Anesthesia for the Patient with Heart Disease

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"Heart disease" comes in many different versions. Electrical problems include sinus bradycardia, A-V conduction disturbances, right or left bundle branch blocks, supraventricular tachycardia, and ventricular pacemaker activity. Mechanical problems include mitral insufficiency, aortic stenosis, dilative cardiomyopathy, hypertrophic cardiomyopathy, and pericardial tamponade. Each of these abnormalities present different anesthetic concerns and mandate different anesthetic protocols. Be sure to factor in the magnitude of disease as well. Whereas mild mitral regurgitation or hypertrophic cardiomyopathy warrant little or no concern, severe forms of either disease warrant maximal concern. When a cardiac abnormality is identified, it should be thoroughly evaluated and stabilized as much as possible prior to induction of anesthesia. Cardiac disease decreases an animal's tolerance to general anesthesia and owners should be so informed.

The two most important aspects of the anesthetic plan are drug selection and the physiologic management of the patient, so as to minimize further compromise of the underlying disease abnormality. Certain anesthetic drugs have certain characteristics that, pharmacologically, make them a better or worse choice compared to other available choices. In many circumstances, anesthetic drugs have no distinguishing characteristics that differentiate them from other available choices. In all circumstances there are no absolutely indicated or contraindicated drug choices; drug choices simply "hedge your bet" toward a favorable outcome. Far more important than "smart" drug choices is to use the chosen drugs in a smart way. Intimate familiarity with the use of a drug is a more important safety factor than the inherent pharmacologic characteristics of that drug.

The physiologic management of the patient is the most important aspect of the anesthetic plan; i.e. the prevention of hypotension or hypertension when either (or both) compromise the underlying disease.

There are 4 groups of adjunctive sedatives: opioids (low dose for sedation and analgesia) (morphine, meperedine, oxymorphone, methadone, butorphanol, buprenorphine), benzodiazepines (diazepam, midazolam), phenothiazines (acepromazine, prochlorperazine), and alpha$_2$-agonists (xylazine, metdetomidine, romifidine). There are 7 groups of anesthetic drugs: opioids (high dose for "anesthesia") (morphine, oxymorphone, fentanyl, alfentanil, sufentanil), cyclohexanones (ketamine, tiletamine), alphaxalone, barbiturates (thiopental, pentobarbital), etomidate, propofol, and inhalationals (halothane, isoflurane, sevoflurane, and desflurane).

The different agents have different effects on the different components of cardiovascular and pulmonary function. Anesthetic agents may impact cardiovascular function by affecting heart rate, myocardial contractility, cardiac output, arterial blood pressure, peripheral vasomotor tone, or peripheral tissue perfusion, and may impact pulmonary function by causing hypoventilation or increasing venous admixture (hypoxemia).

Anesthetic concerns for specific forms of heart disease

Sinus bradycardia, and first and second degree heart block

Bradycardia (< 50 to 60 beats/min) may be caused by organic lesions causing SA node impairment or atrioventricular conduction block; idiopathic "sick sinus syndrome"; excessive vagal tone (pharyngeal, laryngeal or tracheal stimulation; by pressure on the eyeball or rectus

muscles; by visceral inflammation or distention), hyperkalemia, hypothermia, terminal hypoxia, drugs (opioids agonists, alpha-2 agonists, cholinergics, excessive doses of any general anesthetic, digitalis), hypothyroidism, visceral organ failure, end-stage multiple organ failure syndrome, or organophosphates/carbamate poisoning.

Treatment of bradycardia should first be to correct the underlying disease process if possible. The first symptomatic therapy would be the administration of an anticholinergic (atropine: 0.01 to 0.04 mg/kg IV, IM; glycopyrrolate: 0.005 to 0.02 mg/kg IV, IM). If this is not effective, a sympathomimetic (ephedrine: 1-5 mg/kg; dopamine: 3 to 7 mcg/kg/min; dobutamine: 5 to 10 mcg/kg/min) could be administered.

The bradyrhythm should be corrected prior to anesthetic induction by therapy directed at the underlying cause or by anticholinergic therapy. Opioids agonists and alpha-2 agonists should perhaps be avoided in persistent bradycardia because they can worsen the bradyrhythm. The more potent vasodilator anesthetics should, perhaps, be avoided in persistently bradycardic patients in case heart rate and cardiac output cannot respond so as to maintain arterial blood pressure (acepromazine, propofol, inhalational); although such concerns would be mute as long as blood pressure was monitored and supported. Opioid agonist-antagonists, benzodiazepines, thiopental, alfaxalone, ketamine, or etomidate may represent the first choice drugs.

The ECG should be monitored and effective therapy readministered if the bradyrhythm recurs. Arterial blood pressure should be monitored and hypotension should be avoided (mean blood pressured should be maintained above 80 mmHg if possible and above 60 mmHg absolutely; if mean blood pressure values are not available, systolic pressure should be maintained above 100 mmHg if possible and above 80 mmHg absolutely). If ephedrine or dopamine are not effective in restoring blood pressure to an acceptable level, phenylephrine (1-6 mcg/kg/min) or norepinephrine (0.2 to 2 mcg/kg/min) could be administered. If these drugs are not available, epinephrine (0.1 to 1 mcg/kg/min) could be administered.

3rd degree heart block

Third degree heart block (complete atrio-ventricular conduction block) is usually not reversible with anticholinergic therapy. The ventricular rate can be temporarily accelerated with sympathomimetic therapy but persistent palliative therapy requires the placement of a pacemaker.

In 3rd degree heart block, the use of vagotonic agents like opioid agonists and alpha-2 agonists are not discouraged since they can hardly make the A-V conduction block worse. Potent vasodilators should, perhaps, be avoided, but, most importantly, arterial blood pressure should be monitored and supported as for any bradyrhythm.

Sinus Tachycardia

Tachycardia may be caused by hypovolemia or hypotension, excitement, pain, hypoxemia, hypercapnia, hyperthermia, visceral organ failure, sepsis, drugs (ketamine, anticholinergics, sympathomimetics), or diseases (hyperthyroidism, pheochromocytoma). Treatment of excessive tachycardia (>160 in a large-breed dog; > 180 in a small-breed dog; > 220 in a cat) should first be to correct the underlying disease process if it can be found. If the tachycardia is thought to be due to pain or nociception, perhaps an analgesic should be administered. Perhaps a vagal maneuver (pressure on the eyeball; pressure on the carotid sinus) would be effective. If this does not work, perhaps a beta-receptor blocking agent would decrease

the rate (esmolol: 0.2 to 0.5 mg/kg IV; 50 to 200 mcg/kg/min; atenolol: 0.2 to 1 mg/kg; propranolol: 0.01 to 0.03 mg/kg IV, 0.2 to 1.0 mg/kg PO q 8 hours).

Severe sinus tachycardia shortens diastolic filling time and can decrease stroke volume and cardiac output. Tachycardia increases myocardial work and oxygen consumption but this is generally well tolerated. The exception is hypertrophic cardiomyopathy in which, for both reasons, sinus tachycardia should be avoided.

The use of anticholinergics and ketamine is discouraged There are no discriminating characteristics amongst the other anesthetic agents.

Supraventricular tachycardia and atrial fibrillation

All of the physiologic and anesthetic concerns of simple sinus tachycardia are relevant here. The difference is that these two conditions are less likely to respond to the aforementioned medical therapy. Therapy rather needs to be directed at slowing conduction through the A-V node with calcium-channel blockers (diltiazem: 0.05-0.25 mg/kg; 0.05-0.3 mg/kg/hr; verapamil: 0.05-0.25 mg/kg) or digoxin (5-10 mcg/kg).

Bundle branch block

Right bundle branch block (a wide QRS with the major deflection to the negative, preceded by a P wave [to differentiate these from a ventricular ectopic pacemaker) are often benign and intermittent while left bundle branch blocks (a wide QRS with the major deflection to the positive, preceded by a P wave) are more often irreversible and associated with significant heart disease. Bundle branch blocks, per se, represent alternate routes of conduction (muscle to muscle) and depolarization (discoordinated ventricular contraction), but contractility is normal. Aside from some interventricular interference, stroke volume and cardiac output are minimally affected. Cardiovascular monitoring should be as comprehensive as possible. There are no anesthetic drug preferences applicable to this disorder.

Ventricular ectopic pacemaker activity

Ventricular ectopic pacemaker activity may be caused by endogenous release of catecholamines secondary to any stress, exogenous catecholamine therapy; hypoxia or hypercapnia; hypovolemia or hypotension; digitalis toxicity (potentiated by hypokalemia and hypercalcemia); hypokalemia (potentiated by respiratory or metabolic alkalosis, glucose or insulin therapy); hyperkalemia (potentiated by acidosis, hypocalcemia, succinylcholine or may be iatrogenic); certain anesthetics lower the threshold to endogenous or exogenous catechol-amines (halothane, alpha-2 agonists, thiopental); myocardial inflammation, disease or stimulation (intracardiac catheters, pleural tubes); thoracic and non-thoracic trauma; congestive or hypertrophic heart failure; visceral organ disease (gastric volvulus/torsion); intracranial disorders (increased pressure, hypoxia); pheochromocytoma; or heart failure.

Ectopic pacemaker activity indicates the presence of an underlying abnormality which should be identified, if possible, and treated. Slow-rate ventricular ectopic rhythms can often be "hidden" by speeding up the sinus rate with an anticholinergic. Symptomatic antiarrhythmia therapy is indicated when the ventricular arrhythmia is severe: when the rate exceeds (or would if the paroxysmal rhythm continued for an entire minute) 180 to 200 beats per minute; when the arrhythmia is multiform in nature; when the incidence or severity is becoming higher or more severe; when the ectopic foci fires during the T wave of the preceding complex (i.e. there is not visible separation between two successive ventricular depolarizations); or when there is evidence

of inadequate cardiac output. Total elimination of the arrhythmia is not necessarily the objective of therapy since, many times, the adverse effects of the antiarrhythmic drug occur prior to reversion of the arrhythmia to a normal sinus rhythm. A simple decrease in the rate or severity of the arrhythmia is a suitable end-point to the titration of the antiarrhythmic drugs.

Antiarrhythmic drugs

Drug	Mechanism	Indication	IV Dosage
Lidocaine	Sodium channel blocker	VPCs	1-4 mg/kg; 2-6 mg/kg/hr
Procainamide	Sodium channel blocker	VPCs; APCs	1-4 mg/kg; 2-6 mg/kg/hr
Quinidine	Sodium channel blocker	VPCs; APCs	5-15 mg/kg
Amiodarone	Sodium channel blocker and other effects	VPCs	5 mg/kg over 20 minutes
Atenolol	Beta blocker	APCs; VPCs	0.2-1 mg/kg
Esmolol	Beta blocker	APCs; VPCs	0.2-0.5 mg/kg; 0.5-10 mg/kg/hr
Propanolol	Beta blocker	APCs; VPCs	0.01-0.3 mg/kg
Diltiazem	Calcium channel blocker	APCs	0.05-0.25 mg/kg; 0.05-0.3 mg/kg/hr
Verapamil	Calcium channel blocker	APCs	0.05-0.25 mg/kg

VPCs = ventricular arrhythmia; APCs = supraventricular arrhythmia

Cats may be more sensitive to many of the antiarrhythmics and these drugs should be used in reduced dosages in this species.

The ECG should be monitored during anesthesia. If the arrhythmia worsens, perhaps one should start or increase the dosage of antiarrhythmic. Proarrhythmogenic anesthetics should be avoided (alpha-2 agonists, thiopental, halothane). There are no discriminating characteristics that would preclude the use of other anesthetics.

Mitral insufficiency

In mitral insufficiency, bradycardia should be avoided as this may increase the proportion of regurgitant blood flow. The ECG should be monitored. Hypotension should be avoided because of the reduced ability of the heart to increase cardiac output in response. Hypertension should be avoided because an increased afterload increases the regurgitant fraction of the stroke volume. Arterial blood pressure should be monitored and maintained within a low-normal range or preoperative baseline values for that patient. To the extent that there is dilative cardiomyopathy, anesthetic-induce myocardial depression (propofol, inhalationals, high dosages of any anesthetics) should be avoided. Anesthetic depth should be closely monitored and maintained as light as is compatible with completion of the surgical procedure. Locoregional anesthetics techniques, to minimize the use of general anesthetic drugs, should be utilized whenever possible.

Aortic stenosis

In aortic stenosis, bradycardia should be avoided because of the strain on the heart induced by the effort to eject a larger stroke volume through the narrowed aortic valve. To the extent that there is hypertrophic cardiomyopathy, tachycardia should be avoided because: 1) the

higher heart rate results in sarcoplasmic reticulum calcium loading which enhances the hypertrophic problem, which 2) decreases diastolic performance of the heart, 3) increases the magnitude of the outflow obstruction, and 4) decreases subendocardial oxygenation. ECG should be monitored and heart rate should be maintained within the baseline range for that patient (use anticholinergics or beta agonists to increase heart rate; use beta blockers to decrease heart rate). Avoid the use of anesthetic agents which either decrease (large-dose opioid agonist) or increase heart rate (ketamine). Avoid hypotension because of the limited ability of the heart to respond to it with an increase in heart rate. An increase flow through a narrowed outflow tract can result in turbulence, which will logarithmically increase the magnitude of the functional outflow obstruction. Minimize the use of agents with obvious hypotensive qualities (acepromazine, alpha-2 agonists, propofol, and inhalationals). Monitor arterial blood pressure and maintain it with the baseline range for that patient.

Dilative cardiomyopathy

Dilative cardiomyopathy is associated with reduced contractility and all anesthetics should be considered to be myocardial contractility depressants. It is perhaps better to avoid the relatively greater myocardial depressants (propofol, inhalationals, and heavy dosages of any anesthetic) and it might be preferable to utilize drugs with cardiostimulatory properties (ketamine) or with the least negative inotropic effects (opioids, etomidate, alfaxalone, thiopental). Sedatives with marked systemic vascular effects (either vasoconstriction – alpha-2 agonists or vasodilation – acepromazine) should be avoided in preference to opioid agonists, opioid agonist-antagonists, and benzodiazepines. Monitor arterial blood pressure and maintain it at normal or preoperative baseline levels. Treat hypotension first with drugs with beta-agonist activity (dopamine, ephedrine, dobutamine, and, as a last resort, epinephrine). Dilative cardiomyopathy, in the latter stages of the disease process, is associated with mitral insufficiency and the aforementioned concerns with this would apply (avoid bradycardia, hypotension, and hypertension). Dilative cardiomyopathy hearts are also easy to overload with fluids and central venous pressure monitoring may help define fluid administration.

Hypertrophic cardiomyopathy

Hypertrophic cardiomyopathy is associated with diastolic dysfunction (the ability to relax and accept a volume). Because room for diastolic filling is limited, the ventricle fills up rapidly; the heart is unable to take advantage of longer diastolic filling times and bradycardia should be avoided. High-side normal-range filling pressures may be important in order to maximize diastolic filling in the face this reluctance to fill, but these hearts are also easy to overload with fluids. Monitoring central venous pressure may aide efforts to optimize preload pressures. Tachycardia may be associated with a further decrease in diastolic performance, with impaired subendocardial oxygenation, and with enhanced narrowing of the left ventricular outflow tract. ECG monitoring is helpful for monitoring and maintaining a mid-range heart rates. Anesthetic drugs which tone up the heart (ketamine) should be avoided and anesthetic drugs which decrease (large-dose opioid agonists, alpha-2 agonists) or increase (anticholinergics, ketamine) heart rate should perhaps be avoided. Hypotension should be avoided because of the hearts reduced ability to compensate. Anesthetic agents that are potent vasodilators (acepromazine, alpha-2 agonist, inhalationals, propofol) should perhaps be avoided. Arterial blood pressure should be monitored and maintained within the normal to high-normal range or at preoperative baseline for the patient.

Restrictive cardiomyopathy

Pericardial tamponade and fibrosis decrease diastolic performance of the heart, which impairs a heart's ability to increase stroke volume and cardiac output in response to hypotension. Pericardial fluid should be removed prior to induction of anesthesia. Bradycardia should be avoided in favor of a normal heart rate or even tachycardia. Normally bradycardia is associated with increased diastolic filling and stroke volume which helps maintain cardiac output but this offsetting process is limited in hearts with impaired diastolic function. Anesthetic drugs which promote bradycardia (opioid agonists, alpha-2 agonists) should perhaps be avoided. Low venous filling pressures should be avoided in favor of normal to high filling pressures. Central venous pressure should be monitored and maintained within the 5 to 10 cmH_2O range.

Guidelines for selecting anesthetic drugs

There is no anesthetic which is absolutely safe and none which are absolutely contra-indicated; every choice is relative. Try to pick anesthetics with pharmacologic characteristics that best complement the physiologic complications of the patient. Calm handling of the animal and sedative drugs prior to induction, reduce the dosages of anesthetic required for induction and intubation, and diminish the incidence of many common induction problems. Rapid, "crash", inductions should be avoided (except in an animal which has recently eaten or that has a mega-esophagus). Slow, prolonged inductions should be avoided in animals with respiratory disorders. When inducing a critically ill patient, administer initially only 10% of the calculated dose; you can always give more if you didn't give enough the first time, but you can't get it back if you give too much (except for inhalationals and the "reversibles", but then it might be too late). It is common to select a combination of drugs to "double up" on their mutually beneficial effects, while minimizing the detrimental effects of large doses of any one agent.

Local anesthetics and regional blocks have also been advocated to diminish the quantity of general anesthetic necessary to complete the surgical procedure.

There are many reasons to select, or avoid, particular anesthetics for particular patients other than their physiologic interaction with the animal and its disease (ease of use and availability, speed of induction and recovery, organ-specific effects and cost). Familiarity with an anesthetic drug is, perhaps, the most important reason to select a particular anesthetic drug. Whatever anesthetic drug choices are made, the clinician should be aware of how they might impact the delicate balance between the patient and the disease. Knowing that an animal's physiologic response to an anesthetic cannot be predicted, prior preparation of the patient and ongoing monitoring of the physiologic responses are the keys to the success of the procedure.

Summary of anesthetic protocols for cardiac disorders

Problem	"Green" drugs	"Yellow" drugs	"Red" drugs	Avoid	Goals
Bradyrhythms	Anticholinergics Beta-agonists In absence of the bradyrhythm – any In the presence of the bradyrhythm: Opioid ag-antag, Benzodiazepines Ketamine, Etomidate Thiopental, Alfaxalone	Opioid agonists Alpha-2 agonists	With persistent bradyrhythms: Acepromazine Propofol Inhalational	With persistent bradyrhythms: hypotension	Normal heart rate (above 60 in dogs; 90 in cats) Normotension (above 80 mean or 100 systolic in dogs or dats)
Tachyrhythms	Beta-antagonists Opioids, Acepromazine, Aalpha-2 agonists, Benzodiazepines Propofol, Thiopental, Alfaxalone Etomidate, Inhalationals		Atropine Ketamine	Excessive tachycardia (>160 in large dogs; >180 in small dogs; >220 in cats	Heart rate <140 in large-breed dogs; <160 in small-breed dogs; <200 in cats
Ventricular ectopic pacemaker activity	Antiarrhythmic drugs Opioids, Acepromazine, Benzodiazepines, Alfaxalone, Propofol, Inhalationals, Etomidate, Ketamine		Alpha-2 agon, Thiopental, Halothane	Impairment of "forward flow parameters" Instant rate >200 "R on T"	To keep arrhythmia below treatment threshold values
Mitral insufficiency	Locoregional anesthesia/analgesia Opioids, Benzodiazepines Etomidate, Thiopental, Alfaxalone Ketamine	If DCM, alpha-2 agonists, acepromazine, propofol, inhalationals, heavy dosages of any anesthetic		Bradycardia, Hypotension, Hypertension	Normal-range heart rate and blood pressure
Aortic stenosis	Benzodiazepines, Opioid agonist-antagonists, Etomidate, Thiopental, Alfaxalone	Large-dose opioid agonists Acepromazine Alpha-2 agonists,	Ketamine	Bradycardia Tachycardia Hypotension	

		Propofol Inhalationals			
Dilative cardiomyopathy	Opioid agonist/antagonists Benzodiazepines Ketamine, Opioid agonists	Etomidate Thiopental Alfaxalone	Acepromazine Alpha-2 ag Propofol Inhalationals Heavy dosages of any anesthetic	Hypotension Hypertension Fluid overload Bradycardia	
Hypertrophic cardiomyopathy	Anticholinergics Benzodiazepines, Opioid premeds Etomidate, Thiopental, Alfaxalone	Large dose opioid agonists Anticholinergics	Acepromazine Alpha-2 ag Ketamine Propofol Inhalationals	Bradycardia Hypotension	Optimal preload Normal range arterial blood pressure
Restrictive caridiomyopathy	Anticholinergics Benzodiazepines, Opioid premeds Etomidate, Thiopental, Alfaxalone Ketamine	Large dose opioid agonists Acepromazine Propofol Inhalationals	Alpha-2 ag	Bradycardia Hypotension	Optimal preload

Commonly recommended sedative/analgesia and anesthetic dosages

Anesthetic or sedative		Sedative dose* (mg/kg IV, IM, SQ)	Analgesia CRI (mg/kg/hr)	Anesthesia induction dose (mg/kg IV)	Anesthesia maintenance dose (mg/kg/hr IV)
$Alpha_2$ agonists	Xylazine	0.1-0.2	?	na	na
	Medetomidine	0.005-0.01	?	na	na
	Dexmedetomidine	0.001-0.005	0.0005-0.002	na	na
Benzodiazepines	Diazepam	0.2-0.5	na	na	na
	Midazolam	0.1-0.25	na	na	na
Phenothiazines	Acepromazine	0.01-0.05	na	na	na
	Chlorpromazine	0.1-0.5	na	na	na
	Prochlorpromazine	0.1-0.5	na	na	na

Opioids	Morphine	0.2-1.0 q4hr¶	0.05-0.25	0.5-2	2-4
	Oxymorphone	0.05-0.1 q4hr	0.005-0.025	0.05-0.2	0.2-0.6
	Hydromorphone	0.05-0.1 q4hr	0.005-0.025	0.05-0.2	0.2-0.6
	Methadone	0.2-1.0 q4hr	0.05-0.25	0.5-2	2-4
	Fentanyl	0.002-0.01 q4hr	0.0005-0.0025	0.005-0.02	0.02-0.06
	Sufentanil	0.001-0.002 q4hr	0.00025-0.0005	0.002-0.004	0.006-0.01
	Butorphanol	0.2-0.4 q 4hr	0.05-0.1	na	na
	Buprenorphine	0.01-0.02 q 4hr	0.0025-0.005	na	na
Cyclohexanones	Ketamine	2-5 q2hr	0.2-1	6-12 IV, IM	?
	Telazol®	1-2 q2hr	?	2-3 IV, IM	?
Barbiturates	Thiopental	na	na	6-10	1-4
	Pentobarbital	2-6 IV	na	15-25	1-4
Etomidate		na	na	1-2	na
Propofol		na	na	4-6	6-24
Alfaxalone		?	?	1-3 (dogs); 2-5 (cats)	6-9 (dogs); 7-11 (cats)
Inhalationals	Halothane	na	na	1.5 – 2.5 %	1.0 - 1.4 %
	Isoflurane	na	na	2.0 - 3.0 %	1.2 - 1.6 %
	Sevoflurane	na	na	2.5 – 3.5 %	2.0 – 2.5 %
	Desflurane	na	na	8.0 – 9.0 %	7.0 - 8.0 %

*Same dose for the purposes of anxiolysis, analgesia (for those drugs with such qualities), premedication or as an adjunct to a general anesthetic. CRI = constant rate infusion. na = not applicable ¶approximate repeat schedule to maintain effect over time.

The relative merits and precautions of common sedative and anesthetic drugs

Alpha$_2$-agonists

The alpha$_2$-agonists are reliable sedatives and potent adjuncts to other anesthetics. They cause an initial, peripherally-mediated, vasoconstriction and hypertension which may be disadvantageous in the brain injured patient, in dilative cardiomyopathy heart failure, and when maximizing visceral perfusion is important. The reflex bradycardia should not be treated with an anticholinergic. Subsequent to this peripheral effect, these agents cause a centrally-mediated sympatholytic decrease in cardiac output, systemic vascular resistance, and arterial blood pressure which may be disadvantageous in the hypotension-prone patient. These agents are reversible (Atipamezole 0.02-0.05 mg/kg IV). These agents possess some analgesic qualities but due to their cardiovascular effects are not used as a primary analgesic.

Characteristics and precautions of alpha2-agonists

Advantages and uses	Precautions
Good muscle relaxation Reversible Some analgesia	Initial vasoconstriction and hypertension Subsequent vasodilaton and hypotension Ventricular arrhythmias

Benzodiazepines

Benzodiazepines are not reliable tranquilizers in animals with normal cerebral function; they often cause either no sedation or excitation. In animals with depressed cerebral function (either by disease or by other drugs), the benzodiazepines can have adjunctive tranquilization/sedation effects. The benzodiazepines independently have minimal cardiopulmonary depressant effects but can enhance the changes associated with other anesthetics. These drugs are reversible (Flumazenil 0.005-0.02 mg/kg). These drugs have no analgesic qualities.

Characteristics and precautions of benzodiazepines

Advantages and uses	Precautions
Minimal cardiovascular effects Reversible	Not reliable tranquilizers when used alone in patients with normal CNS function No analgesia

Phenothiazines

The phenothiazines are reliable tranquilizers but are alpha$_1$-receptor blocking agents which may, in a unpredictable fashion, cause vasodilation and hypotension in hypotension-prone animals. These drugs have no analgesic qualities but are commonly used as anti-emetics.

Characteristics and precautions of phenothiazines

Advantages and uses	Precautions
Economical	Unpredictable vasodilation and hypotension No analgesia

Opioids

Agonist opioids may be administered in low dosages for sedation or analgesia or in high dosages to induce a deep narcosis for surgical procedures. Agonist-antagonist opioids (butorphanol and buprenorphine) may be administered for sedation or analgesia but will not induce sufficient CNS depression for deep narcosis. Agonist opioids are not complete anesthetics like the barbiturates, propofol or the inhalationals. Animals that are well narcotized may move spontaneously and in response to sharp noise. Such animals can be intubated, but the procedure must be accomplished with finesse since strong pharyngeal/laryngeal stimulation will also cause a patient response. For this reason, agonist opioids are not suitable for routine anesthetic inductions in normal animals. Opioids, in spite of a notable, centrally-mediated bradycardia, maintain cardiac output, arterial blood pressure and tissue perfusion very well. For this reason, they are a highly regarded anesthetic option for critically ill, hypotension-prone animals. An anticholinergic should be administered to prevent/treat the bradycardia so as to further augment pressure and flow parameters. Opioid "anesthesia" also commonly necessitates the administration of an adjunctive tranquilizer/sedative to provide for an acceptable anesthetic state for surgical purposes. Opioids may also cause CNS excitation at higher dosages. Cats are so susceptible to this effect that large-dose narcosis/anesthesia is not recommended. Agonist opioids are potent respiratory depressants and animals should be oxygenated before and after their administration. Opioid inductions tend to be slow in comparison with other injectable techniques and, in combination with the respiratory depression effect, should be used with caution in the respiratory compromised patient. Some patients may require positive pressure ventilation. Opioids may also cause panting, a response that is attributed to an affect on the thermoregulatory center. Opioid-induced panting does not represent hyperventilation; such animals are usually normo-ventilating. Opioids exhibit very good analgesic properties and are reversible (nalbuphine 0.02, repeated to effect up to 0.1 mg/kg; naloxone 0.01 mg/kg, repeated to effect up to 0.06 mg/kg). Analgesia is reversed at the same time as the CNS and respiratory depression. Animals that do not exhibit unacceptable respiratory depression generally do not need to be reversed. If unacceptable respiratory depression is present, titrate small dosages of reversal agent; the goal is to minimize the respiratory depression while maintaining as much of the analgesia as possible. Small sedative/analgesic dosages of the agonist opioids and recommended dosages of the agonist-antagonist opioids do not cause excessive sedation or respiratory depression except, perhaps, in animals with pre-existing CNS or respiratory disorders.

Characteristics and precautions of opioids

Advantages and uses	Precautions
Minimal myocardial depression or hypotension Good analgesia Reversible	Not complete anesthetics Slow induction process Respiratory depression Vagal induced bradycardia

Cyclohexanones

Cyclohexanones are associated with a centrally-mediated, sympathomimetic stimulation of most cardiovascular parameters with little change in systemic vascular resistance and usually only transient respiratory depression. For this reason ketamine is commonly recommended for

hypotension-prone patients and in patients with dilative cardiomyopathy; it is not recommended in hypertrophic cardiomyopathy. Ketamine is a direct myocardial depressant, however, and this effect may manifest in larger dosages or in sicker patients.[20] Muscle tone is always high and spontaneous movement is common, and an adjunctive tranquilizer/sedative is routinely utilized.[20] Cerebral electrical and metabolic activity is enhanced with ketamine and this, in combination with the increase in arterial blood pressure (increases cerebral blood flow and intracranial pressure) is not recommended in patients with intracranial disease. Ketamine may cause seizures, but it may also treat them, depending upon the underlying cause of the seizure. In contrast to many anesthetics, ketamine can be administered intramuscularly and is readily absorbed across non-epithelialized membranes such as the mouth or nasal cavity. It is cummulative with repeated dosages. Ketamine has good analgesic qualities. It causes hypersalivation and an anticholinergic premed is recommended. The eyelids remain open, predisposing the cornea to drying and trauma (apply ophthalmic ointment liberally and protect the corneas from abrasion). It causes some bronchodilation and may be a favored anesthetic in animals with asthma. It may increase intra-ocular pressure and should not be used in patients with glaucoma or a descemetocele. Recovery may be associated with hyper-reactivity to tactile and auditory stimulation.

Characteristics and precautions of cyclohexanones

Advantages and uses	Precautions
Indirect, sympathomimetic cardiovascular stimulation (heart rate, cardiac output) Slight vasodilation Rapid induction Good analgesic Can be administered intramuscularly and is absorbed across oral/nasal mucous membranes Some bronchodilation	Mucle hypertonus Potentially seizurogenic Direct myocardial depression Intermediate recovery; cummulative Transient respiratory depression Salivation May increase intra-ocular pressure Eyelids remains open Recovery may be prolonged in cats with renal failure Increases CBF & ICP

CBF = cerebral blood flow; ICP = intracranial pressure.

Barbiturates

The stable anesthetic state is associated with systemic vasoconstriction and mild hypertension; cardiac output and respiratory parameters are well maintained. The initial barbiturate bolus can, however, cause transient, severe myocardial and respiratory depression, and this effect may be more prominent in the cardiovascularly compromised patient. Thiopental induction is rapid and recovery following a single induction dose is intermediate (except in sight hounds where is may be somewhat prolonged); repeated doses are cummulative. Pentobarbital induction is slow and recovery is prolonged and hyper-reflexive; this agent is seldom used for clinical anesthesia. The primary exception is when the anesthetic state is expected to be prolonged (days) such as in seizure control or long-term positive pressure ventilation. Barbiturates decrease cerebral metabolic activity, cerebral blood flow, intracranial pressure, and intra-ocular pressure and are therefore recommended for patients with intracranial or intra-ocular disease. Short-acting barbiturates can cause arrhythmias and enhance laryngeal and bronchial

muscle sensitivity. Laryngeal sensitivity (to laryngospasm) is disadvantageous when trying to endotracheally intubate and is advantageous when assessing laryngeal nerve competence. Barbiturates are more potent if there is an increase in the unionized portion (acidosis), if there is a decrease in the protein-bound portion (hypoproteinemia), or in situations in which the proportion of cardiac output distributed to the brain is increased (peripheral vasoconstriction). Barbiturates have no analgesic qualities and can cause tissue sloughing if injected perivascularly .

Characteristics and precautions of barbiturates

Advantages and uses	Precautions
Decreases $CMRO_2$, CBF, ICP and intra-ocular pressure Sustained cardiovascular effects are mild	Initial myocardial depression and hypotension Arrhythmogenic Intermediate recovery Cummulative Not analgesic Splenic dilation - decreased hemoglobin concentration Enhanced laryngospasm and bronchial reflexes Action enhanced with hypoproteinemia and acidosis Can cause tissue sloughing if injected perivascularly

CBF = cerebral blood flow; ICP = intracranial pressure; $CMRO_2$ = cerebral metabolic rate for oxygen.

Propofol

Propofol is associated with rapid induction and recovery, and, due to its rapid redistribution and extensive metabolism, it has minimal cumulative effects in dogs (it is cummulative in cats) . Of the injectables, it is the most potent myocardial and respiratory depressant, peripheral vasodilator and hypotensive agent (on a par with the inhalationals), and therefore must be used with caution in critically ill patients. One must avoid the common tendency to assume that a fast anesthetic is the same as a safe anesthetic. Surely a short anesthetic/operative procedure is to be preferred to a long one, but a fast anesthetic technique (regardless of the anesthetic) without regard to appropriate monitoring and patient support is asking for trouble. Propofol is commonly used as an anticonvulsant but has also been reported to cause seizures in some individuals. It decreases cerebral metabolic activity, cerebral blood flow and intracranial pressure. It has no analgesic qualities, and its high lipid content predisposes to lipemia and an infection hazard.

Characteristics and precautions of propofol

Advantages and uses	Precautions
Rapid induction and recovery Non-cumulative in dogs Decreases $CMRO_2$,CBF, and ICP Anticonvulsant Bronchodilaton	Potent myocardial depression and hypotension May cause/potentiate bradycardia Potent respiratory depressant Cumulative in cats Myoclonic muscle twitching Not analgesic High lipid content: lipemia with CRI; infection hazard

CBF = cerebral blood flow; ICP = intracranial pressure; $CMRO_2$ = cerebral metabolic rate for oxygen

Alphaxalone

Alphaxalone is a steroidal anesthetic (derived from progesterone), which is a central and peripheral GABA agonist, like the benzodiazepines, barbiturates, propofol, etomidate, and the inhalational anesthetics. GABA agonism inhibits neuronal chloride channels and T-type calcium channels. Alphaxalone is not water soluble and is therefore solubilized in cyclodextrin which is a water soluble oligosaccharide with a hydrophobic interior. Alphaxalone has a post-synaptic inhibitory effect on neurotransmission in laminae II of the dorsal horn of the spinal cord; it may have some analgesic qualities.

Alphaxalone is associated with rapid induction and intermediate duration (10 to 30 minutes) and recovery (20-50 minutes), depending upon the dose. The recommended dosage for dogs is 1-3 mg/kg and for cats is 2-5 mg/kg, depending upon animal's condition and whether or not premedication sedatives have been administered, administered over 60 minutes. Recovery may be associated with twitching and hyper-reactivity to tactile stimulation. Alphaxalone may be administered intramuscularly (it is not associated with tissue damage) and is minimally cumulative.

Studies suggest minimal depression of contractility in dogs (with standard dosages) and mild myocardial depression in cats. Heart rate increases in dogs while decreasing in cats. Cardiac output is usually well maintained. Blood pressure may decrease associated with a dose-dependent vasodilation. Alphaxalone appears to be a moderate, dose-dependent, respiratory depressant; hypoventilation (hypercapnia) and transient apnea are not uncommon.

Characdteristics and precautions of alphaxalone

Advantages and uses	Precautions
Rapid induction No tissue damage Can be given intramuscular Noncummulative Good muscle relaxation Not arrhythmogenic Some analgesia Minimal myocardial depression	Intermediate recovery Dose-related vasodilation Dose-related hypotension Dose-related respiratory depression Hyper-reactive to physical stimulation during recovery

Etomidate

Etomidate is formulated in 35% propylene glycol (osmolality = 4640 mOsm/L), which may cause pain, phlebitis, thrombosis and hemolysis when administered into a small vein or as a continuous infusion; it should be administered with fluids. Etomidate is associated with rapid induction and recovery and variable cardiopulmonary effects. It is noncummulative with repeated dosages. It decreases cerebral blood flow, intracranial pressure, and intra-ocular pressure. It is expensive compared to other anesthetics and may interfere with adrenal cortical function for several hours.[21] It has no analgesic properties. It remains relatively expensive.

Characteristics and precautions of etomidate

Advantages and uses	Precautions
Rapid induction and recovery Noncummulative Minimal myocardial depression/hypotension Minimal respiratory depression Decreases CBF, ICP, and intra-ocular pressure Anticonvulsant	Osmolality (4600 mOsm/kg) Pain when injected by itself Phlebitis/thrombosis with continuous infusion Hemolysis if administered undiluted Hyperosmolality and lactic acidosis No analgesia Suppresses adrenal response to ACTH Myoclonic muscle twitching Most expensive

CBF = cerebral blood flow; ICP = intracranial pressure.

Inhalationals

The inhalationals, compared to the injectables (with the exception of propofol) are potent myocardial depressants, peripheral vasodilators, hypotensive agents. Of the three anesthetics in common use (halothane, isoflurane, and sevoflurane), halothane is the most potent myocardial depressant, isoflurane causes the most vasodilation, and they are approximately equally hypotensive (in a dose-dependent manner). They may cause excessive respiratory depression. They cause cerebral vasodilation and are therefore not recommended for patients with intracranial disease. Inhalational anesthetics are, however, easy to administer as a "continuous rate infusion", they are retrievable by turning down/off the vaporizer, and recovery is rapid. Mask or chamber inductions are time consuming and excitation is common; they are not ideal routine induction agents. Halothane is lowers the threshold to catecholamine-induced arrhythmias (not isoflurane or sevoflurane). Isoflurane has good analgesic qualities (not halothane or sevoflurane). Environmental pollution is a potential hazard to personnel working in the area and therefore these gases must be safely removed from the operating room environment.

Characteristics and precautions of the inhalationals

Advantages and uses	Precautions
Easy maintenance of anesthesia with rapid recovery Retrievable Good analgesia with isoflurane No arrhythmias with isoflurane or sevoflurane Isoflurane and sevoflurane minimally metabolized	Mask induction time consuming and excitation is common Chamber induction is polluting and excitation is common Myocardial depression (isoflurane<sevoflurane=halothane) Hypotensive agents (dose-related) Respiratory depr (isoflurane>sevoflurane=halothane) No analgesia with sevoflurane or halothane Need an anesthetic machine and specific vaporizer Halothane is arrhythmogenic Halothane is possibly (but rare) heptaotoxic metabolites Potential environmental pollution hazards (must be scavenged)

Rate of:	Induction	Recovery

The ease and route of administration constitute important reasons to choose one anesthetic over another; some can administered intramuscularly or intravenously (ketamine, alfaxalone, opioids, phenothizines, alpha$_2$-agonists), some only intravenously (barbiturates, propofol, etomidate), and some only by inhalation. Speed of induction and recovery very between anesthetics.

Fast	Barbiturates Propofol Alphaxalone Ketamine Etomidate	Inhalants Propofol Opioids w reversal Etomidate
Intermediate		Thiopental Ketamine Alphaxalone
Slow	Opioids Inhalants	Opioids wo reversal Ketamine CRI Barbiturate CRI

Anesthesia is the ability of an anesthetic to cause cortical depression and eliminate perception of one's environment (including pain); analgesia is the ability of an anesthetic drug to eliminate pain perception (without reference to CNS depression). All anesthetized patients are analgesic; not all analgesic patients are anesthetized. The use of anesthetics without good analgesic qualities may be associated less stabile anesthetic plane during anesthesia, the need for greater amounts of anesthetic during the procedure, and greater amounts of early postanesthesia analgesia requirements.

Anesthetic drug	Anesthetic qualities	Analgesic qualities
Ketamine	Good	Good
Propofol	Good	None
Barbiturates	Good	None
Alphaxalone	Good	Some
Etomidate	Good	None
Halothane	Good	None
Isoflurane	Good	Good
Sevoflurane	Good	None
Nitrous oxide	Poor	Good
Opioids	Poor	Good
Benzodiazepines	Poor	None
Phenothiazines	Poor	None
Alpha$_2$-agonists	Intermediate	Some