Pediatric Anesthesia and Sedation for Interventional Radiology

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Introduction

As interventional radiology evolves, the emerging technological advances and increased complexity of procedures challenge the anesthetic technique. In infants and children, even the simplest procedures may require a general anesthetic to provide safe and motionless conditions. Indications for general anesthesia or sedation, aside from the inability to remain motionless on one's own, include the need for intermittent breath holding during image acquisition. Further indications for an endotracheal intubation may include those situations in which there is a risk of vasospasm (cerebral angiography and embolization). In these circumstances, controlled ventilation with purposeful hypercarbia can promote vasodilatation.

Interventional techniques include nonvascular and vascular intervention [1]. Biopsies, insertion and/or repositioning of drainage catheters, and insertion of catheters for central intravenous access often represent the majority of procedures and may be managed with a straightforward anesthetic or sedation. In some circumstances, regional anesthesia may provide a viable alternative. Intercostal nerve blocks may be very useful for lung or rib biopsies, chest tubes, biliary or subphrenic drainage procedures, and insertion of biliary stents.

The vascular interventions can range from straightforward angiography to complex procedures. Embolization and sclerotherapy for vascular malformations and anomalies tend to represent the more complex interventional vascular procedures. Percutaneous transluminal angioplasty and fibrinolytic therapy have been shown to benefit from procedural sedation or anesthesia [2]. The basic indications for embolization are occlusion of vascular malformations, management of uncontrollable hemorrhage, medical renal ablation, and presurgical embolization of hypervascular masses.

Sedation Strategies for Radiological Imaging Studies

Interventional radiological procedures for pediatric patients frequently require either general anesthesia or deep sedation for successful completion. Procedures that in adults would normally be performed with minimal sedation or local anesthesia often demand deep sedation or anesthesia in children.

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Patient Selection

A thorough medical history and review of systems should be completed and documented prior to scheduling a patient, in addition to relevant clinical consults and laboratory studies. A list of medical conditions that would immediately contraindicate non-anesthesiologist-delivered sedation can help guide this triage process as well as ensure consistency of decision-making (Table 3.1). Prior to the scheduled study, all families should receive a prescreen telephone call to confirm if there have been recent changes in medical history along with the nil per os (NPO) instructions. In most circumstances, families are instructed to administer the child's routine morning medications with a sip of clear fluid.

The patients scheduled for non-anesthesiologist-delivered sedation are typically American Society of Anesthesiologists level 1 or level 2 but rarely level 3 (Table 3.2).

Table 3.1 Red flags for sedation

1.	Apnea
2.	Full-term infant less than 1 month of age (unless an inpatient admitted to the hospital)
3.	Respiratory compromised patients
4.	Uncontrolled/unpredictable gastroesophageal reflux or vomiting that poses an aspiration risk
5.	Craniofacial abnormality that may make it difficult to establish effective mask airway
6.	Cyanotic cardiac disease or unstable cardiac status
7.	Painful procedure that may be challenging to provide adequate analgesia without a general anesthetic
8.	High-risk procedure that may require presence of an anesthesiologist for resuscitation
9.	Procedure that requires absolute immobility only achievable with a general anesthetic
10.	Procedure being performed in remote location that is so removed that immediate emergency backup assistance would be virtually impossible
11.	Inadequate qualified personnel available to provide safe procedural sedation

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In the United States, the delivery of deep sedation by non-anesthesiologists should be administered according to the American Society of Anesthesiologists Guidelines [3]. Under these guidelines, registered nurses are no longer qualified to administer deep sedation. The sedation provider must be a physician, nurse anesthetist, or anesthesia assistant. Specifically, the sedation care provider is expected to be experienced in the delivery of positive pressure ventilation via a facemask, endotracheal intubation, and insertion of laryngeal mask airways along with placement of nasal and oropharyngeal airways. A minimum of 35 patients or simulated cases must be performed in order to demonstrate competence. Recently, the Center for Medicaid and Medicare Services published their guidelines which are consistent with the American Society of Anesthesiologist's qualification requirements for sedation providers [4].

In the event that there are questions regarding the medical status or appropriateness of a child for sedation, a liaison from the Department of Anesthesia can facilitate the evaluation process by reviewing the history and, if appropriate, requesting consultations with appropriate specialty services (cardiac anesthesia, otolaryngology, surgery, nephrology, cardiology, or endocrinology). If the patient is deemed appropriate to receive sedation, then personal discussion between the consulting physician and sedation care provider is helpful to maximize safe care.

Table 3.2 ASA physical status classification

1.	A normal healthy patient
2.	A patient with mild systemic disease
3.	A patient with severe systemic disease
4.	A patient with severe systemic disease that is a constant threat to life
5.	A moribund patient who is not expected to survive without the operation
6.	A declared brain-dead patient whose organs are being removed for donor purposes

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It is important for the practitioner responsible for sedation to have a thorough understanding of the procedure requested. For example, the same patient may be medically appropriate to undergo sedation for an MRI scan but may be an inappropriate sedation candidate for a nephrostomy tube, placed with the patient prone in interventional radiology. Although a patient may meet the medical criteria for sedation, a collaborative discussion between the practitioners responsible for the sedation and the radiologist will ensure that the procedure and patient lend itself to sedation. In the event that the procedure is deemed high risk (e.g., cerebral embolization), associated with significant pain (e.g., sclerotherapy with doxycycline), or long in duration, the patient is usually best referred to general anesthesia for management. Additional, important, considerations should be the physical layout of the procedure room and its geographical proximity to the operating rooms. In the event of an emergency and the need for a "code team," the physical layout is important. If the radiological suites are physically isolated and distant from backup assistance, the more conservative approach will be to request anesthesia services prior to the initiation of a high-risk procedure.

Patient Sedation Guidelines

To minimize the chance of drug delivery error or miscalculation, it is helpful to have preprinted order sheets that should be approved by the Hospital Sedation Committee as recommended by JCAHO. The practice standards adopted by the American Society of Anesthesiologists in 1986 for basic intraoperative monitoring apply as well to extramural locations. Practice standards and guidelines promulgated by the American Academy of Pediatrics [5] are exceeded by established practice standards in anesthesiology [6]. Significant variances may exist when non-anesthesiologists sedate [7]. Practice Standards for Nonanesthetizing Locations were adopted by the American Society of Anesthesiologists in 1994 [8]. Recent practice standards by the American Society of Anesthesiologists for deep sedation by non-anesthesiologists stipulate monitoring which includes electrocardiogram, pulse oximetry, capnography, and noninvasive blood pressure monitoring [3].

A director of anesthesia services for a busy extramural radiology site will facilitate the delivery and coordination of anesthesia and sedation services. By being available to answer questions, do on-site consults, examine patients, and provide backup support or emergency airway expertise, the anesthesiologist is critical to the viability of a non-anesthesiologist-delivered sedation program. In addition to the American Society of Anesthesiologist, the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) Anesthesia and Sedation Manual has set guidelines for credentialing of all personnel who administer sedation [3, 9].

Medications

The selection of a sedation agent depends on the patient's underlying medical condition, age, drug tolerance, and anticipated procedure. Each medication has its own property which can include a hypnotic, anxiolytic, and/or analgesic. In order to appropriately make a sedation plan for each procedure, it is important to understand the properties of each medication and its potential synergistic actions with adjuvant medication. The more common sedatives administered for light, moderate, and deep sedation will be reviewed below.

Ketoralac

Ketoroloac (Toradol; Abbott labs, N. Chicago, IL) is an analgesic. It does not have sedative, hypnotic, or amnestic properties. Ketorolac tromethamine can be administered intravenously every 6 h with a maximum of 72 h of administration. It is useful for onetime administration to provide analgesia for short procedures such as biopsies. As a nonsteroidal anti-inflammatory agent, ketorolac may inhibit platelet aggregation and prolong bleeding time, which may be an undesirable effect for some interventional procedures. Agreement to administer a nonsteroidal should

be obtained from the interventional radiologist prior to administration. Alternative analgesics could include narcotics or ketamine.

Narcotics

The choice of narcotic should depend on the duration of the procedure and the extent of analgesia required. Morphine (Baxter Healthcare Corp, Deerfield, IL) and fentanyl (Baxter) are the more popular narcotics. Morphine requires approximately 10 min for effect and can provide analgesia for up to 2 h. Fentanyl works within minutes and has 100 times the potency of morphine. It generally needs to be redosed every 30–60 min, depending on the procedure. Narcotics work best when administered prior to (in anticipation of) the painful stimulus so that adequate analgesia is present at the time of the stimulus.

Ketamine

Ketamine, 2-(o-chlorophenyl)-2-(methylamino) cyclohexane, a phencyclidine and cyclohexamine derivative, was developed and introduced into clinical anesthesia practice in the 1960s. It may be administered via intravenous, intramuscular, oral, rectal, nasal, epidural, or intrathecal routes. The use of ketamine for pediatric sedation and analgesia has been described in various non-operating room settings that include emergency departments [10], gastroenterology [11], oncology [12], dental [13], and radiology suites [14, 15]. Ketamine produces rapid onset of deep sedation and analgesia with minimal respiratory depression and cardiovascular side effects [16–21]. A review of the literature reveals that despite the widespread use of ketamine by non-anesthesiologists, there is no consistent protocol for ketamine administration. Mason et al. describe the intravenous or intramuscular administration of ketamine, up to 2 mg/kg, for interventional radiological procedures. The intravenous dosage is followed by a continuous infusion of up to 125 μg/kg/h ketamine until the procedure is completed [17, 18]. When given in small bolus doses, it provides analgesia for an average of 30 min. As an infusion, ketamine can produce a continuous state of analgesia that may be titrated up and down in response to (or in anticipation of) the painful stimulus. It is especially useful for patients who are going to undergo an exceptionally painful procedure (doxycycline sclerotherapy, chest tube), are on chronic opioids, or have a high tolerance to opiates. The coadministration of ketamine with an anticholinergic is no longer recommended [19]. Ketamine provides an effective alternative to narcotics in some patients.

Hallucinations, delusions, nightmares, and emergence delirium are phenomenon most commonly described as a potential side effect of ketamine; these are more commonly noted in adults [22, 23]. The presence of these adverse events in the pediatric population is controversial [13, 24]. In adults, the concomitant administration of benzodiazepines (midazolam or diazepam) with ketamine has been shown to decrease the incidence of these events. Again, the utility of benzodiazepines in reducing these events in children is controversial [25–27]. Some reports indicate that the addition of benzodiazepines leads to an increased incidence of oxygen desaturation events [28]. Under age five, there is no definitive evidence that benzodiazepine administration will reduce the hallucinations, delusions, and excitatory behavior that can occur with ketamine. Children over age five may in fact benefit from concomitant benzodiazepine administration. Although ketamine administration and supervision by interventional radiologists is not a widely recognized technique, it offers an alternative agent for children who require profound analgesia albeit the risk of dissociative side effects.

Collaboration between the Departments of Anesthesiology and Radiology can provide for the radiologist-supervised administration of ketamine by nurses for interventional procedures, liver and renal biopsies included, in pediatric patients who might otherwise have required a general anesthetic. With sufficient triage and careful review of the medical history as well as relative and absolute contraindications to ketamine administration, radiologists can safely incorporate ketamine into their sedation armamentarium (Tables 3.3 and 3.4). Patients and parents are often relieved and grateful to avoid general anesthesia.

Table 3.3 Exclusion criteria for ketamine induced sedation

1.	Active pulmonary infection or disease
2.	Known or potential (i.e., risk of) airway compromise
3.	Pulmonary hypertension
4.	Age of 3 months or younger
5.	History of apnea or obstructive sleep apnea
6.	Craniofacial defect that would make mask ventilation difficult
7.	Complex cardiac disease
8.	Acute globe injury
9.	Prior adverse reaction to ketamine
10.	History of bipolar disease or schizophrenia
11.	Head injury associated with loss of consciousness, altered mental status, or emesis
12.	Intracranial hypertension (i.e., CNS mass lesions, hydrocephalus, head injuries associated with increased intracranial pressure): if there is any doubt, please have radiologist consult ordering physician to determine whether there is increased intracranial pressure risk
13.	Any child in whom there is a question of increased intracranial pressure
14.	Child with potential ventriculoperitoneal shunt malfunction
15.	Increased intraocular pressure
16.	Patient or parent refusal

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Table 3.4 Adverse events and parent and patient satisfaction

Variable	Total cohort ($n=65$)	Liver biopsy ($n=35$)	Renal biopsy ($n=30$)
Adverse events (no. of patients)			
During sedation	2[a]	0	2
During recovery	8[b]	6	2
24 h after procedure	4[c]	2	2
7 day after procedure	0	0	0
Sedation failure (no.)	0	0	0
Satisfaction (%)[d]			
Dissatisfied	0	0	0
Neutral	8	6	10
Satisfied	58	60	57
Very satisfied	34	34	33

[a]Renal biopsy: range ($n=1$), marked hypertension ($n=1$)
[b]Liver biopsy, need for supplemental oxygen ($n=1$), need for inhalers ($n=1$), vomiting or nausea (or both) ($n=4$); renal biopsy, agitation ($n=1$), vomiting and nausea ($n=1$)
[c]Liver biopsy, rash ($n=1$), vomiting ($n=1$); renal biopsy, irritability ($n=1$), drowsiness ($n=1$)
[d]Parent- and patient-based assessment
With permission from Mason KP, Padua H, Fontaine P, Zurakowski D. Radiologist Supervised Ketamine Sedation for Solid Organ Biopsies in Children and Adolescents. Am J Roentgenol 2009;192(5):1263 (*requested permission from American Roentgen Ray Society*)

Preparing for Emergencies in Areas Distant to the Operating Room

There are three particularly challenging scenarios that may occur in nonoperating room (off-site) locations: (1) the child with a known difficult airway, (2) the child with an unrecognized difficult airway, and (3) cardiovascular arrest. Each challenging situation will be addressed in order and in detail below. Most interventional radiology suites are remote to the operating room, to skilled and knowledgeable airway (otolaryngology, anesthesia, and surgery) assistance, and to backup airway support (bronchoscopes and alternative airway devices). Fiber-optic equipment and procedures are not routine in outfield areas and thus, when anticipated, should be reserved for the operating room environment. It is suggested that the "potential difficult airway" be managed first in the operating room and, after the airway is secured, the patient can then be transported to the radiological suites.

In the operating room, there are appropriate backup support and supplies if needed. Remember that each extramural anesthetizing location is unique with regard to conducting resuscitation. Redundancy of monitoring devices and equipment is important; one should not be limited to a single item that could malfunction at the time of resuscitation. The physicians, nurses, anesthesiologists, technologists, and support personnel must know the location of emergency equipment. In addition, a hard board to be placed under the

patient during resuscitation should be readily available. Mock codes and simulation of emergencies should be performed regularly to ensure adequate flow, teamwork, and delineation of responsibilities.

The administration of iodine-containing contrast for interventional procedures necessitates a complete knowledge of risk factors for anaphylaxis and appropriate prophylaxis and intervention (Table 3.5). Patients with multiple allergies, shellfish allergies, or atopic disease are at increased risk of exhibiting anaphylaxis to iodine-containing contrast. These patients may benefit from pretreatment with steroids and antihistamines.

The unrecognized and unanticipated difficult airway should be a scenario for which alternate airway devices, such as laryngeal mask airways and even tracheostomy sets, are routinely available and stocked in off-site locations. In the event that the child cannot be ventilated nor intubated, the laryngeal mask airway may be life saving [29, 30]. Transfusion requirements are rare in extramural locations, yet preprocedural anemia, accidental perforation of vascular structures, or medical transfusion requirements, such as sickle cell disease or prematurity, may require transfusion therapy. Equipment consistent with that available in the operating room must be available in these off-site locations.

Table 3.5 Management of acute reactions in children

Urticaria
• No treatment needed in most cases • Give H_1-receptor blocker: diphenhydramine PO, IM, or IV 1–2 mg/kg, up to 50 mg • If severe or widely disseminated, give ∝-agonist, epinephrine SC (1:1,000) 0.01 mL/kg
Facial edema
• Give O_2 6–10 L/min (via mask, face tent, or blow-by stream) administered at 2 times the maintenance rate in order to monitor electrocardiogram, O_2 saturation (pulse oximeter), and blood pressure • Give ∝-agonist: epinephrine SC or IM (1:1,000) 0.01 mL/kg/, up to 0.3 mL/dose. Repeat in 15–30 min as needed • Give H_1-receptor blocker: diphenhydramine IM or IV 1–2 mg/kg, up to 50 mg • If no response to therapy, seek appropriate assistance (e.g., cardiopulmonary arrest response team)
Laryngeal edema or bronchospasm
• Give O_2 6–10 L/min (via mask, face tent, or blow-by stream). Monitor electrocardiogram, O_2 saturation (pulse oximeter), and blood pressure • Give β-agonist inhalers: bronchodilators, such as metaproterenol, terbutaline, or albuterol 2–3 puffs. Repeat as necessary • Give epinephrine SC or IM (1:1,000) 0.1 mL/kg, maximum 3 mL/dose. Repeat in 3–5 min as needed • Call for assistance (e.g., cardiopulmonary arrest response team) for severe bronchospasm or if O_2 saturation <88 % persists
Pulmonary edema
• Give O_2 6–10 L/min (via mask, face tent, or blow-by stream). Monitor electrocardiogram, O_2 saturation (pulse oximeter), and blood pressure • Give diuretic: furosemide IV 1–2 mg/kg • Call for assistance (e.g., cardiopulmonary arrest response team)
Hypotension with tachycardia
• Give O_2 6–10 L/min (via mask, face tent, or blow-by stream). Monitor electrocardiogram, O_2 saturation (pulse oximeter), and blood pressure • Legs elevated 60° or more (preferred) or Trendelenburg position • Keep patient warm
• Give IV or IO normal saline or lactated Ringer's solution 20 mL/kg over 5–10 min. Bolus infusion over 10–20 min in patients with myocardial dysfunction • Seek appropriate assistance (e.g., cardiopulmonary arrest response team)
Hypotension with bradycardia (vagal reaction)
• Give O_2 6–10 L/min (via mask). Monitor electrocardiogram, O_2 saturation (pulse oximeter), and blood pressure • Legs elevated 60° or more (preferred) or Trendelenburg position • Keep patient warm • Give IV or IO normal saline or lactated Ringer's solution 20 mL/kg over 5–10 min. Give infusion over 10–20 min in patients with myocardial dysfunction • Give atropine IV 0.02 mg/kg if patient does not respond quickly to steps 2, 3, and 4. Minimum initial dose of 0.1 mg. Maximum initial dose of 0.5 mg (infant/child), 1 mg (adolescent). Atropine dose may be doubled for second administration • Seek appropriate assistance (e.g., cardiopulmonary arrest response team)

IM intramuscular, *IO* intraosseous, *IV* intravenous, *SC* subcutaneous, *PO* per os (orally)

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Summary

The demand for anesthesia and sedation services in sites distant to the operating room can be challenging and with extra risk. Although the incidence of adverse outcomes for anesthesia and sedation in these radiological areas has not been reported, reports from office-based and ambulatory surgery centers have extrapolated risks. In Florida, the incidence of adverse events is higher in office-based versus outpatient surgical centers [31]. Although these outcomes cannot be directly compared with off-site anesthetizing locations, it prompts the consideration of the level of added risk in the off-site location. Sedation, monitored anesthesia care, and general anesthesia are all choices that carry risks. Historically, an avoidance of a general anesthesia has been thought to minimize the risk of adverse outcome. Closed-claims analysis demonstrates that monitored anesthesia care poses an equal risk to general anesthesia with respect to severity of injury, death, and permanent brain damage. Twenty-four percentage of all monitored anesthesia care claims involve oversedation and respiratory depression [32]. Anesthesia and sedation providers must recognize that a careful risk analysis is critical when selecting patients and formulating a plan of care.

This chapter has reviewed some general issues and some specific and challenging situations that anesthesiologists and radiologists must be prepared for in the interventional radiology suite. These guidelines will be best tailored to the unique setup, support, and equipment available at each facility. As the American Society of Anesthesiologists and Center for Medicaid and Medicare Services continue to present guidelines for deep sedation, it is likely that the involvement of anesthesiologists in caring for children outside of the operating room will burgeon.

Special Topics: Anesthesia for Vascular Anomalies

The anesthetic management of patients with vascular malformations can be challenging. Vascular malformations are congenital aberrant connections between vessels, which may be comprised of lymphatics, arteries, capillaries, and veins. These lesions, although present at birth, may not become clinically apparent until the child grows. A rapid proliferative phase may occur in response to hormonal changes (pregnancy and puberty), trauma, or other stimuli [33]. Vascular malformations may present high-flow or low-flow lesions. High-flow lesions include arteriovenous fistulas, some large hemangiomas, and arteriovenous malformations. Extensive lesions with an arterial component may create a high-output cardiac failure with resultant congestive heart failure and the potential for pulmonary edema. Low-flow lesions, those with venous, intramuscular venous, and lymphatic malformations, do not present such a risk. Surgical resection of symptomatic vascular malformations presents risks of significant intraoperative bleeding and coagulopathy, in addition to surgical and anesthetic risk. For this reason, invasive angiography and embolization have become popular alternatives to surgical resection when possible.

Because vascular malformations tend to grow, even those lesions that are asymptomatic may someday require intervention. Accompanying clinical conditions can include pain, tissue ulceration, disfigurement, multiorgan compromise, impairment of limb function, coagulopathy, claudication, hemorrhage, and progressive nerve degeneration or palsy.

A dedicated anesthesia team committed to interventional radiology has an advantage: in addition to gaining a familiarity with the procedures and the radiologists, nurses, and technologists, the patients and parents often return for multiple procedures and are comforted by seeing familiar anesthesiologists. Especially with these complicated patients, familiarity with the patient, their vascular lesion, the procedures involved, and the interventional radiologist all benefit from a core group of anesthesiologists. Vascular embolization may be used as a bridge to surgical resection and may decrease the risk of intraoperative bleeding.

When embolizing vascular malformations, radiologists may use various techniques and agents: ethanol, stainless steel coils, antibiotics, absorbable gelatin pledgets and powder, polyvinyl

alcohol foam, glues, thread, and ethanol. The choice of agent depends on the clinical situation and the size of the blood vessel. When permanent occlusion is the goal, polyvinyl alcohol foam and ethanol are often employed as they both occlude at the level of the arterioles and capillaries. Medium- to small-sized arteries may be occluded with coils, which are the surgical equivalent of ligation. In trauma situations, when only temporary (days) occlusion is the goal, absorbable gelatin pledgets or powder is employed [34]. Absolute ethanol (99.9 % alcohol) is a powerful sclerosing agent, which has particular implications for the anesthesiologist and perioperative care provider.

Ethanol can cause thrombosis of the vascular endothelium, which can extend to the capillary bed. A powerful sclerosant, it is particularly useful in the embolization of symptomatic vascular malformations. For that reason, using selective catheterization and direct percutaneous puncture, normal blood vessels are avoided. Ethanol causes denaturation of blood proteins and may produce a coagulum of blood with endothelial necrosis [35]. Sclerotherapy or embolization with absolute (99.9 %) ethanol may elicit a post-procedure coagulopathy [36] marked by positive d-dimers, elevated prothrombin time, and decreased platelets. Extensive ethanol injections (usually considered to be >0.5 mL/kg) can cause hematuria and should require the placement of a Foley catheter during the procedure for careful monitoring of urine output throughout and in recovery. On average, it has been our practice to administer between 50 and 100 mL/kg intravenous fluids over the course of the procedure. When hemoglobinuria is noted during the procedure, the anesthesiologist should notify the radiologist so that the need for continued injections of ethanol is reevaluated. Aggressive and immediate treatment of hematuria is essential as soon as it is recognized to minimize the risk of renal damage. Inadequate hydration with subsequent hemolysis has resulted in renal failure with subsequent hemodialysis (personal correspondence). Hemoglobinuria may not occur until the end of the procedure, particularly when a large volume of ethanol is injected towards the end of the procedure or with procedures that involve the injection of lower extremity lesions below a tourniquet. With tourniquets, hemoglobinuria should be expected within 10 min of deflation. In anticipation of hematuria following tourniquet deflation, generous fluid replacement should be initiated prior to deflation and continued thereafter in order to mitigate hematuria. Furosemide intravenous (0.5–1.0 mg/kg) promotes diuresis and a faster resolution of gross hematuria (personal experience). It is important to recognize that the appearance of hemoglobinuria may be delayed and can present up to 1–2 h after completion of the procedure. It is suggested that following large injections of ethanol, patients be observed for a minimum of 2 h for hematuria in recovery prior to discharge to the floor. Fluid administration should be balanced with urine output. At our institution, persistent hemoglobinuria is treated with sodium bicarbonate (75 mEq/L in 5 % dextrose and water), which is administered at a rate of 2 times the maintenance in order to alkalinize the urine and minimize the risk of hemoglobin precipitating in the renal tubules [37]. All hematurias should be resolved prior to discharge from post-anesthesia recovery room.

Administration of ethanol has the potential for severe complications. Albeit infrequent, there is a risk of cardiovascular collapse, which is generally preceded by hypoxemia and bradycardia. Most reported cases of cardiovascular collapse involved lower extremity malformations [38]. The etiology of the cardiovascular collapse associated with ethanol is unclear, although its occurrence has been reported coincident with the injection of ethanol into the systemic veins or after the release of lower extremity tourniquets after ethanol injection. It is critical that the radiologist communicate with the anesthesiologist whenever ethanol is being injected and before the deflation of the tourniquet. In our practice, sudden desaturation without arrhythmia or hypotension has occurred with ethanol administration, without cardiovascular sequela. Alternatively, pulmonary embolism from thrombus dislodgement at the site of the vascular malformation has occurred with mild (mid 80 % to low 90 %) oxygen desaturation and prolonged (24–48 h) hypoxemia, presumably from micro-thromboembolism.

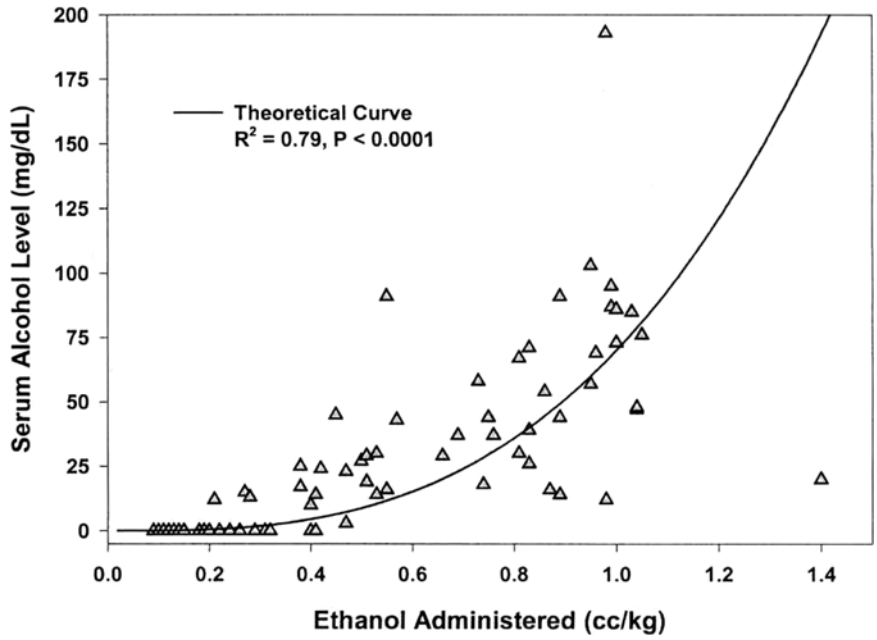

Fig. 3.1 Graph shows the positive relationship between serum ethanol level and amount of ethanol administered in all 71 patients. *Solid line* indicates the theoretic curve based on the nonlinear exponential power model y 5 $70x3$, where x is the amount of ethanol administered and y is the predicted serum ethanol level. *Triangles* represent empirical values. Theoretic curve demonstrates the most accurate fit compared with all other linear and nonlinear models tested. *Reprinted with permission from Mason KP, Michna E, Zurakowski D,* et al. *Serum Ethanol levels in children and adults after ethanol embolization or sclerotherapy for vascular anomalies. Radiology 2000;217:127-132 © Radiological Society of North America*

These patients benefit from systemic anticoagulation without long-term sequelae.

In addition to neuropathy and tissue necrosis, if not injected selectively, ethanol can produce a state of intoxication. The ethanol used for embolization and sclerotherapy is concentrated to 95–98 %. Patients who receive >0.75 mL/kg can be clinically intoxicated. Blood levels correlate with the volume of ethanol administered, regardless of the location or type of vascular malformation (Fig. 3.1).

On extubation, particularly following large injections of ethanol, patients can display extremes of behavior ranging from significant agitation to extreme somnolence. In both situations, narcotics, if needed, should be administered with caution, as these patients tend to be slow to emerge from anesthesia (some even have strong odor of alcohol on their breath). High serum levels of ethanol provide analgesia. Narcotics may produce a synergistic effect with the potential for respiratory depression. Until the extent of pain is assessed, narcotics should be titrated in small, conservative doses. Ketorolac can provide analgesia in those who are not at risk of developing a coagulopathy or a post-procedure bleed.

Large hemangiomas may be associated with a coagulopathic condition called Kasabach–Merritt syndrome. In this condition, the hemangioma traps and destroys platelets and clotting factors, resulting in thrombocytopenia and an increased risk of hemorrhage. As the hemangioma involutes, the coagulation status tends to improve [39]. A condition described as systemic intravascular coagulation can occur after the embolization of extensive vascular malformations. Systemic intravascular coagulation is a condition similar to disseminated intravascular coagulation (DIC) but specific for the coagulopathy, which results from

embolizations: an elevated prothrombin time with a decrease in coagulation factors and platelets. Other patients with vascular malformations, particularly venous malformations, can have preexisting coagulation disturbances that resemble DIC [40–44]. A hematology consult should be obtained for those patients with laboratory values consistent with a consumptive coagulopathy. They may be initiated on heparin for 2 weeks before the procedure in order to replenish their fibrinogen levels. During extensive embolizations, cryoprecipitate or platelets may be administered to promote clotting and successful sclerosis. The use of ethanol for sclerosis or embolization can elicit a coagulation disturbance that resembles DIC. There is a statistical relationship between the amount (mL/kg) of ethanol administered and the degree of coagulation disturbance elicited [36]. The coagulopathy is generally not symptomatic, resolves in about 5 days, and does not require additional cryoprecipitate or fresh frozen plasma transfusions. Major surgery is usually deferred until the coagulation parameters have normalized.

There are a number of concerns and perioperative issues. Following extensive embolization procedures, these patients frequently experience pain from the tissue necrosis and swelling. A variety of analgesic techniques should be considered. Steroids, although they do not have analgesic properties, may reduce edema and postembolic neuritis with resultant analgesia. Postembolic swelling will impact the perioperative airway management following procedures in the head and neck. Pediatric patients in particular may need to remain intubated after such procedures, particularly when edema in the floor of the mouth, tongue, hypopharynx or oropharynx, or anterior neck could compromise a patent airway. An additional post-procedure concern is that vomiting may, because of the Valsalva maneuver, increase venous blood pressure and aggravate bleeding and swelling at puncture sites or cause swelling and airway obstruction following the head and neck procedures. Hypothermia is a risk in interventional radiology, particularly with long procedures. Heating lamps and body surface warming devices may be used when safe and appropriate. Finally, with the use of iodine-containing radiocontrast media, sclerosing, and embolizing agents, consideration must be given to adequate volume resuscitation, the risk of a contrast reaction, and bladder catheterization for detection of oliguria, polyuria, or hematuria.

Special Topics: Anesthesia and Angiography

Cerebral angiography typically requires endotracheal intubation. Hypercarbia to end tidal CO_2 >50 mmHg will promote vasodilation to allow better access and visualization of cerebral vasculature (Fig. 3.1). Orogastric, nasogastric tubes, esophageal stethoscopes, and esophageal temperature probes should be avoided during cerebral angiography as they can create artifacts on the angiographic images. Cerebral studies may be indicated in the work-up or postoperative follow-up of vascular malformation or tumor resections, stroke, hemorrhagic events, vascular disease, and unexplained mental status changes. It is important to know the indications for the cerebral angiography, as these indications may guide the perioperative management. For example, any child requiring a study for the potential or confirmed diagnosis of moyamoya should be treated with utmost precaution, with anesthetic techniques that minimize the risk of transient ischemic attacks and stroke during the procedure [45]. The recommended anesthetic technique is to hydrate with 10 mL/kg intravenous fluid prior to anesthetic induction to reduce the risk of hypotension (and potential cerebral ischemia) with induction. Inhalational inductions are generally discouraged in favor of a well-controlled intravenous induction with concomitant hemodynamic stability. Hypocarbia should be avoided to minimize risk of cerebral vasoconstriction and normocarbia is generally the goal throughout. In the event of vasospasm or difficult access of small, torturous vessels, the interventional radiologist can administer (through the intravascular catheter) nitroglycerin in small doses (25–50 μg) to promote vasodilation and improve visualization and access. Small doses of nitroglycerin are

generally successful in vasodilating specific discrete and local areas and do not have a clinically relevant effect on systemic blood pressure.

Angiographic imaging of the abdomen or pelvis may be enhanced through the use of glucagon, administered in divided doses of 0.25 mg to a maximum of 1.0 mg intravenously. Glucagon is efficacious for digital subtraction angiography, visceral angiography, and selective arterial injection in the viscera. Risks with glucagon include hyperglycemia, vomiting (particularly when given rapidly), gastric hypotonia with post-procedure vomiting, anaphylaxis with rapid administration, and physiologic signs (tachycardia and hypertension) that mimic pheochromocytoma [46–48]. Antiemetics may be considered prophylactically or as a treatment in the recovery room.

Imaging of the lower extremities and pelvis may involve the added challenge of positioning the patient in reverse position on the fluoroscopy table, the addition of extra long ventilator tubing, and the added awareness that the patient's airway is distant to the anesthesia machine and anesthesiologist. Particularly in these circumstances, the anesthesiologist should determine a plan of action in the event of an airway emergency. Unless the patient can be repositioned quickly with the head at the head of the bed adjacent to the anesthesiologist, emergency anesthesia assistance should be heralded immediately and the ancillary medical staff (nurses and radiologists) should be trained to assist as help is summoned.

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