Interventional neuroradiology—anesthetic considerations

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This work is supported in part by National Institutes of Health, Grants K24-NS02091 (W.L.Y.).

Interventional neuroradiology (INR) is a hybrid of traditional neurosurgery and neuroradiology, with certain overlaps with aspects of head-and-neck surgery. It can be broadly defined as treatment of central nervous system (CNS) disease by endovascular access for the purpose of delivering therapeutic agents, including both drugs and devices. Because of a recent advancement in the field of INR, more anesthesiologists are involved in care of patients undergoing INR procedures. Anesthesiologists have several important concerns when providing care to patients who undergo INR procedures, including (1) maintenance of patient immobility and physiologic stability; (2) manipulating systemic or regional blood flow; (3) managing anticoagulation; (4) treating and managing sudden unexpected complications during the procedure; (5) guiding the medical management of critical care patients during transport to and from the radiology suites; and (6) rapid recovery from anesthesia and sedation during or immediately after the procedure to facilitate neurologic examination and monitoring. To achieve these goals, anesthesiologists should be familiar with specific radiological procedures and their potential complications.

Preanesthetic considerations

The preanesthetic evaluation of a patient undergoing a potentially long diagnostic and therapeutic procedure in the neuroradiology suite expands on the routine preanesthetic examination of the neurosurgical patient. Airway evaluation should include routine evaluation of the potential ease of laryngoscopy in an emergent situation, and also take into the
account the fact that, with the head and neck kept in a neutral position, sedation may compromise airway patency. Further, this patient population often includes head-and-neck tumor patients with their associated airway considerations.

Baseline blood pressure and cardiovascular reserve should be assessed carefully, especially when blood pressure manipulation and perturbations are anticipated. A careful neurologic examination should be performed to characterize any deficits that may be present prior to the procedure, and special note should be made of the patient's sensorium. Furthermore, careful padding of pressure points may assist in the patient's ability to tolerate a long period of lying supine and motionless and decrease the requirement for sedation, anxiolysis, and analgesia. In addition to the issues normally considered during the preanesthetic evaluation of the neurosurgical patient, the anesthesiologist should review the patient's previous experiences with angiography, noting if there were adverse reactions to radiographic contrast agents, such as allergy or excessive dehydration. Because of the possibility of significant radiation exposure, the possibility of pregnancy in female patients should be explored.

Prophylaxis for cerebral ischemia is in a state of development. Some centers use a variety of agents such as oral nimodipine for this purpose. The use of calcium channel blockers has been suggested to decrease catheter-induced vasospasm as well; transdermal nitroglycerin has also been used for this purpose.

Monitoring and vascular access

Secure intravenous (i.v.) access should be available with adequate extension tubing to allow drug and fluid administration at maximal distance from the image intensifier during fluoroscopy. Access to i.v. or arterial catheters can be difficult when the patient is draped and the arms are restrained at the sides. Stopcocks and nonlocking tubing connections under the drapes should be minimized. Prior to covering the patient, the tightness of connections between segments of tubing should be verified. Infusions of anticoagulant or potent medications, such as nitroprusside and remifentanil, should be through minimal dead space, into ports that are as proximal to the patient as possible (e.g., into a T-connector at an i.v. catheter). This allows the infusion of medications to be relatively independent of the rate of the i.v. carrier fluid.

Standard monitors should be applied, regardless of anesthetic technique. For i.v. sedation, capnography sampling via the sampling port of special nasal cannula is especially useful. A pulse oximeter probe can be placed on the great toe of the leg that will receive the femoral introducer sheath. This may give an early warning of femoral artery obstruction or distal thromboembolism.

For intracranial procedures and postoperative care, beat-to-beat arterial pressure monitoring and blood sampling can be facilitated by an arterial line. A side port of the femoral artery introducer sheath can be used, but most radiologists will remove the sheath immediately after the procedure. Using a coaxial or triaxial catheter system, arterial pressure at the carotid artery, vertebral artery, and the distal cerebral circulation can be measured. The presence of a coaxial catheter frequently underestimates the systolic and overestimates the diastolic pressure; however, mean pressures are reliable, and may be used to safely monitor the induction of either hyper- or hypotension. In a patient who requires continuous blood pressure monitoring postoperatively, it is convenient to have a separate radial arterial blood pressure catheter. Bladder catheters are required for most of the procedures; they assist in fluid management as well as patient comfort. A significant volume of heparinized flush solution and radiographic contrast is often used.

Radiation safety

There are three sources of radiation in the INR suite: direct radiation from the x-ray tube, leakage (through the collimators' protective shielding), and scattered (reflected from the patients and the area surrounding the body part to be imaged). A fundamental knowledge of radiation safety is essential for all staff members working in an INR suite. It must be realized that the amount of exposure decreases proportionally to the square of the distance from the source of radiation (inverse square law). It should also be realized that digital subtraction angiography delivers considerably more radiation than fluoroscopy.

Optimal protection would dictate that all personnel should wear lead aprons, thyroid shields, and radiation exposure badges. The lead aprons should be periodically evaluated for any cracks in the lead lining that may allow accidental
radiation exposure. Movable lead glass screens may provide additional protection for the anesthesia team. Clear communication between the INR and anesthesia teams is crucial for limiting radiation exposure. With proper precautions, the anesthesia team should be exposed to less than the annual recommended limit for health care workers (see [http://pdg.lbl.gov/](http://pdg.lbl.gov/)).

**Anesthetic technique**

Choice of anesthetic technique is a controversial area, and varies between centers. There are no data that support improved outcome with one technique or another. There appears to be a trend to move more towards general endotracheal anesthesia, but it is highly dependent on local practice and training.

**Intravenous sedation**

Primary goals of anesthetic choice for i.v. sedation are to alleviate pain, anxiety and discomfort, and to provide patient immobility. A rapid recovery from sedation is often required for neurologic testing.

Many neuroangiographic procedures, while not painful per se, can be psychologically stressful. This is especially true when there is a risk of serious stroke or death, particularly patients who have already suffered a preoperative hemorrhage or stroke. There may be an element of pain associated with injection of contrast into the cerebral arteries (burning) and with distention or traction on them (headache). A long period of lying can cause significant pain and discomfort.

A variety of sedation regimens are available, and specific choices are based on the experience of the practitioner and the aforementioned goals of anesthetic management. Common to all i.v. sedation techniques is the potential for upper airway obstruction. Placement of nasopharyngeal airways may cause troublesome bleeding in anticoagulated patients, and is generally avoided. Laryngeal Mask Airways may be useful in rare emergencies in patients with difficult airway. Endotracheal intubation, however, remains a mainstay for securing the airway during neurological crises.

**General anesthesia**

The primary reason for employing general anesthesia is to reduce motion artifacts and to improve the quality of images, especially in small children and uncooperative adult patients. This is especially pertinent to INR treatment of spinal pathology, in which extensive multilevel angiography may be performed. The specific choice of anesthesia may be guided primarily by other cardio- and cerebrovascular considerations. Total i.v. anesthetic techniques, or combinations of inhalational and i.v. methods, may optimize rapid emergence [6]. To date, pharmacologic protection against ischemic injury during neurosurgical procedures has not been proven. A theoretical argument could be made for eschewing the use of N₂O because of the possibility of introducing air emboli into the cerebral circulation, but there are no data to support this.

**Anticoagulation**

Careful management of coagulation is required to prevent thromboembolic complications during and after the procedures. Whether heparinization should be used for every case of intracranial catheterization is not clear to date. Generally, after a baseline activated clotting time (ACT) is obtained, i.v. heparin (70 units/kg) is given to a target prolongation of two to three times baseline. Heparin can then be given continuously or as an intermittent bolus with hourly monitoring of ACT. Occasionally, a patient may be refractory to attempts to obtain adequate anticoagulation. Switching from bovine to porcine heparin or vice versa should be considered. If antithrombin III deficiency is suspected, administration of fresh-frozen plasma may be necessary. At the end of the procedure, heparin may need to be reversed with protamine.

Antiplatelet agents (aspirin, ticlopidine, and the glycoprotein IIb/IIIa receptor antagonists) are used quite extensively in patients with coronary stents, and may have great relevance for patients undergoing INR procedures. Activation of the glycoprotein IIb/IIIa receptor is a final common pathway for platelet aggregation. Abciximab (ReoPro), a chimeric murine–human monoclonal antibody that directly binds to the receptor, has been shown to decrease mortality and morbidity after coronary stenting [7]. Other agents in this class include the peptide receptor antagonists, Eptifibatide [8].
These agents have various pharmacokinetic and pharmacodynamic properties. Based on experiences in coronary stenting, several basic observations on their use become clear. First, the effects of these agents on platelet aggregation are difficult to monitor clinically because there is no accurate bedside test of platelet aggregation. Second, the duration of the effects is approximately 12–24 hours. Rapid reversal of antiplatelet activity can only be achieved by platelet transfusion. Finally, use of these agents along with heparin may result in unexpected hemorrhage. Therefore, reducing procedural heparin dosage and early removal of vascular access sheaths should be carefully considered to decrease bleeding complications. The sustained long-term reduction in morbidity and mortality of coronary thrombosis patients (undergoing angioplasty/stenting or thrombolysis) by an antiplatelet agent has led to great interest for use in endovascular procedures of the CNS, but their use is not clearly defined in the setting of cerebrovascular disease.

Superselective anesthesia functional examination (SAFE)

SAFE is carried out to determine, prior to therapeutic embolization, if the tip of the catheter has been inadvertently placed proximal to the origin of nutritive vessels to eloquent regions, either in the brain or spinal cord. Such testing is an extension of the Wada and Rasmussen test in which amobarbital is injected into the internal carotid artery to determine hemispheric dominance and language function. Its primary application is in the setting of brain arteriovenous malformation (BAVM) treatment, but it may also be used for tumor or other vascular malformation work. Prior to the testing, the patient should be fully awake from sedation or general anesthesia. Careful selection of motivated patients and preoperative teaching may decrease the anxiolytic requirements of these patients and ensure ideal testing conditions. This topic is reviewed elsewhere.

Deliberate hypotension

The two primary indications for induced hypotension are (1) to test cerebrovascular reserve in patients undergoing carotid occlusion, and (2) to slow flow in a feeding artery of BAVMs before glue injection.

The most important factor in choosing a hypotensive agent is the ability to safely and expeditiously achieve the desired reduction in blood pressure while maintaining the physiological stability of the patients. The choice of agent should be determined by the experience of the practitioner, the patient's medical condition, and the goals of the blood pressure reduction in a particular clinical setting.

Intravenous adenosine has been used to induce transient cardiac pause, and may be a viable method of partial flow arrest. Further study for its safety and efficacy is needed.

Deliberate hypertension

During acute arterial occlusion or vasospasm, the only practical way to increase collateral blood flow may be an augmentation of the collateral perfusion pressure by raising the systemic blood pressure. The Circle of Willis is a primary collateral pathway in cerebral circulation. However, in as many as 21% of otherwise normal subjects, the circle may not be complete. There are also secondary collateral channels that bridge adjacent major vascular territories, most importantly for the long circumferential arteries that supply the hemispheric convexities. These pathways are known as the pial-to-pial collateral or leptomeningeal pathways.

The extent to which the blood pressure has to be raised depends on the condition of the patient and the nature of the disease. Typically, during deliberate hypertension the systemic blood pressure is raised by 30–40% above the baseline or until ischemic symptoms resolve. Phenylephrine is usually the first line agent for deliberate hypertension, and is titrated to achieve the desired level of blood pressure.

Management of neurologic and procedural crises

Complications during endovascular instrumentation of the cerebral vasculature can be rapid and life threatening, and require a multidisciplinary collaboration. Having a well thought-out plan for dealing with intracranial catastrophe may make the difference between an uneventful outcome and death. Rapid and effective communication between the
anesthesia and radiology teams is critical.

The primary responsibility of the anesthesia team is to preserve gas exchange and, if indicated, secure the airway. Simultaneous with airway management, the first branch in the decision-making algorithm is for the anesthesiologist to communicate with the INR team and determine whether the problem is hemorrhagic or occlusive. In the setting of vascular occlusion, the goal is to increase distal perfusion by blood pressure augmentation with or without direct thrombolysis. If the problem is hemorrhagic, immediate cessation of heparin and reversal with protamine is indicated. As an emergency reversal dose, 1 mg protamine can be given for each 100 units heparin total dosage during the case. The ACT can then be used to fine tune the final protamine dose.

Bleeding catastrophes are usually heralded by headache, nausea, vomiting, and vascular pain related to the area of perforation. Sudden loss of consciousness is not always due to intracranial hemorrhage. Seizures, as a result of contrast reaction or transient ischemia, and the resulting post-ictal state can also result in an obtunded patient. In the anesthetized patient, the sudden onset of bradycardia or the radiologist's diagnosis of extravasation of contrast may be the only clues to a developing hemorrhage.

Postoperative management

After INR procedures, patients spend the immediate postoperative period in a monitored setting to watch for signs of hemodynamic instability or neurologic deterioration. Blood pressure control, either induced hypotension or induced hypertension, may be continued during the postoperative period. Complicated cases may go first to CT or some kind of physiologic imaging such as single photon emission computed tomography (SPECT) scanning; only rarely is an emergent craniotomy indicated.

Specific procedures

Brain arteriovenous malformations (BAVMs).

BAVMs are typically large, complex lesions made up of a table of abnormal vessels (called the nidus) frequently containing several discrete fistulae. They are often called cerebral or pial arterio-venous malformations. There are usually multiple feeding arteries and draining veins. The goal of the therapeutic embolization is to obliterate as many of the fistulae and their respective feeding arteries as possible. BAVM embolization is usually an adjunct for surgery or radiotherapy. In rare cases, embolization treatment is aimed for total obliteration. SAFE is frequently used during BAVM embolization.

There are generally two schools of thought on how to manage anesthesia in the patient undergoing endovascular therapy, especially with permanent agents such as cyanoacrylate glues. One must rely on the knowledge of neuroanatomy and vascular architecture to ascertain the likelihood of neurologic damage after deposition of the embolic agents. The “anatomy” school, therefore, will prefer to embolize under general anesthesia. Arguments for this approach include improved visualization of structures with the absence of patient movement, especially if temporary apnea is used. Further, it is argued that if the glue is placed “intranidal,” then, by definition, no normal brain is threatened. There are two major concerns for this approach. A considerable variation in the normal localization of function exists, and cerebral pathology may cause neurologic function to shift from its native location to another one. The other school, which we might call the “physiologic” school, trades off the potential for patient movement for the increased knowledge of the true functional anatomy of a given patient. Localization of cerebral function may not always follow textbook descriptions, as described in the section on SAFE. Furthermore, the BAVM nidus or a previous hemorrhage may result in a shift or relocalization of function. The “physiologic” approach demands, at the present, careful titration of sedation to wake the patient for SAFE before injection of embolic material.

The cyanoacrylate glues offer relatively “permanent” closure of abnormal vessels. Although less durable, polyvinyl alcohol microsphere embolization is also commonly used. If surgery is planned within days after PVA embolization, the rate of recanalization is low and PVA is felt to be easier and safer to work with. Advances in polymer development may obviate some of the risks of glue therapy.
Dural arterio-venous malformations

Dural AVM is currently considered an acquired lesion resulting from venous dural sinus stenosis or occlusion, opening of potential arterio-venous shunts, and subsequent recanalization. Symptoms are variable according to which sinus is involved. Dural AVMs may be fed by multiple meningeal vessels, and therefore, multistaged embolization is usually performed. SAFE is performed in certain vessels such as the middle meningeal artery and the ascending pharyngeal artery to evaluate the blood supply to peripheral cranial nerves and the possible existence of dangerous extra- to intracranial anastomosis. Complete obliteration is not always necessary considering the purpose of treatment, which is to reduce risk of bleeding or to alleviate symptoms. Subsequent spontaneous thrombosis can be expected in view of pathogenesis of this disease.

It is important to bear in mind that dural AV fistulas can induce increased venous pressure. Venous hypertension of pial veins is a risk factor for intracranial hemorrhage. Additionally, the venous hypertension should be factored into estimating safe levels of reductions in systemic arterial, and therefore, cerebral perfusion pressure.

Carotid cavernous and vertebral fistulae

Carotid cavernous fistulae (CCF) are direct fistulae usually caused by trauma to the cavernous carotid artery leading to communication with the cavernous sinus, usually associated with basal skull fracture. Treatment of CCF, a challenging surgical procedure, has become relatively easier with the development of detachable balloons [12]. Vertebrobasilar fistulae are connections to surrounding paravertebral veins, usually as a result of penetrating trauma, but may be congenital, associated with neurofibromatosis, or result from blunt trauma. In addition to cerebral involvement, spinal cord function may also be impaired.

Vein of Galen malformations

These are relatively uncommon but complicated lesions that present in infants and require a multidisciplinary approach including an anesthesiologist skilled in the care of critically ill neonates. The patients may have intractable congestive heart failure, myocardial lesions, intractable seizures, hydrocephalus, and mental retardation [13].

Spinal cord lesions

Embolization may be used for intramedullary spinal AVMs, dural fistulae, or tumors invading the spinal canal. Often, general endotracheal anesthesia with controlled ventilation is used to provide temporary apnea that may increase the ability to see small spinal cord arteries at the limits of angiography imaging resolution and exquisitely sensitive to motion artifact. For selected lesions, intraoperative somatosensory and motor-evoked potentials may be helpful in both anesthetized and sedated patients. Intraoperative wake-up tests may be requested to test neurologic function during embolization.

In cases where wake-up tests might be needed, preoperative discussion of the logistics of the wake-up procedure and the testing process may facilitate the intraoperative management of this part of the procedure.

Carotid test occlusion and therapeutic carotid occlusion

Carotid occlusion, both permanent and temporary, may be used in several circumstances. Skull base tumors frequently involve the intracranial or petrous portion of the carotid artery or its proximal Willisian branches. Large or otherwise unclippable aneurysms may be partly or completely treated by proximal vessel occlusion. To assess the consequences of carotid occlusion in anticipation of surgery, the patient may be scheduled for a test occlusion in which cerebrovascular reserve is evaluated in several ways. A multimodal combination of angiographic, clinical, and physiologic tests can be used to arrive at the safest course of action for a given patient's clinical circumstances. The judicious use of deliberate hypotension can increase the sensitivity of the test [14] [15].

Intracranial aneurysm ablation

http://home.mdconsult.com/das/article/body/35116666-2/jorg=journal&source=MI&sp=12597045&sid=244
The two basic approaches for INR therapy of cerebral aneurysms are occlusion of proximal parent arteries and obliteration of the aneurysmal sac. The aneurysmal sac may be obliterated by use of coils and balloons. However, obliterating the aneurysmal sac while sparing the parent vessel is still challenging. Manipulation of the sac may cause distal thromboembolism and rupture. Incomplete obliteration may result in recurrence and hemorrhage. The anesthesiologist should be prepared for aneurysmal rupture and acute SAH at all times, either from spontaneous rupture of a leaky sac or direct injury of the aneurysm wall by the vascular manipulation. It should be noted after coil ablation of aneurysms, that at the present time, there is not the same degree of certainty that the lesion has been completely removed from the circulation as with application of a surgical clip. There may be areas of the aneurysmal wall that are still in contact with the arterial blood flow and pressure. Therefore, attention to postoperative blood pressure control is warranted.

**Balloon angioplasty of cerebral vasospasm from aneurysmal SAH**

Angioplasty may be used to treat symptomatic vasospasm with correlating angiographic stenosis refractory to maximal medical therapy. Angioplasty is usually reserved for patients that have already had the symptomatic lesion surgically clipped (for fear of rerupture), or for patients in the early course of symptomatic ischemia to prevent transformation of a bland infarct into a hemorrhagic one. A balloon catheter is guided under fluoroscopy into the spastic segment and inflated to mechanically distend the constricted area.

It is also possible to perform a “pharmacologic” angioplasty. There is the greatest experience with papaverine, but there are potential CNS toxic effects (see ref. for a review), but other agents such as calcium channel blockers may find a place for this purpose.

**Sclerotherapy of venous angiomas**

Craniofacial venous malformations are congenital disorders causing significant cosmetic deformities, that may impinge on the upper airway and interfere with swallowing. Absolute alcohol (95% ethanol) opacified with contrast is injected percutaneously into the lesion, resulting in a chemical burn to the lesion and eventually shrinking it. The procedures are short (30–60 minutes) but painful, and general endotracheal anesthesia is used. Complex airway involvement may require endotracheal intubation with fiberoptic techniques. Because marked swelling often occurs immediately after alcohol injection, the ability of the patient to maintain a patent airway must be carefully assessed in discussion with the radiologist before extubation. Alcohol has several noteworthy side effects. First, upon injection it can cause changes in the pulmonary vasculature and create a short-lived shunt or a ventilation-perfusion mismatch. Desaturation on the pulse oximeter is frequently noted after injection. Absolute alcohol may also cause hypoglycemia, especially in younger children. Finally, the predictable intoxication and other side effects of ethanol may be evident after emergence from anesthesia.

**Angioplasty and stenting for atherosclerotic lesion**

Angioplasty with or without stenting for atherosclerosis has been tried in cervical and intracranial arteries with favorable results. Risk of distal thromboembolism is the major issue to be resolved in this procedure and methods. A catheter system that employs an occluding balloon distal to the angioplasty balloon has been proposed. Carotid angioplasty and stenting may provide a therapeutic option for patients particularly at risk of surgery. However, efficacy and indications in relation to carotid endarterectomy remain to be determined.

Potential complications include vessel occlusion, perforation, dissection, spasm, thromboembolism, occlusion of adjacent vessels, transient ischemic episodes, and stroke. Furthermore, compared to carotid endarterectomy, there appears to be...
an increased incidence of cerebral hemorrhage and/or brain swelling after carotid angioplasty [23]. Although the etiology of this syndrome is unknown, it has been associated with cerebral hyperperfusion, and it may be related to poor postoperative blood pressure control.

**Thrombolysis of acute thromboembolic stroke**

In acute occlusive stroke, it is possible to recanalize the occluded vessel by superselective intra-arterial thrombolytic therapy. Thrombolytic agents can be delivered in high concentration by a microcatheter navigated close to the clot. Neurologic deficits may be reversed without additional risk of secondary hemorrhage if treatment is completed within 6 hours from the onset of carotid territory ischemia and 24 hours in vertebrobasilar territory. One of the impediments in development in this area has been the fear of increasing the risk of hemorrhagic transformation of the acute infarction patient. Despite an increased frequency of early symptomatic hemorrhagic complications, treatment with intra-arterial pro-urokinase within 6 hours of the onset of acute ischemic stroke with middle cerebral artery (MCA) occlusion significantly improved clinical outcome at 90 days [24].

**Important points and objectives**

There is a rapidly expanding list of application of INR procedures in the field of the treatment of CNS disease. Anesthesiologists should be familiar with specific procedures and their potential complications. Constant and effective communication between the anesthesia and radiology teams is critical to safely carry out INR procedures and to deal with intracranial catastrophe.

**Acknowledgement**

The authors wish to thank Broderick Belenson, Mark Espinosa, Sabrina Larson, and Gaurab Basu for assistance in preparation of the manuscript; Van V. Halbach, MD, and Christopher F. Dowd, MD, John Pile-Spellman, MD, Lawrence Litt, MD, PhD, and Nancy J. Quinnine, RN, for development of clinical protocols discussed herein; members of the UCSF Center for Stroke and Cerebrovascular Disease, UCSF Center for Cerebrovascular Research, and the Columbia University AVM Study Group for continued support.

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