Chapter 52

Selected Diagnostic Procedures

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Introduction

Several minimally invasive advanced diagnostic and therapeutic procedures have become more commonly used over the last decade because of increased availability of the technology and expertise in application and interpretation. General anesthesia or sedation is usually required to assure patient immobility during these procedures. Animals vary greatly in physical status and underlying disease processes. Thus, the saying "There is no *one* ideal anesthetic protocol" applies aptly to these patients. Because many of the procedures discussed in this chapter may be considered to be elective, minimally invasive, and of short duration, an anesthetic protocol that will provide a rapid recovery is desirable. Perianesthetic considerations are presented for selected minimally invasive diagnostic techniques, including laryngoscopy, bronchoscopy, bone marrow aspiration, thoracic drain placement, and esophagostomy tube placement; for advanced imaging techniques, including computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography; and for radiation therapy. With a few exceptions, these procedures are not considered lifesaving, but rather diagnostic, and should be planned to minimize the potential adverse effects of general anesthesia or sedation.

The approach to anesthetic management should be kept simple, with the following principles in mind:

1. Identify and correct (when possible) underlying patient problems to minimize anesthetic risk.

2. Formulate an anesthetic protocol that will work in the existing environment and that can be readily adapted to each individual patient and its unique disease process(es).
3. Apply effective and adequate monitoring tools that will alert the anesthetist to potential problems so that quick and effective correction can be instituted.
4. Provide appropriate supportive therapy (as guided by underlying patient disease and information provided by monitoring devices).

Laryngoscopy and Bronchoscopy

Laryngoscopy is used in evaluating laryngeal disease—specifically, laryngeal paralysis. Sedation is required to facilitate relaxation of the jaw, but must be carefully selected to have a minimal effect on laryngeal function. It can be challenging to keep patients adequately sedated without affecting laryngeal function. A neuroleptanalgesic combination of an opioid and benzodiazepine (Table 52.1) is adequate for most patients. These drugs have the advantage of preserving laryngeal function and being reversible if respiratory distress develops. Challenge with doxapram (1.0 mg/kg intravenously [IV]) to increase respiratory activity may be used if evaluation is hindered by drug-induced respiratory depression.

Bronchoscopy is performed in dogs and cats for evaluation of airway disease and to perform bronchoalveolar lavage. Many of the patients presented for laryngoscopy and bronchoscopy are at increased risk for development of hypoxemia. Preoxygenation should accompany both procedures, and the anesthetist should always be prepared to take control of the airway by intubation and application of ventilatory support. During the bronchoscopy, oxygen may be delivered to smaller patients via an endoscope (working channel). Larger patients may be intubated and connected to oxygen by a breathing system; a Y-piece aperture may be used to pass the endoscope into the trachea. An opioid-benzodiazepine combination for sedation, followed by administration of low-dose propofol to effect, is commonly used to facilitate bronchoscopy (Table 52.1).

Thoracic Drain Placement

Thoracostomy tube placement may be required to manage pleural space disorders, such as pneumothorax, pyothorax, and chylothorax. These patients are often high risk, especially animals

Table 52.1. Suggested anesthetic doses for protocols for diagnostic procedures[a]

Premedication: opioid-benzodiazepine combination	
Opioids (IV, IM, or SC; IV administration of morphine is not recommended)	
Butorphanol	0.2–0.4 mg/kg
Buprenorphine	0.01–0.04 mg/kg
Morphine	0.4–1.0 mg/kg
Hydromorphone	0.1–0.2 mg/kg
Oxymorphone	0.05–0.1 mg/kg
Benzodiazepines (diazepam: IV only; midazolam: IV, IM, or SC)	
Diazepam	0.1–0.4 mg/kg
Midazolam	0.1–0.3 mg/kg
Antagonists	
Naloxone (opioid)	0.001 mg/kg
Flumazenil (benzodiazepine)	0.01–0.02 mg/kg
Induction	
Propofol	2–6 mg/kg IV
Etomidate	0.5–2.0 mg/kg IV
Ketamine	2–5 mg/kg[b] IV, IM
Maintenance	
Inhalation anesthesia: isoflurane or sevoflurane	
Propofol CRI	0.4 mg/kg/min
Propofol IB	0.5–2.0 mg/kg

CRI, continuous-rate infusion; IB, intermittent bolus; IM, intramuscular; IV, intravenous; and SC, subcutaneous.

[a]These protocols pertain to dogs and cats.

[b]Ketamine for induction is administered IV at 5 mg/kg combined with a benzodiazepine at 0.25 mg/kg and given to effect. For feline immobilization, 2 mg/kg IM is used with a benzodiazepine-opioid combination.

with pneumothorax and concurrent pulmonary contusions. In dogs, thoracic drain placement can often be performed using sedation in combination with a local anesthetic technique, such as infiltration or intercostal nerve block (see Chapter 20). To assure airway control, oxygen delivery, and provision of ventilatory support throughout the procedure in patients with respiratory distress or with hypoxemia, general anesthesia may also be used and may be superior. For cats, general anesthesia is preferred. Reversible agents with mild cardiopulmonary effects, such as the combination of a benzodiazepine with butorphanol or buprenorphine (Table 52.1), provide adequate sedation for most patients. For general anesthesia, a rapid-sequence induction to gain control of the airway is recommended. Propofol, benzodiazepine-ketamine combination, or etomidate (Table 52.1) are good induction choices, providing for relatively rapid recoveries.

Bone Marrow Aspiration

This is performed to evaluate bone marrow disease and to stage certain cancer patients. Protocol selection should be based on the individual patient; depending on the level of an animal's activity, bone marrow aspiration may be performed in dogs with local in-

filtration alone or in combination with sedation. Uncooperative dogs and the majority of cats may require general anesthesia. The aforementioned protocols for thoracostomy tube placement are appropriate.

Esophagostomy Tube Placement

This is used to provide enteral nutrition for both dogs and cats. General anesthesia is required to protect the airway in case of regurgitation and the endotracheal tube facilitates placement of the esophageal tube. The aforementioned protocols for thoracostomy tube placement are applicable for this procedure.

For the procedures listed earlier, identification of an individual animal's underlying disease, anticipation of and planning for potential complications, and close monitoring throughout the anesthetic period will help to assure a successful outcome, regardless of the anesthetic agents used.

Computed Tomography and Magnetic Resonance Imaging

General Considerations

CT and MRI were first introduced in 1972 and 1980, respectively. Routine clinical use of CT and MRI technology has evolved recently as availability of equipment and expertise in interpretation have increased. Anesthetic management for CT and MRI presents a unique challenge in that there is no painful stimulation during the anesthetic period; thus, response to a noxious stimulus does not provide a method for assessing anesthetic depth. The majority of scans are performed with the patient in dorsal recumbency; this position has the most significant detrimental effects on ventilation and perfusion matching. And patient access is usually limited during both CT and MRI. Depending on unit configuration, patients placed in a magnet are often difficult to access, so subjective evaluation, such as assessment of pulse quality and mucous membrane color, may not be feasible. With CT, although patient access is not problematic, exposure of the anesthetist to radiation is an issue, and direct patient assessment while the scan is being performed is discouraged.

Contrast Agents for CT and MRI

An additional consideration is the common use of contrast for both MRI and CT. While reaction to contrast administration appears to be relatively uncommon in animals, anesthetists must be aware of this potential complication. Intravenous iodinated contrast is often given to patients during a CT scan. These contrast agents consist of meglumine and/or sodium salts of iothalomate or diatrizoate (Table 52.2) and are ionic and hyperosmolar, which contributes to their side effects. Adverse reactions to these contrast agents include hypotension, tachycardia, and depressed ST segments and prolonged Q-T intervals on the electrocardiogram (ECG).[1] One case of cardiac arrest has been reported in a dog after intravenous (IV) administration of iodinated contrast media.[2] Adverse reactions are usually seen in the first 5 to 10 min following administration and are potentiated by dehydration; thus, normal hydration status is essential prior to the CT contrast

Table 52.2. Properties of contrast agents used for diagnostic imaging

Ionic, hyperosmolar iodinated contrast media

Brand Name	Cation	Anion	mg I/mL	Osmolality (mOsm/kg H_2O)	Viscosity at 37°C
Conray	Meglumine	Iothalamate	282	1400	4
Conray 400	Sodium	Iothalamate	400	2300	4.5
Hypaque 76	Meglumine 66% Sodium 10%	Diatrizoate	370	2016	9
Hypaque 50%	Sodium	Diatrizoate	300	1515	2.34
Hypaque 60%	Meglumine	Diatrizoate	282	1415	4.12
Renografin 76	Meglumine 66% Sodium 10%	Diatrizoate	370	1940	8.4
Renografin 60	Meglumine 52% Sodium 8%	Diatrizoate	290	1450	4

Nonionic, low-osmolar iodinated contrast media

Brand Name	Generic Name	mg I/mL	Osmolality (mOsm/kg H_2O)	Viscosity at 37°C
Omnipaque	Iohexol	140	322	1.5
		180	408	2
		240	520	3.4
		300	672	6.3
		350	844	10.4
Isovue	Iopamidol	150	342	1.5
		200	413	2
		300	616	4.7
		370	796	9.4
Visipaque	Iodixanol	270	290	6.3
		320	290	11.8
Ultravist	Iopromide	300	607	4.9
		370	774	10
Optiray	Ioversol	160	355	1.9
		240	502	3
		300	651	5.5
		320	702	5.8
		350	792	9
Imagopaque	Iopentol	150	310	1.7
		200	410	2.8
		250	520	3.9
		300	640	6.5
		350	810	12

administration. Humans are at risk for serious reactions if they have any of the following preexisting conditions: diabetes mellitus, renal insufficiency, congestive heart failure, hypovolemia, multiple myeloma, hypertension, or combined hepatic and renal failure.[1] No specific treatment is necessary following a mild reaction to the contrast media; however, fluid administration rate should be increased for treatment of mild hypotension and tachycardia. If an anaphylactic reaction does occur, administration of epinephrine, diphenhydramine, and/or corticosteroids is indicated. Fluid administration rate for patients with underlying renal disease should be increased to 20 mL/kg during the first 30 min of anesthesia to promote contrast clearance and to maintain adequate renal perfusion.

All contrast agents used in MRI contain a paramagnetic element: gadolinium. These contrast agents present a lower osmotic burden to the patient, and smaller volumes are required compared with CT contrast agents. There have been no reported cases of adverse reactions to MRI contrast agents in animals, but allergy-type symptoms, hypotension, hypertension, vasodilation, tachycardia, nausea, vomiting, and headache have been reported in humans. An increased administration rate of IV fluids should be used to treat hypotension and tachycardia.[3]

MRI Safety Considerations

MRI safety is an important concern in anesthesia monitoring because ferromagnetic objects are attracted toward the magnet; therefore, projectile-related accidents can occur. Traditional anesthetic equipment and monitors may be unsafe, may be damaged, may malfunction, or may interfere with image generation when used in the MRI suite. The MRI consists of a strong static magnetic field, gradient magnetic fields, and radiofrequency (RF) fields. Any ferromagnetic object has the potential to be drawn into the bore of the magnet, causing injury to the patient or personnel in the room. The influence of the MRI scanner on equipment depends on the strength of the magnet, proximity to the magnet bore, the amount of ferromagnetic material present, and the design of the circuitry.[4] Also, the RF fields and the applied magnetic gradient fields in the room can affect the function and accuracy of the monitoring equipment, or, conversely, the monitoring equipment can alter the quality of the images obtained. Ferromagnetic equipment within the room should be replaced with nonferromagnetic or minimally ferromagnetic metal, such as stainless steel, brass, or aluminum. Alternatively, ferromagnetic equipment may be securely anchored to a wall or the floor as far away from the bore of the magnet as possible. Monitoring equipment may be adapted by placing the devices outside of the room and using long connecting wires. If possible, oxygen tanks should be located outside of the MRI suite, or tanks made of aluminum should be used.

Several companies sell MRI-compatible anesthesia and monitoring equipment. Keep in mind the definitions of MRI safe and MRI compatible. *MRI safe* means that the device, when used in the MR environment, has been demonstrated to present no additional risk to the patient or other individual, but may affect the quality of the diagnostic information. *MRI compatible* means that a device is MR safe and, when used in the MR environment, has been demonstrated neither to significantly affect the quality of the diagnostic information nor to have its operations affected by the MR unit.[4] Some companies market their product as MRI compatible, but the instruction manuals must be carefully read because there have been several reports of "MRI compatible" monitoring equipment being propelled into the bore of the magnet.[5,6] Instructions for such potentially hazardous equipment state that the item must be placed a certain distance away from the magnet.[6,7] Ideally, equipment should be checked by a biomedical engineer responsible for the area before it is brought into the vicinity of the MRI scanner. Some companies that supply MRI-compatible or MRI-safe anesthetic equipment and monitors are listed in Table 52.3.

Special consideration should also be given to patients with any type of metallic implants, such as hemoclips, patent ductus arteriosus (PDA) occlusion coils, or pacemakers. Ferromagnetic hemoclips can dislodge and migrate, causing internal damage. An electrical current can be induced in PDA coils, causing thermal damage, and pacemaker leads or generators can dislodge. The magnetic field may cause the pacemaker generator to malfunction or readjust. An electrical current in the lead wire may produce enough heat to cause injury. If a metallic implant is located in the region that is being imaged, severe image artifacts often occur, resulting in a nondiagnostic study.

Table 52.3. Companies that manufacture MRI-compatible, MRI-safe anesthesia equipment

Smiths Medical PM, Veterinary Division (Surgivet)	www.surgivet.com/index.asp
DRE Medical	www.dreveterinary.com
In vivo	www.invivoresearch.com
Medrad	www.medrad.com
Datex	www.datex-ohmeda.com
Nonin	www.nonin.com

One other safety issue that may occur in the MRI suite is magnetic quenching. If the liquid helium that surrounds and cools the superconducting solenoid of the magnet rapidly escapes, it can displace the oxygen in the room, causing hypoxia to the patient and personnel present. Ideally, oxygen sensors should be placed in MRI suites.

Ultrasonography

This has been used in veterinary medicine since the late 1970s and has become a routine diagnostic procedure for animals. Most animals tolerate ultrasonographic evaluation without sedation or anesthesia, but sedation may be necessary in fractious, aggressive, or painful animals. Ultrasound-guided organ or tissue biopsies are becoming more common as a method for collecting samples less invasively. Small animals usually tolerate the procedure well with sedation and local anesthetic infiltration, but general anesthesia may be more effective in some individuals. Local anesthetic infiltration alone or with mild sedation, combined with proper restraint, is effective for collecting biopsy samples in standing horses, cows, and other large animal species.

Radiation Therapy

External beam radiation is used to treat many types of neoplasia in small animals. Treatment usually consists of multiple small doses of radiation daily for a curative intent or larger, less frequent doses for pain palliation. Treatment times per dose last anywhere from about 1 min up to 7 or 8 min. Therefore, patients must remain motionless and be precisely positioned for radiation therapy. Since most animals receive their radiation doses daily and remain in the hospital for up to 4 weeks or go home nightly, a profound sedation or general anesthetic protocol should be used that is easily administered and has a quick recovery time. During treatment, personnel cannot be present in the therapy room to directly monitor the animal because of radiation safety. Remote monitors or cameras focused on the patient and in-room monitors should be used to assess the patient.

Patient Preparation

The procedures presented in this chapter, though essential to the well-being of the individual patient, are largely elective. Ade-

Table 52.4. Disease processes that may be present in patients presented for computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography

Organ or Organ System: Examples
Skull: orbital, nasal, sinus, and oral tumors
Brain: tumors, cerebrovascular bleeding (stroke), and hydro-cephalus
Spinal cord: tumors, intervertebral disk disease, and trauma
Musculoskeletal: soft tissue and skeletal tumors, and ligament and cartilage damage
Thorax: intrathoracic masses, effusions, and pneumonia
Cardiac: masses, murmurs, and arrhythmias
Abdomen: abnormalities associated with the liver, pancreas, adrenal glands, spleen, kidneys, ureters, and bladder

This list is not exhaustive but is based on the literature and personal experience of the authors. As a general rule, CT is superior for skeletal imaging, whereas MRI is superior for soft tissue imaging. Movement artifact can be problematic for abdominal and thoracic MRI, depending on the speed and sophistication of the scanner. CT may provide superior images for body cavity structures.

quate preanesthetic patient assessment, including physical examination and laboratory evaluation (complete blood count, chemistry panel, and urinalysis), is essential for successful outcome. Fortunately, since the aforementioned techniques may be considered to be advanced techniques, a thorough workup has already been performed in many of the presenting patients. For marrow and organ biopsy, a coagulation profile should also be evaluated. Table 52.4 provides some examples of disorders that may exist in patients presented for MRI, CT, and ultrasound procedures. Readers are directed to Chapters 36 to 51, which address anesthetic management of system-specific diseases, for additional anesthetic management considerations.

Protocol Selection

When formulating an anesthetic plan, reversibility, familiarity (comfort zone), and maintenance of homeostasis by provision of adequate supportive care and monitoring should be addressed. Since the technique itself will vary minimally among patients, an anesthetic plan that will meet the needs of the majority of patients and will be compatible with the facility is desirable. The drugs used should be short-acting and/or reversible; some options are listed in Table 52.1. For premedication, an opioid alone or combined with a benzodiazepine has relatively mild cardiopulmonary effects and will provide sedation and reduce induction and maintenance requirements. These drugs can be reversed with an opioid antagonist, such as naloxone, and the benzodiazepine antagonist flumazenil, if necessary (Table 52.1). Acepromazine premedication may be beneficial for healthy animals that are difficult to restrain or aggressive, if there are no patient contraindications. Acepromazine facilitates a smooth but somewhat prolonged recovery, so benefits should be weighed against this disadvantage. Intramuscular ketamine (2 to 4 mg/kg),

with an opioid-benzodiazepine combination, may be beneficial in fractious cats to provide sedation and immobilization. Induction options include propofol, etomidate, ketamine, and inhalation agents. Propofol is probably most frequently used because of its short duration of action, but can be detrimental in animals with underlying hypotension that remains uncorrected prior to induction. Etomidate may provide a better alternative in cardiovascular-compromised patients. Ketamine with a benzodiazepine represents an alternative method of induction, but recovery may be prolonged (compared with etomidate, propofol, and inhalation agents). Contraindications for ketamine use, such as a history of seizures and the presence of increased intracranial pressure, are particularly germane to patients undergoing MRI and/or CT. Induction with an inhalation agent via face mask may be used if rapid control of the airway is not an issue, if the patient is tractable, and if the induction room is well ventilated. However, this method is recommended only when other options present unacceptable patient risk. A major disadvantage to mask induction is waste-gas pollution and subsequent exposure of personnel. Anesthesia for MRI and CT is most commonly maintained with an inhalation agent. Isoflurane and sevoflurane both facilitate a rapid recovery. Anesthesia machines and ventilators that are MRI compatible or MRI safe are available, and some suppliers are listed in Table 52.3. If an MRI-compatible anesthesia machine is not available or if a traditional machine cannot be configured from outside the MRI room, anesthesia can be maintained with propofol by using a constant rate infusion or intermittent bolus technique (Table 52.1). Maintenance with propofol should always include intubation, supplemental oxygen, and a method for ventilatory support.

Monitoring
General Considerations
Considering the diversity of patient signalment, physical status, and organ system abnormalities, and irregardless of the relatively short duration of the procedures, one or more monitoring devices should be applied to every individual patient to help assure its well-being. Monitoring techniques could include continuous ECG, pulse oximetry, capnography, blood pressure monitoring, and measurement of end-tidal anesthetic gas concentration (ET_{agent}). Application should be tailored to the individual and to the procedure. For example, pulse oximetry is especially important for assessing patients at risk for developing hypoxemia, such as during bronchoscopy and thoracostomy tube placement. Capnography is useful for intubated patients at risk of hypoventilating (thoracostomy tube placement). Readers are referred to Chapter 19 for a detailed description of the information afforded by these devices.

Monitoring for MRI and CT
Considering the challenge of patient accessibility and the diversity of patient presentation, several monitoring tools should be applied to maximize patient safety. Essential monitoring devices include capnography, pulse oximetry, and continuous ECG. Capnography ($ETCO_2$) and pulse oximetry (SpO_2) provide con-

tinuous, noninvasive methods of assessing adequacy of ventilation, perfusion, and oxygenation, and also provide an assessment of respiratory rate and pulse rate, respectively. The capnographic waveform provides an early warning to the anesthetist that a problem is developing. Noninvasive or invasive blood pressure monitoring and ET_{agent} monitoring are also recommended. Anesthetic agents compromise cardiovascular homeostasis and, in the absence of a surgical stimulus, hypotension should be anticipated, especially if underlying cardiovascular abnormalities are present. Use of blood pressure monitoring will alert the anesthetist to the development of hypotension so that supportive measures can be instituted (increase in fluid administration rate, administration of an inotrope, or decrease in anesthetic depth). ET_{agent} reflects an agent's alveolar partial pressure and thus closely approximates arterial and brain anesthetic partial pressures (once equilibration is reached). The minimum alveolar concentration (MAC) has been reported for inhalant agents commonly used for a variety of animals. Although many factors, such as premedications administered, will affect patient inhalation agent requirements, maintaining an ET_{agent} concentration of 1.2 to 1.4 MAC is considered to be appropriate for most animals. Some suppliers that offer MRI-compatible monitoring equipment are listed in Table 52.3. Additional information regarding MRI-compatible equipment has been published.[5,6]

Monitoring patients undergoing MRI can be difficult for many reasons in addition to patient inaccessibility. Some scanners are extremely loud during image acquisition, making direct cardiopulmonary auscultation impossible. The gradient magnetic fields and RF fields are capable of generating electrical currents in metal wires, so ECG leads can burn a patient's skin. Burns caused by ECG leads during MRI have been cited in the literature on human patients[8] and have been reported to occur during animal imaging. Electrical current induction can occur within a loop of wire in a pulse oximetry unit, which can severely burn patients. To avoid patient injury, it is important that MRI-compatible lead connections be used. Additionally, the MRI may interfere with ECG waveforms, making it difficult to evaluate the rhythm trace.

Patients anesthetized for MRI and CT require intravenous fluid administration to maintain adequate perfusion and the application of monitoring devices to identify and address alterations in homeostasis proactively. Availability of mechanical ventilation to provide intermittent positive-pressure ventilation (IPPV) is important during diagnostic imaging. Application of IPPV in combination with capnography will enhance patient management by assuring ventilatory homeostasis. Increased intracranial pressure caused by trauma or brain tumor is a common presenting sign in patients undergoing CT and MR imaging. Maintaining these patients in a mildly hypocapneic state (e.g., $PaCO_2 = 30$ mm Hg) will improve anesthetic outcome by minimizing the detrimental effects of increased $PaCO_2$ on intracranial pressure.[9]

Summary

Anesthetic management of patients presented for advanced diagnostic and therapeutic techniques should include thorough preoperative patient assessment, a protocol that addresses patient needs, and application of effective monitoring tools and supportive therapy throughout the anesthetic period.

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