ARTERIOVENOUS MALFORMATION, COMPLICATIONS, AND PERIOPERATIVE ANESTHETIC MANAGEMENT

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Abstract

Arteriovenous malformations (AVMs) are the most common intracranial vascular malformation, with an estimated occurrence of 1:5000-1:2000 persons. The repair requires careful embolization, often followed by stereotactic radiosurgery and can also include open craniotomy. Preoperatively, patients may be healthy or dramatically unstable, as 30-50% of these cases present with acute cerebral hemorrhage[1]. One of the most important considerations for the anesthesiologist should be attempting to achieve hemodynamic stability in the face of potential increased intracranial pressure and subsequent vulnerability of the tissues to ischemic insult. Knowledge of the risks and hazards of the procedure and collaboration with specialists, including neuroradiologists, critical care physicians, and potentially neurosurgeons, ultimately form the basis for appropriate management. AVM's can lead to potentially fatal ischemic or hemorrhagic complications that may occur in up to 8% of cases[2].

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The protection of the airway, adequate monitoring, and maintaining cardiovascular and neurological stability, are critical. Further, in the setting of a radiological suite, peripheral location considerations involving equipment, monitors, and appropriate drugs and sustaining the patient's immobility during the radiological procedures, while managing potential perioperative complications are all essential[3].

Keywords: arteriovenous malformation, embolization, anesthesia, radiological procedures.

Background: AVMs are knotted anastomoses of blood vessels of varying levels where arteriovenous shunting occurs in a central nidus. This nidus is defined as the site where multiple feeding arteries converge and where large veins drain. The etiology of AVMs have been the subject of controversy and speculation because of the radical improvements in imaging of the brain's vasculature in the last twenty years coupled with the difficulty in obtaining large population studies. Currently, the incidence of AVMs is estimated to be ~1:100,000 per year in unselected populations, with a prevalence of ~18:100,000 in adults. 1 to 2% of all strokes result from AVMs, but are possibly the cause of up to ~4% of strokes in young adults. A need for large, prospective studies of the incidence and prevalence of AVMs in well-defined, stable populations is needed before accurate numbers can be given[4].

Indications

Harvey Cushing defined vascular malformations as tumors arising from cerebral blood vessels, and he resected the first AVM nearly 3 years after it had been irradiated. He stressed the importance of preoperative diagnosis due to the challenges imposed by radical resection of non-embolized vascular malformations[5]. With that said, of equal importance must be the intraoperative concerns of assessment and stability as appreciated by the anesthesiologist. Indications and rationale for general endotracheal anesthesia in the neuroradiology suite include[5]:

1) Improved imaging on immobilized patients

2) Airway control in the supine position

3) Induced hypotension facilitated

4) Improved control of elevated ICP

5) Augmentation of Blood Pressure (BP) with occlusive disease

6) Management of possible neurologic complications/emergencies, such as ventriculostomy for ICP control, pentobarbital coma induction, treatment of status epilepticus, and emergency craniotomy.

Yamada has suggested that AVM surgery to be performed under local anesthesia with the possibility of intraoperative functional testing[4], but Jaeger, et al.[6] advocate that the majority of embolizations for AVM repair should be performed under general anesthesia. Save for the few occurrences where functional testing would be required, such as AVM in a dominant, functional area of the brain, general anesthesia is recognized as the primary method.

Contraindications

The contraindications to the interventional neuroradiology procedures are similar to those in the neurosurgery suite. In a patient with a coagulation disorder, the administration of a local anesthetic by means of a needle or via the insertion of a catheter into the epidural space or spinal cavity, may lead to bleeding and hematoma formation, with a danger of pressure on the spinal cord or nerve roots[7]. Spinal anesthesia is also relatively contraindicated in patients with a history of lumbar spinal surgery, although Jost, et al.[8] suggest that spinal anesthesia is a viable technique in these patients. Other major contraindications to regional anesthesia include patient refusal and infection at site of needle insertion, while some relative contraindications include pre-existent neurologic deficit, certain disease states (respiratory failure, cardiac disease) and increased ICP[9] **[Table 1]**.

Table 1
Contraindications For Interventional Neuroradiology Procedures

1	Coagulation Disorder
2	History of lumbar spinal surgery
3	Infection at site of needle insertion
4	Pre-existent Neurological Deficit
5	Respiratory Failure
6	Cardiac Disease
7	Increased Intracranial Pressure

Neurovascular Anatomy

The cerebral blood supply originates from two sources, the paired vertebral and internal carotid arteries. After entering the skull through their respective foramina, branches of these four arteries come together to form the vascular Circle of Willis. The vertebral arteries join to become the basilar artery at the base of the brain and this basilar artery terminates as the paired posterior cerebral arteries (PCA). The PCA is connected to the middle cerebral artery (MCA), one of the terminal branches of the internal carotid, by the posterior communicating artery on either side. It is this connection that is responsible for providing collateral flow between the posterior circulation and the anterior circulation. The remainder of the circle, composed of the anterior cerebral arteries (ACA) and the single anterior communicating artery, provide much of the collateral flow between the left and right circulation **[Table 2]**.

Table 2
Neurovascular Anatomy: Cerebral Arteries and their Respective Targets

Vertebral, Basilar, Posterior Cerebral Arteries	Base of the Brain, Occipital and Posterior Lobes
Middle Cerebral Arteries	Temporal Lobe
Anterior Cerebral Arteries	Frontal Lobe
Posterior Communicating Arteries	Collateral Flow Between the Anterior and Posterior Circulation
Anterior Communicating Arteries	Collateral Flow Between the Left and Right Circulation

The PCA are responsible for providing circulation to the posterior cerebral cortex and parts of the brain stem. The MCA provides blood flow to most of the parietal and temporal cortices, with some flow to the frontal lobes as well. The ACA provide the remainder of the cortical flow, including that to the internal aspect of the cerebral hemispheres, as it courses between the two.

Clinical Presentation

The presentation of AVMs in community-based populations has not been well studied. Moreover, the frequencies found in the majority of hospital-based studies are different from each other. Currently more than 15% of people are asymptomatic when the AVM is detected. About 20% of patients with AVMs present with seizures and two-thirds with hemorrhage. It is uncertain which factors govern whether someone with an AVM will present with hemorrhage, epilepsy, headache, focal neurological deficit, although we may conclude that the size and location of the AVM plays a role[4].

Embolization

General Indications

Embolizations can be utilized in situations where the AVMs are large and cannot be surgically resected or treated with radiosurgery. For example, if the patient needs surgery but is in a hypercoaguable state and requires the use of anticoagulants, or has a medical condition that predisposes him to hemorrhage (hypertension), then embolization would be the ideal way to decrease these risks. This treatment works by decreasing the flow of the AVM and also diminishing the size of the nidus. By this procedure, the chances of success with radiosurgery are greatly improved and there is less risk of hemorrhage in the postirradiation period[1].

Cyanoacrylate Embolization

In AVMs, one popular method of embolization is the use of cyanoacrylate glue embolic agents such as N-butyl-2-cyanoacrylate (Histoacryl). These glue embolic agents offer many advantages to the procedure when compared to solid particles such as polyvinyl alcohol (PVA), silk, coils or balloons. For example, N-butyl-2-cyanoacrylate (NBCA) can cause permanent occlusion whereas the solid embolic agents cannot. This characteristic of the glue agents is extremely useful, because it allows one to perform radiosurgery on the remaining nidus successfully without the risk of recanalization of the previously embolized nidus. Hence, the glue agents used in this situation can prevent the patient from hemorrhage due to its propensity to provide a more adequate occlusion than its solid particle counterparts[1,10].

Furthermore, NBCA can provide better embolization than solid particle counterparts due to its ability to reach the nidus more easily. The solid particles need larger, stiffer delivery systems that utilize guidewires for catheter placement. Moreover, the difficulty of embolization with these embolic agents is further augmented due to bigger and more rigid catheters which make it hard to reach the target AVM nidus. These inflexible catheters increase the chances of the solid embolic agent to reflux into the normal vasculature and cause vascular damage. In contrast, these risks are not as great with the use of cyanoacrylate glues that can be delivered with flow directed microcatheters[1] which allows the NBCA to penetrate the AVMs better than PVA particles. NBCA also can be used at a lower concentration than other acrylates, and this characteristic causes hardly any catheter gluing. In addition, the embolic masses produced by NBCA are more biocompatible than the other embolic agents[11]. Even though the advantages of NBCA are evident, there are still relatively new studies that have compared NBCA to the more conventional embolic agent, PVA, and the results show that both of these agents produce similar results in treating cerebral AVMs in terms of nidus reduction and the number of feeding pedicles that have been embolized[12]. Hence, even though there are limited studies showing that NBCA can produce the same results as some of the more conventional solid particle agents, such as PVA, the advantages offered by the glue agents seem to make NBCA a good choice when treating an AVM with embolization **[Table 3]**.

Table 3
Advantages of N-butyl-2-cyanoacrylate Over Solid Embolic Agents

Diminishes risk of hemorrhage due to permanent occlusion
Allows radiosurgery without risk of recanalization of previously embolized nidus
Can reach nidus more easily without the need for larger, stiffer delivery systems
Can be used at lower doses
Does not cause catheter gluing

Ethanol Endovascular Management of Brain AV Malformations

Absolute ethanol is a liquid agent that causes immediate vessel sclerosis and occlusion, making it an effective but dangerous liquid embolic agent[13]. As a liquid, ethanol has excellent penetration to the capillary beds and is responsible for almost complete tissue destruction and necrosis. A 1995 article detailing a 35-year retrospective study concluded that the embolization cure rate of brain AVM's was 4-5%[14]. However, none of these studies examined ethanol as the lone embolic agent. Yakes claims a greater than 50% cure rate when using ethanol as the lone embolic agent[15]. Cure of AVM's is unusual with other embolic agents, but is common with the use of ethanol.

Stereotactic Radiosurgery and Management of Pial and Dural AV Malformations

Cerebral AVMs can be extremely dangerous for the majority of the patients. The risk for adverse symptoms increases with age, and many people with AVMs may suffer fatal hemorrhages during their lifetime[16]. Radiosurgery is an excellent choice of treatment for a myriad of reasons. Cerebral AVMs impede brain perfusion in patients and, initially, patients present with high transnidal flow and perinidal perfusion disturbances. After radiosurgery, the brain perfusion anomalies return to normal[17].

Radiosurgery works best with small to medium sized AVMs. It is these types of situations where optimal treatment is seen with minimal side effects[18]. Long term studies have indicated that this treatment can be performed on the patients without them experiencing measurable deterioration of their cognitive function[19].

When deciding on the plan to treat AVMs with radiosurgery, one must consider that there are two different types of AVMs: pial and dural. Pial AVMs are congenital lesions and are found in the brain parenchyma and have an incidence ranging from .04% to .52%[1]. Pial AVMs are more common than dural AVMs. Dural AVMs, on the other hand, are found in the dura mater. These lesions are acquired and present differently, and the incidence for these lesions remains unknown. However, what is known about the dural AVMs is that they arise in adults and are more commonly seen in women. These types of AVMs are composed of one or more AV fistulae, allowing these dural AVMs to be referred to as arteriovenous fistulous malformations (AVFM). These AVFMs manifest in patients with pulsatile tinnitus, headaches, and seizures, as well as ocular problems unlike the pial AVMs that present with intracranial hemorrhages[1].

Stereotactic radiosurgery is a single fraction, high dose irradiation of and "imaging-defined target". This procedure can be performed with a gamma knife, modified linear accelerators, or specially designed cyclotrons[1]. This single fraction, high dose radiation induces apoptosis, consequently transforming the fibroblasts into myofibroblasts. Immunohistochemical observation indicates this transformation by the presence of transforming growth factor-beta (TGF-beta) and the elevated levels of alpha smooth muscle action (alpha-SMA) in the irradiated AVM. This is one of the mechanisms that leads to the deterioration and obliteration of AVMs[20]. The radiation from this procedure targets the nidus of the AVM without the inclusion of the feeding arteries and draining veins. The exclusion of the vasculature surrounding the nidus is due to the need for accuracy (<1 mm) so the radiation can be safely administered to the patient without harming the surrounding normal vasculature. Furthermore, when just the nidus is being targeted, a higher dose of radiation can be used to obliterate the nidus with greater success.

This strategy of increasing radiation to obliterate the nidus has displayed greater success in treatment of AVMs[21]. In fact, higher doses of radiation are suggested to treat AVMs in children as well. This recommendation resulted from a recent study that showed a low complications rate when children were being treated with radiation doses to those given to adults[22].

After the procedure, the patient should be examined at the 12, 24, and 36 month mark by computer tomography (CT) and magnetic resonance imaging (MRI) to make sure the nidus was permanently obliterated. After these follow up exams show up positive for obliteration, a follow up angiography should be undertaken by the patient to confirm the obliteration of the AVM. If these exams show that the AVM is still patent, then radiosurgery should be repeated for permanent treatment[1]. These follow up tests are necessary to correctly assess the AVM structure[22] and have been crucial in helping interventionists select the proper doses of radiation for follow up treatments for the AVMs that may require a few years of staged interval therapy to cure[23].

For larger AVMs, there can be various approaches for treatment. One approach is to carry out radiosurgery in conjunction with embolization to diminish the volume of the nidus. The drawback to this approach is that the embolization can recanalize or make the AVM irregular or even divide the AVM into multiple compartments. If any of these adverse effects result, then radiosurgery may become difficult. Due to these risks with embolizations, sometimes radiosurgery is performed on large AVMs without embolizations. This procedure is performed by stage progression of radiosurgery, for example, 6 month intervals. These intervals allow the radiosurgery to treat the patient without the problems with embolization; moreover, the time between the surgeries allow the interventionists to administer higher radiation during the radiosurgery procedures to further obliterate the nidus[1]. This approach can be used, but the patient is in a vulnerable state. For example, large AVMs do not pose the risk of bleeding as much as small AVMs do, however, the large AVMs may pose a grave risk for bleeding as well due to longer periods of time between the staged intervals of radiosurgery where the nidus is not completely obliterated[1].

Another option for treating large AVMs may incorporate the use of hypofractionated conformal stereotactic radiotherapy. Between 1986 to 2001, this procedure was performed on 29 patients at a university hospital. After 5 years of treatment, the obliteration rates for AVMs 4 to 10 cm were 81% and 70% for AVMs larger than 10 cm.

These results show that hypofractionated conformal stereotactic radiotherapy may be an excellent alternative to the conventional radiosurgery when large AVMs are concerned. The procedure's advantage is that it has the ability to deliver a higher radiation dose than conventional radiotherapy, which resulted in significant success for the treatment of large AVMs[24].

In the case of dural AVMs or AVFMs, the treatment protocol is different. In these situations, radiosurgery should be performed before the embolization[25].

Radiosurgery is done first so the fistulae of the AVM can be targeted for occlusion. After the radiosurgery procedure, embolization can be completed to lower the risk for a post operation hemorrhage or embolization and can be utilized in instances to treat AVFMs for patients who are not good candidates for radiosurgery[1].

Complications of a Ruptured AVM and Its Treatment

The major intraoperative and perioperative complication of a ruptured AVM is some form of intracerebral bleeding and subsequent tissue ischemia and damage, with the possibility of clinical stroke. Subarachnoid hemorrhage, followed by parynchemal and intraventricular bleeds are the most common. The injury to the brain is compounded by the failure of the autoregulatory system to compensate for the full force of the systemic blood pressure, which allows mechanical injury to occur, in addition to ischemia. However, in AVM, as opposed to simple aneurysm rupture, low-resistance arteriovenous shunts can reduce the perfusion pressure at the site of injury, resulting in less damage and improving outcomes in the AVM rupture group[26].

Hartmann, et al. propose some additional theories as to why the outcome of a ruptured AVM is more favorable than the outcome of a ruptured cerebral aneurysm. In addition to the fact that full systemic pressure often drives blood through an aneurysmic rupture, aneurysms are always arterial in nature, while some AVM hemorrhages result in low-pressure venous bleeds, which have a lower clinical impact. Age has also been shown to be an independent predictor of clinical outcome, and those patients with bleeds from AVM tend to be significantly younger than those presenting with hypertensive bleeds[27].

Treatment of a ruptured AVM must include occlusion of the offending vessel, assuming no spontaneous resolution. Hong, et al.[28] describe a case where an intraoperative AVM rupture is successfully sealed with microcatheter administration of N-butyl cyanoacrylate, the same compound used for the embolism. In their case, the authors remark on the uniqueness of fixing the rupture using the same microcatheter and embolic agent that would be used to occlude the AVM. If consistently effective, this treatment is significant due to its capability to limit the variability of treatment options and expected outcomes, as well as the likely decrease in time spent under acute conditions. In any case, direct embolization with the preferred embolic agent is the ideal treatment for an intraoperative AVM rupture.

Hemodynamic stability could easily be compromised after a rupture. In the setting of increased intracranial pressure, cerebral perfusion and physiology must be compensated for with a higher MAP. Failure to appreciate basic cerebral vascular physiology and pathophysiology can result in a decrease in cerebral perfusion pressure and a worsening of the clinical outcome. It is recommended that cerebral perfusion pressure (MAP-ICP) be maintained above 70 mmHg, and MAP greater than 110 should be avoided in the immediate postoperative period. Although universally accepted standardized therapy protocols for elevated ICP have not been established, a stepwise escalation of initial procedures to control ICP can be followed. Theoretically, reduction of ICP by hyperventilation ceases when the pH of cerebrospinal fluid reaches equilibrium. However, this is not likely to occur acutely, and adverse rebound effects can occur if normal ventilation is resumed too quickly. When hyperventilation is no longer necessary, gradual normalization of serum PCO_2 should occur over a 24- to 48- hour period. In general, if hyperventilation is instituted for elevated ICP, PCO_2 should be maintained between 30 and 35 mmHg until ICP is controlled. In addition, most patients will require sedation with agents such as propofol, benzodiazepines and morphine and treatment with intermittent muscular paralysis. Propofol, specifically, will not raise ICP. Patients should have ventilatory support and airway protection to avoid aspiration of gastric contents[29].

If elevated ICP cannot be controlled with the above treatments, induced barbiturate coma may be instituted. Short-acting barbiturates such as thiopental have been shown to effectively reduce ICP, and they also reduce brain swelling and overall brain volume. Complications include a bolus-induced hypotension and cardiovascular side effects may be aggravated by previous therapeutic measures, such as dehydration promoted by osmotherapy with diminished cardiac filling pressures.

Perioperative Anesthetic Considerations

A. Sedation: Nidus embolization must be performed under extremely sensitive imaging guidance, and any movement of the patient during the procedure will result in loss of landmarks and delay in the treatment. Safe maximal embolization cannot be performed with general anesthesia and paralysis[30]. Proponents of this method argue that the nidus of an AVM is nonfunctional tissue, and neurological impairment is not likely, assuming technical proficiency. Therefore, they believe the possible risk of patient movement carries much greater significance than the risk of damaging healthy neural tissue in this case. Oftentimes during stereotactic neurosurgery or IR procedures, it is essential that anesthesia be discontinued as quickly as it was begun. Propofol is the standard drug used for sedation, as it has a quick onset of action, can be readily infused, and has a short half-life. Accepted dosing regimens are 1-2.5 mg/kg as a bolus initially, followed by 40-200 mcg/kg/h infusion. Some authors report higher GCS scores post-surgery, as well as a higher percentage of patients showing deliberate eye opening and responding to commands than in patients receiving 3-6 mg/kg thiopental and 0.5-1.5% isofluorane[31]. Debailleul, et al. reassert the positive qualities of propofol, stressing its action as a powerful hypnotic that allows for deep sedation and also quick recovery. The level of anesthesia is also easily controlled and scaled, allowing for easy transition from deep anesthesia and light sedation[32]. Berkenstadt also reports open craniotomy where patient interaction was essential. The case was managed with propofol and remifentanil, the analgesic of choice. Premedication can be done with clonidine, intraoperative propofol, remifentanil and labetalol, and the sedation can be adjusted to allow for patient interaction[33]. The authors report difficulty of achieving adequate sedation without compromising ventilation and oxygenation, and the potential problems with an awake patient have already been detailed. However, when considering an AVM in an extremely important functional area of the brain, such as the left parieto-temporal region, an awake procedure should be considered as an option.

B. Local: It is understood that the attachment of the Mayfield skull clamp and most incisions or injections, will cause the heart rate to rise and associated hemodynamic changes to occur. Since these are often not desirable effects, local anesthetic is often utilized for these situations. Schaffranietz investigated two similar drugs, 1% Lidocaine and 0.5% bupivicaine, and determined they were reasonably equivalent in their anesthesia, and their study suggests that reduction of the hemodynamic effects associated with insertion of the Mayfield skull clamp can be reasonably managed[34].

C. General Anesthesia: Neuroprotective properties such as reduced neuronal death have been described in animal models, although their effect in humans has yet to be proven[35]. However, cerebral circulation is improved, ICP is maintained under hyperventilation, and metabolism is decreased with desfluorane, isofluorane and sevofluorane. Furthermore, Kaye et al. have demonstrated that neither desflurane nor isoflurane significantly alters lumbar cerebrospinal fluid pressure on craniotomy patients with supratentorial mass lesions with evidence of midline shift or edema. These surgeries were performed during moderate hypocapnia[36]. Studies on sevoflurane demonstrate that the inhalational agent increases cerebral blood flow and decreases cerebrovascular resistance in patients with cerebral tumors. These findings were found to be dose dependant[37].

D. Postoperative hemodynamics appear to be improved in patients who undergo isoflurane anesthesia alone rather than those who undergo isofluorane anesthesia in conjunction with fentanyl infusion[38]. Although the Tsai study deals with individuals undergoing elective craniotomy, its findings could reasonably extend to those described in this paper. Desflurane and to a lesser degree sevoflurane, based on solubilities and clinical findings, would represent the agents with superior recovery profiles relative to isoflurane.

E. Analgesia/Pain Management: It is well accepted that fentanyl and its derivatives are the mainstay of analgesia in cranial procedures. The major advantage of the 4-anilodopiperidine class and its derivatives, in addition to anesthesia and sedation equivalent to morphine, is its lack of any profound hypotensive effect. Fentanyl also carries a shorter duration of analgesic activity and lacks emetic activity. Some of the classical effects of opiates, such as respiratory depression, cannot be avoided, however, and this will likely require constant ventilatory management during procedures where fentanyl must be applied at higher concentrations. Remifentanil and sufentanil are two further derivatives of this group, and they have unique ancillary benefits, such as marked reduction in extubation times and superior level of consciousness reported with remifentanil, which is appropriate when rapid recovery and neurological evaluation are required. Sufentanil, on the other hand, is more suitable when postoperative mechanical ventilation and postponed recovery are planned[39]. The major drawback of these drugs is their lack of residual analgesia and possible postoperative hyperalgesia.

F. Asepsia/Anitbiotics: It is important to remain vigilant when considering procedural-related complications of catheterization and other techniques. Of these, infection is a rare but serious problem, and should be managed both intraoperatively and perioperatively. Rebuck, et al. describe a study that shows a significant percentage (7.4%) of individuals with cerebral ICP monitors developing complications of CSF infection. Although antibiotic prophylaxis was administered over 60% of the time, it was not effective in preventing infection[40]. However, it is difficult to suggest that no antibiotics be administered in such a case, and cefazolin 1 g administered at the beginning of the procedure appears to be the drug of choice. Vancomycin has also been used extensively. Recently, rifampin and clindamycin-impregnated catheters have been used successfully to prevent or reduce the incidence of CSF shunt infection[41]. This technology, which effectively eliminated shunt infection in the study above, will likely see its application extended to use in all catheter-related systems, such as those used to feed embolic agents to AVM sites and to introduce spinal anesthesia. While catheter-related epidural abscesses are rare[42], as more catheter-based interventional procedures are developed, the overall incidence of such complications should be expected to rise, and proper prophylaxis should be in place.

G. Calcium channel blockers: Cerebral vasospasm is associated with cerebral trauma and blood accumulating on the brain surface. Calcium-channel blockers, such as dihydropyridines, can be used to prevent the ultimate source of neuronal injury: the entry of excessive amounts of calcium into the cell. Nimodipine has been shown to decrease the amount of cochlear neuronal death after trauma[43], and similar mechanisms are being investigated for protection of cortical tissue after injury, which can occur with ischemic insult or as a result of the direct toxicity of blood on the cortical surface. Kasuya describes the use of nicardipine-based prolonged release implants to help alleviate vasospasm after subarachnoid hemorrhage, with excellent results and complete vasospasm prevention[44].

H. Anticoagulant: Postoperative anticoagulant therapy can prevent venous thromboembolism after repair of AVM[45]. Some researchers have reported venous thrombosis as an important cause of hemorrhage of AVMs, leading to the likelihood that anticoagulation will become a mainstay of therapy in the near future[46]. A major problem with the progression of AVMs is the potential for vasogenic edema due to back pressure resulting from chronic venous obstruction in the region of the

AVM. Anticoagulation is indicated in cases where vasogenic edema might precipitate a neurological deterioration or where spontaneous rupture of the AVM is expected.

I. Heparin: Known AVMs are considered a contraindication to acute thrombolysis, although researchers have reported examples of patients with AVM needing emergency thrombolytic therapy for pulmonary embolism, with no resulting complications[47]. Postoperatively, the patient should be heparinized to maintain an activated clotting time (ACT) of at least 1.5 times normal[48]. The rationale behind this technique is to limit the acute thrombosis expected after endothelial trauma as well as to minimize retrograde clot formation due to the inherently invasive nature of the catheterization and embolization. Heparin 1 mg/kg is a suitable dose to keep the ACT in range, and it is recommended that heparin be maintained for 24 hours postoperatively, to allow for "pseudo-epithelialization" of the injured vasculature.

J. Allergy: Because contrast media is used, there is a risk of allergic reaction. Some of the symptoms include headaches, dizziness, nausea, diarrhea, vomiting, abdominal pain, cutaneous eruptions (rash, erythema, urticaria), and persistent pain at injection sites. Many studies have shown that the reaction oftentimes represents a type-IV (cell-mediated) hypersensitivity. Romano et al. report successful prophylactic therapy by giving a patient 6-alpha-methylprednisolone and cyclosporine 1 week before and 2 weeks after using iobitridol as contrast media for angiograms in a patient with AVM. The contrast media was well tolerated, suggesting that this prophylactic regimen may prevent some adverse reactions to contrast media[49].

K. Cerebral Hemodynamic Monitoring: The type of monitor used is dependent on several characteristics, such as resources and infectious risk.

a. Intraventricular catheters (IVCs) are the most widely used, and are unique in that they can diagnose and treat elevated intracranial pressure, the latter through release of CSF through the catheter, if necessary. IVCs also provide the most accurate measure of intracranial pressure[50]. They are the most invasive type, however, and may increase the infection risk.

b. Fiberoptic monitors can be used when it is not desirable to cannulate the ventricular system, and they provide an accurate measure of the ICP through a monitor that senses the change in the reflection of a light source from the tip of a pressure sensitive diaphragm[51]. These devices require frequent recalibration, as they may suffer from ‘drift’.

c. Subarachnoid bolts provide a much less accurate measurement of intracranial pressure, and are also limited in the fact that they cannot provide for CSF drainage, should the need arise. Several resource-depleted areas still employ this method for measurement, however[52].

d. Epidural monitors are theoretically advantageous in that they provide ease of placement and likely decrease the infectious risk, but this must be balanced against the risk of inaccurate readings[53].

Summary

AVM, an abnormal and congenital collection of blood vessels, is a rare presentation; however, the risk of bleeding and subsequent mortality is real. Management and surgical intervention vary dramatically depending on the site and characteristics of each individual lesion. The anesthesiologist must be aware of the various sedation plans, anesthetic protocols, pain management techniques, pharmacology parameters, and intraoperative monitoring methods currently available in order to achieve the best possible outcome for these patients.

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