremity can be immobilized by taping or strapping it to an IV board.

2.24.2. Catheters

1. Catheters should be small in caliber and short in length (to minimize dead space in the catheter) (≤ 60 cm).
2. Newborns and young infants:
 - (a) 3-F Harwood-Nash.
 - Very peculiar curve makes it easy to access the left subclavian artery but difficult to navigate into the aortic arch
 - Requires a small guidewire (e.g., 0.018–0.025 in. steerable hydrophilic wire)
3. Older infants and young children:
 - (a) 4-F Pediatric Berenstein
 - (b) 4-F Harwood-Nash
4. All pediatric patients:
 - (a) 3-F Angioptic™ (AngioDynamics, Queensbury, NY).
 - Comes in steam-shapeable straight or curved configurations
 - Use a 21 gauge needle and a small guidewire (e.g., 0.018–0.021 in. steerable hydrophilic wire)

2.24.3. Saline, contrast dose, and volume considerations

1. Use less heparin in the flush: Saline with 20 units of heparin per mL
2. Double flushing with heparinized saline: Be careful to aspirate the minimum amount of blood to minimize blood loss and heparin dose
3. Use small syringes (3 mL or 5 mL) to limit the amount of volume
4. Limit contrast to 4 mL of Omnipaque® 300 per kg body weight
5. Limiting volume is particularly critical in children with Vein of Galen malformations, as these patients often have some degree of high-output congestive heart failure

2.24.4. Imaging parameters and radiation exposure

1. Image intensifier:
 - (a) Use a small field of view.
 - (b) Remove the filter if possible.
 - (c) Lower the X-ray dose as much as possible:
2. Limit fluoroscopy time.
3. Lower the pulse rate during fluoroscopy (e.g., 3–6 fps).
4. Maximize collimation to minimize scatter.
5. Use “low-dose fluoro option” if available as a part of the imaging equipment.
6. Place a lead shield under the gonads if possible.

2.25. Tips for imaging specific vascular structures and lesions

2.25.1. Atherosclerotic carotid and vertebrobasilar disease

- Aortic arch angiogram: identifies aortic atheromas and common carotid artery lesions, and helps planning for potential carotid angioplasty and stenting procedures.
- To image the carotid bifurcation, on the PA view, place the angle of the mandible in the center of the image.
- Oblique views are sometimes necessary to obtain the optimal view of an atherosclerotic plaque.
- When high grade stenosis prevents passage of enough contrast to image the internal carotid artery (ICA), the degree of stenosis can be estimated using the diameter of the contralateral ICA.⁹²
- The vertebral artery origin is best seen with an AP Townes view, because the vertebral artery arises from the posterior wall of the subclavian artery (Fig. 1.37).
- The intracranial vertebral arteries and basilar artery are best seen with an AP Waters view, because the basilar artery travels parallel to the clivus, which is tilted anteriorly in the sagittal plane.

2.25.2. Intracranial aneurysms

- A complete four-vessel angiogram should be done in the setting of subarachnoid hemorrhage, as two or more aneurysms will be found in 15–20% of patients.⁹³
- Selective catheterization of the ICA will prevent branches of the ECA from obscuring the intracranial images.
- External carotid angiography may be needed in aneurysm cases if an extracranial to intracranial arterial bypass is anticipated for surgical treatment, in order to visualize possible donor vessels.
- If a study is done in the setting of subarachnoid hemorrhage, and no aneurysm is found on internal carotid arteriography, external carotid angiography may be useful to rule out an arteriovenous fistula (see below).
- Aneurysm dome, neck, parent vessel, and adjacent vessels should be discerned.
- Selective microcatheter angiography is helpful in imaging large and giant aneurysms.

2.25.3. Cerebral arteriovenous malformations

- All feeding arteries and draining veins should be identified; this usually requires a complete bilateral internal carotid, external carotid, and vertebral angiogram.
- High-speed runs (>5 frames per second) can help clarify anatomy of AVMs, as they are typically high-flow lesions. High-speed runs may also permit more precise measurements of arteriovenous transit times.
- Intracranial aneurysms can be identified and distinguished from enlarged veins by their location on the *arterial side* of the nidus.⁹⁴ In contrast, nidal “pseudoaneurysms” have been described in the arterial or venous side of the nidus; they can be recognized when they appear as a new finding on subsequent angiography.⁹⁵
- Small, obscure AVMs may sometimes be made to be more apparent on angiography by having the patient deliberately hyperventilate for several minutes. Normal vessels will constrict and AVM vessels will be unchanged.⁹⁶

2.25.4. Dural arteriovenous fistulas

- All feeding vessels should be identified; selective catheterization of branches of the external carotid artery is usually necessary.
- After each injection, the angiogram should be allowed to continue until the draining vein (or venous sinus) is imaged.
- On internal carotid and vertebral injections, the venous drainage pathways of the normal brain must be determined to see how it relates to the drainage pathways of the fistula.

2.25.5. Direct (high flow) carotid-cavernous fistulas

- High-speed runs (>5 frames per second) are usually helpful.
- Huber maneuver: Injection of contrast into the ipsilateral vertebral artery with manual compression of the carotid artery; reflux of contrast into the carotid artery can demonstrate the defect in the cavernous carotid artery.⁹⁷
- Slow injection into the internal carotid artery with a compression of the carotid artery below the catheter tip in the neck can also demonstrate the defect in the vessel.⁹⁸
- Special attention should be given to venous drainage and determining whether there is a retrograde cortical venous flow.

2.25.6. Aortic arch

- Angiography of the aortic arch is best done with a power injector and a pigtail catheter positioned in the ascending aorta. The optimal projection is left anterior oblique, 30°, with the patient's head rotated to the left to face the image intensifier. Power injector settings are 20 mL s⁻¹; total of 25 mL.

2.25.7. Assessment of the circle of Willis

- Patency and caliber of the posterior communicating artery can be assessed with the Huber (or Allcock) maneuver: Injection of contrast into the ipsilateral vertebral artery with manual compression of the carotid artery; reflux of contrast into the carotid artery can demonstrate posterior communicating artery.
- The anterior communicating artery can be demonstrated by “cross compression” of the carotid artery. Manual compression of the contralateral common carotid artery while wearing a lead glove during injection of contrast into the ipsilateral internal carotid artery will help visualize the anterior communicating artery.

2.25.8. Carotid siphon and MCA candelabra

- The “Haughton view” can be used to open up the carotid siphon (useful for imaging the origins of the P-comm and anterior choroidal arteries) and to unfurl the branches of the MCA within the Sylvian fissure.⁴⁸ This view is also helpful for imaging ICA and MCA aneurysms. The lateral arc is positioned as if the patient's head is tilted away from the side of the injection and away from the xray tube (Fig. 2.9). A mnemonic to remember this is: “The X-ray tube should *touch the shoulder* on the side of interest.”

The carotid siphon and MCA candelabra can often be seen most clearly by positioning the lateral arc as if the patient's head is tilted *away* from the side of injection.

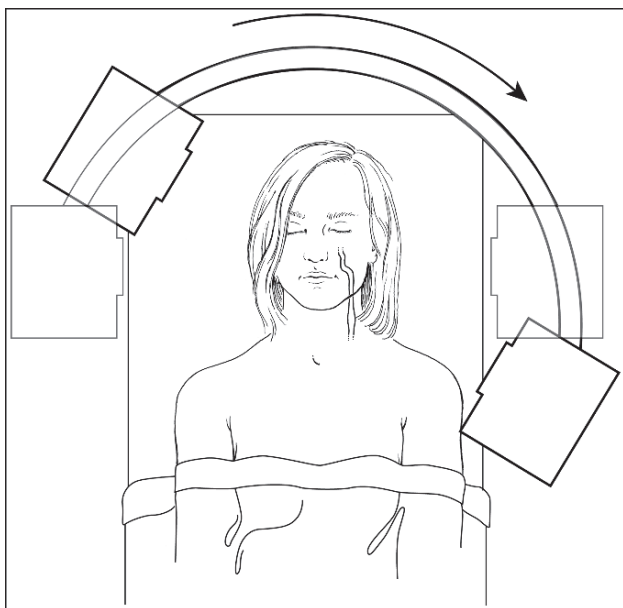


Fig. 2.9 Houghton view for imaging the carotid siphon and the MCA candelabra.

2.26. References

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